FACTORS INFLUENCING THE IMPLEMENTATION OF RAISED FLOOR SYSTEM FOR THE FITOUT OF OFFICE BUILDINGS IN THE AUSTRALIAN CONTEXT

by

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DECLARATION

The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature: ________________________________

Date: ________________________________
The study described in this thesis investigates how the implementation of raised floor system (RFS) for the fitout of office buildings can be promoted in the Australian construction industry. It essentially achieves this goal through justifying the RFS fitout advantages, improving industry practitioners’ awareness of the innovative technology, and identifying the barriers hindering RFS application, and exploring integrated approaches to overcome these barriers.

Due to increasing levels of technological, environmental and organizational changes in office buildings, the traditional office building fitout method cannot deliver flexible services economically and in a timely manner. RFS is highlighted for its superior underfloor distribution technologies and ability to promote healthy workplace environments and organizational flexibilities.

Despite the many benefits RFS may bring, this innovative technology has not been widely used. Therefore, for countries with potential growth in the office building market, including Australia, how to make this state-of-the-art fitout technology more acceptable is of great importance.

To encourage the RFS implementation in office buildings, the research set up five objectives: (1) to justify the RFS advantages for office building fitout compared with traditional fitout method; (2) to identify and present appropriate specifications of RFS products and applications in order to improve industry practitioners’ awareness on RFS fitout; (3) to identify and seek potential solutions to barriers hindering RFS fitout implementation; (4) to integrate the barriers and their solutions into RFS project delivery using constructability study; and (5) to formulate guidelines for RFS fitout implementation in office buildings in the Australian construction industry. A comprehensive research methodology consisting of questionnaire, semi-structured
Abstract

interview, site observations, focus groups, life cycle cost (LCC) comparison, and constructability study was structured to support the exploratory research.

With a combined qualitative and quantitative data analysis method, the questionnaire and interview surveys revealed the low level recognition of RFS within the industry, and identified 20 *significant influence factors* (SIFs) and 15 *real problems* associated with RFS fitout implementation. The site observations and focus groups validated the survey findings and justified the RFS fitout advantages. Then, the LCC comparison established a model and verified the LCC benefits of RFS fitout through a case study.

The final discussion on the SIFs, real problems and their solutions uncovered 36 *project level critical factors* pertaining to RFS fitout design, construction, operation and maintenance. A constructability study was employed to integrate these key factors into RFS fitout project delivery, such as construction knowledge inputs, team skills, and RFS fitout programs. More importantly, five *key issues* with significant influences were revealed. Further investigation of these key issues led to a *framework* for the constructability implementation, a contracting strategy with *nominated specialist contractors under CM/GC*, and a *process-based conceptual model* for the selection of RFS products. Based on these findings, a set of *guidelines* for the RFS fitout implementation in office buildings was formulated as a contribution to practice. Questionnaires were again used to invite comments on the key issues and guidelines, and the results proved the validity of the research outcomes.
KEYWORDS

Raised Floor System, Fitout, Office Buildings, Constructability, Life Cycle Cost, Comparison, Guidelines, Australia

ACRONYMS

Raised Floor System: RFS
Heating, Ventilation and Air Conditioning: HVAC
Power, Video/Voice and Data Communication: PVD
Underfloor Air Delivery: UAD
Life Cycle Cost: LCC
Significant Influence Factors: SIFs
Project Level Critical Factors: PLCFs
Design, Construction, Operation and Maintenance: DCOM
Project Delivery Process: PDP
Construction Management/General Contractor: CM/GC
Design and Build: D&B
Design, Bid and Build: D/B/B
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CHAPTER 1
INTRODUCTION

1.1 Research Background

An office building is not just a place for work. It should also be able to adapt to the changing workplace environment (Turner and Myerson, 1998). From the simplest offices in the ancient time to the most comfortable and sophisticated offices today, the methods of office building construction have undergone significant innovations which were symbolized by using large office building centres to substitute small house-like offices, using brick instead of timber, as well as using concrete and steel concrete as a substitute for brick (White and Romano, 1993). When the structures of office buildings approached relative maturity in the middle of the 20th century, the design of office buildings began to place more importance on the office fitout.

Since the invention of electricity in the last century, there have been tremendous changes in office facilities to improve the workplace environment (Cohen and Cohen, 1983). Firstly, electricity was introduced to offices for lighting and later to power all appliances. Then, telephones, typewriters and fax machines were invented one by one to facilitate the workplace activities. Last, air conditioners, photocopiers and personal computers were brought in to enhance workplace environment and productivity. Up to the late 1970s, office appliances and furniture were affluent enough to meet a diverse range of workplace requirements. However, many new problems appeared subsequently on how to design the office layout to accommodate all these appliances and furniture effectively and efficiently. The conventional fitout method installs the air conditioner in the ceiling and builds the cumbersome cables and wires of the appliance into the walls or just leaves them exposed, which can meet...
temporary uses but cannot satisfy the changing technological, organizational, and environmental requirements pertaining to office buildings. Under these scenarios, a new fitout method – the raised floor system – has been devised to meet all these changing needs (York, 1992a).

Raised floors were initially invented to accommodate bulky cables and wires in computer rooms in the late 1950s, and have proved their worth in the flexible delivery of electrical power and voice-and-data hookups to individual workstations (Standish and Silver, 1997). After 20 years of research and development in extending its applications, particularly for improving the workplace environment, raised floors were introduced gradually to office buildings (Sodec and Craig, 1990). In the early 1980s, raised floor technologies were developed to form raised floor system (RFS) which put the heating, ventilation and air conditioning (HVAC) system, power, voice/video and data (PVD) system and other services in the created floor plenum to satisfy all the possible fitout requirements in office buildings (York, 1992b). A typical RFS application for the fitout of office space is illustrated in Figure 1.1.

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library

Source: Tate Access Floor Pty Ltd, USA. Website: www.tateaccessfloors.com

Figure 1.1 RFS Application for the Fitout of Office Space

Today, RFS is still being continuously developed in response to the changing office environment. Increasing attention is given to the research and optimization of office
building environments. Reasons for office innovations arise from the need to enhance the health standards and convenience of staff, which in consequence improves the workplace productivity. Altering the fitout style from the conventional approach to RFS can be a viable direction, as demonstrated on many projects (Ellison and Ramsey, 1989; York, 1992; Reitz, 2002; Tate, 2002). Also, a number of previous studies have explored the specific benefits enabled by RFS fitout in office buildings, which concluded that RFS fitout may add flexibility, improved ergonomics and better constructability of office buildings and at the same time lower the life cycle cost (York, 1992; Guttmann, 2000; Tate, 2001).

In addition, many researches have come to a conclusion that RFS is able to improve the workplace environment mainly through its two innovative subsystems, i.e. underfloor HVAC and PVD systems. Ylvisake (1990), McCarry (1998), and Bauman and Webster (2001) suggested that with the underfloor HVAC system, building clients have the ability to improve thermal comfort and indoor air quality and ventilation, and enable flexible individual control, etc. In terms of the benefits of underfloor PVD system, Anderson (1985), York (1992), and Standish and Solver (1997) argued that the renovated wiring method can provide easy layout and support higher integration and reliability, etc. In addition to these individual advantages, underfloor HVAC system and PVD system also enable a range of common advantages, e.g. improved safety for installation, holistic facility management, easy relocation and minimum interruption of working hours, etc. More details regarding the RFS fitout benefits can be found in Section 2.6 in Chapter 2.

With the aforementioned potential merits, RFS are used in office buildings to cope with the ever-changing technological, environmental and organizational needs. Three photographs are presented in Figure 1.2 to demonstrate typical RFS uses in the lift lobby, equipment room and general office space.

The research and development of RFS technology is currently being further investigated in Germany, UK and USA, in order to promote its acceptance by the local construction industry (Raumtechnic, 1999; Tate, 2001; Propaflor, 2002; Goldbach; 2004; Linder, 2004). Accordingly, all RFS components including raised floor panels, understructures, floor coverings, underfloor HVAC and PVD units, and
accessories, can be prefabricated in factories and installed on site, which adds to their adaptability into real projects.

Despite the many benefits that the innovative fitout can contribute and the enhanced maturity that it has achieved, the RFS technology is still not commonly used, particularly in office buildings, in Australia. Even in countries where RFS receives prominent attention, how to make this state-of-the-art fitout technology popular in office buildings is still unidentified (Zhang et al., 2002).

Figure 1.2 Typical RFS Applications in Office Buildings

Despite the many benefits that the innovative fitout can contribute and the enhanced maturity that it has achieved, the RFS technology is still not commonly used, particularly in office buildings, in Australia. Even in countries where RFS receives prominent attention, how to make this state-of-the-art fitout technology popular in office buildings is still unidentified (Zhang et al., 2002).
The inception of RFS research and practice in the Australian construction industry is behind the aforementioned three countries. Starting from the middle of 1980s, the Australian raised floor manufacturers developed a set of RFS products for the local office building market, and researchers and industry practitioners endeavored to popularize RFS (Tasman, 2001). However, the RFS fitout technology is still not accepted by the industry except for use in computer and equipment rooms.

According to government development policies of Australia, including “follow-the-sun operating environment” (McKenzie, 2002), RFS presents a sound alternative in fitting out office and other commercial buildings in the country. Furthermore, Australia is also facing a quickly aging building stock as the last building development boom was before the early of the 1980s. Retrofit and upgrade may be imminent for many existing buildings. Nevertheless, the use of RFS as an alternative to traditional fitout methods may encounter a variety of subjective and objective restrictions in its implementation. Because it is innovative, most industry practitioners have neither the knowledge nor experience to use it, which was highlighted by the scarcity of RFS applications in Australia. Under these scenarios, carrying out a research to study RFS fitout applications is not only conducive to improving workplace environment and solving the aging building problem, it will also facilitate the RFS implementation process in the Australian construction industry. Hence, it is both logical and imperative to undertake a study to identify the factors that influence the application of RFS in the Australian market and explore viable solutions to encourage its implementation.

1.2 Research Problems

Based on the aforementioned research background, the research problem can be defined as below:

*How can the RFS implementation for the fitout of office buildings be promoted in the Australian construction industry considering the industry practitioners' recognition of RFS?*
Therefore, this research is about exploring a way to encourage RFS fitout implementation in the Australian construction industry. To achieve this goal, the research needs to be conducted in three steps. Firstly, identify the industry practitioners’ level of awareness and understanding of RFS fitout; secondly, find barriers hindering the RFS application; and finally explore an appropriate way for the RFS fitout implementation.

The awareness on RFS products determines the progress of RFS application. Compared with the traditional office interior design, RFS is a relatively innovative product and fitout method for office buildings. Owing to the human nature of tending to do what they have known very well, general industry practitioners are likely to avoid innovations and so lack the impetus to study and apply RFS technology in office buildings (Terranova, 2001). Therefore, when carrying out the research of RFS application, the industry people’s level of RFS awareness need to be identified at first, the scope of which involves determining the pros and cons of RFS, its products and applications.

Once the level of RFS awareness and understanding in the industry is identified, the exploration of improving its implementation can be initiated. RFS has been researched and further applied for office building fitout for more than 10 years globally, and the RFS technologies are advanced enough to cope with nearly all the potential fitout environments. However, so far the RFS market is not as prosperous as the development of RFS technologies. Besides the lack of RFS information among the industry practitioners, are there any other barriers hindering the RFS implementation in Australia? If yes, how do we overcome these barriers and find appropriate ways to accommodate them in the project delivery? With such an understanding, the research problem can be further divided into two research questions:

1. How to justify the advantages of RFS fitout compared with the traditional method and improve public awareness of RFS fitout if the Australian industry practitioners lack information in this regard?

2. How to overcome the barriers in the RFS fitout project delivery if some barriers hindering the RFS implementation do exist?
1.3 Research Objectives

In order to answer the above two research questions, five research objectives are set up as listed below:

1. To justify the RFS advantages for office building fitout compared with the conventional fitout method;
2. To identify and present appropriate specifications of products and applications in order to improve the industry practitioners’ awareness on RFS fitout;
3. To identify and seek potential solutions to barriers hindering RFS fitout implementation;
4. To overcome the barriers and integrate their solutions into RFS project delivery using constructability study; and
5. To formulate viable guidelines for RFS fitout implementation in office buildings in the Australian construction industry.

Objective 1 and 2 are derived from the first research question which presents two tasks including the justification of the advantages of RFS fitout and the improvement of public awareness of RFS fitout. Prior to the exploration of the two objectives, the industry practitioners’ level of recognition of RFS enabled benefits and awareness of RFS knowledge need to be ascertained, which can be done through a questionnaire survey presented to the industry practitioners. According to the literature review, the state-of-the-art RFS distinguishes itself from the conventional approach for its flexible fitout style to meet the changing office building requirements, ergonomic design, improved productivity, time-saving for construction and maintenance, and lower life cycle cost (LCC). In line with the literature findings in Chapter 2, if a low recognition of these advantages is found, research activities such as interview, site observations and LCC comparison study between RFS fitout and traditional fitout methods will be conducted to ascertain the reality. On the other hand, if the industry practitioners’ low awareness of RFS fitout knowledge is acknowledged, site observations and focus groups will be organized to formulate the specifications of RFS products and applications in order to enhance public awareness in this regard.

The second question forms the main part of this research and leads to the other three research objectives. Since RFS is an innovative product/fitout method for office
buildings, it is inevitable that its implementation will encounter problems during the planning, design, construction, operation and maintenance processes. Accordingly, the barriers hindering RFS implementation and their potential solutions need to be explored in the first place through survey, site observations and focus groups. Once the barriers and solutions are found, a constructability study will be conducted to seek key issues influencing RFS implementation and find the best way to overcome these problems and integrate key issues and solutions into the whole project delivery. The research findings might be difficult for the general industry practitioners to accept and apply in the practice. So, guidelines to integrate the above findings into the RFS fitout project delivery process are formulated as a final research outcome.

1.4 Overview of Research

The research is exploratory in nature, using both qualitative and quantitative methods. The data collection methods consist of five parts, i.e. literature study, questionnaires, semi-structured interviews, site observations and focus groups. A life cycle cost comparison and a RFS fitout constructability study are conducted to ascertain the cost reality of RFS fitout and integrate the key factors influencing RFS fitout implementation into the project delivery process. A succinct model of the research plan is presented in Figure 1.3.

Qualitative analysis is employed to identify, analyze and validate the significant influence factors pertaining to RFS planning and real problems associated with RFS
service operation and maintenance, and to highlight the project level critical factors and key issues pertaining to RFS fitout implementation in Australian office buildings. Qualitative method is also used to justify and demonstrate the advantages of RFS fitout. Specifically, after a review of the literatures relating to the office building development, traditional fitout approach, intelligent buildings and RFS to determine the research scope and content, the research will identify the potential issues hindering RFS fitout implementation through the open question in the questionnaire survey. Then, the research will categorize these issues into potential influence factors and problems and implement semi-structured interviews to pinpoint the real ones. Next, site observations will be conducted to obtain first hand data for developing specifications of RFS products and applications, justifying RFS fitout advantages, exploring good practice and validating interview findings. After that, discussions on the real influence factors and problems will present issues for constructability study which further highlights key issues influencing RFS fitout implementation. Finally, guidelines are formulated based on the earlier survey findings, discussion results and constructability study. The research final outcomes will be sent to industry practitioners for validation in the end.

Quantitative analysis is used on questionnaire feedbacks through descriptive statistics and the LCC comparison between RFS and the conventional fitout approach. Data obtained from the questionnaire will be analyzed through two comparative methods. The first one is to explore the different opinions regarding RFS fitout between the industry practitioners with or without RFS experience. The second one is to explore different opinions between the industry practitioners with different expertise. The LCC comparison involving the establishment of calculation model and illustration through a case study is conducted to ascertain the RFS cost concerns and justify its LCC benefit. More details about these research instruments can be referred to Section 3.4.1 in Chapter 3.

1.5 Definitions of Key Terms

Due to the nature of this research, a number of key terminologies warrant further elaboration as below.
Raised Floor System

Raised floor system, also called access floor system, is an innovative fitout technology which changes the traditional installation methods of typical building services such as PVD system and HVAC system and integrates them into the underfloor plenum structurally created by the raised floor panels and pedestals, in an aim to support sustainable design, construction, operation and maintenance of a proposed built environment.

Underfloor Power, Video/Voice and Data Distribution System

The underfloor power, video/voice and data distribution system, abbreviated to underfloor PVD system, distributes cables and wires in the underfloor plenum and supply power and data through the PVD servicenters embedded in the raised floor panels to each workstation, which is an innovative alternative to the traditional cable and wire distribution methods such as power-pole and poke-through.

Underfloor Heating, Ventilation and Air Conditioning Distribution System

The underfloor heating, ventilation and air conditioning distribution system, abbreviated to underfloor HVAC system, distributes air with or without ducts, or water within pipes in the underfloor plenum to create and supply appropriate air into office spaces through the floor-based air diffusers. It is an innovative alternative to the traditional overhead HVAC system. In this thesis, underfloor HVAC system is also interpreted as underfloor air delivery (UAD) which is an American description.

Constructability

Constructability is defined as the integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve project goals and building performance at an optimal level (CIIA, 1996). It is only through the systematic integration of construction knowledge right from project inception that the potential benefits of constructability can be achieved.

Flexibility

Flexibility in building automation systems and controls means the ability to respond to change for the long term (Boynton & Victor, 1991); means to be easier to operate,
and simpler to install (ACHRN, 1995). As per these definitions, flexibility in this research means the easy construction, operation, relocation, maintenance and reconfiguration of RFS to meet the changing office building requirements.

**Ergonomics**

Ergonomics is defined as “the application of scientific principles, methods, and data drawn from a variety of disciplines to the development of engineering systems in which people play a significant role” (Kroemer and Kroemer, 2001). When ergonomics is applied to offices, it encompasses the design of whole workplaces, of individual workstations, and of their components such as computers or chairs, to enhance people’s wellbeing and allow people to perform efficiently.

**Experienced Group and Inexperienced Group**

In the questionnaire analysis, experienced group and inexperienced group are used to define the respondents for the purpose of feedback comparisons. The experienced group involves respondents who have actually used, designed, or constructed RFS. Reversely, the inexperienced group includes all other respondents.

**Significant Influence Factors and Real Problems**

Many potential issues associated with RFS implementation were identified from the questionnaire survey. These issues can be potential factors influencing RFS planning or potential problems in RFS service operation and maintenance. Through the semi-structured interview, these potential issues were justified as Significant Influence Factors (SIFs) or Real Problems.

**1.6 Delimitation of Scopes**

RFS can be used in commercial buildings, equipment and computer rooms, lift lobbies, dealing/trading rooms, as well as clean rooms. In this research, only the RFS application for the fitout of office buildings will be studied. As one of the main subcategories of commercial buildings, office building typically involves three particular fitout environments, i.e. general office space, computer/equipment rooms
and lift lobby. The RFS application in dealing rooms will also be mentioned in the specification development.

The research puts emphasis on the exploration of key issues influencing RFS fitout implementation. There are many factors potentially influencing the RFS application, such as the social economy, political factors, building industry, market and business prosperity, as well as organizational and technical changes. Given the time and resource constraints, it is impossible to probe all these factors in the research. Hence, only those factors with direct effect on RFS fitout project delivery will be investigated, e.g. project contracting strategy, team skills, design methods, construction specifications, product procurement, etc.

The research needs to explore the general industry practitioners’ recognition of RFS advantages, the level of awareness of RFS fitout and the potential issues with the aid of the questionnaire survey. As such, the selection of respondents for the survey is critical for the research. Generally speaking, construction industry practitioners may consist of all people whose work or benefit is relevant to construction. However, in view of their direct influences on RFS application and market, only five types of stakeholders are chosen, i.e. clients (including owners and occupants), developers, consultants (including architects and consulting engineers), contractors and commercial real estate agents. In the interview survey, manufacturers are also invited for comments.

Constructability is an extensive concept pertaining to the construction industry, which was investigated in many countries. Accordingly a variety of constructability theories and practices have been established. Considering this research is to study RFS implementation in Australia, the 12 constructability principles concluded by the CIIA (1996) will be referred to for the RFS fitout constructability study.

1.7 Outline of the Thesis

The thesis consists of nine chapters. Each chapter begins with an introduction and ends with a brief summary.
Chapter 1 introduced the background for the RFS implementation research, based on which the research problem and questions are presented and research objectives are formulated. This chapter also briefly discusses the research methodology, key terms and research scope.

Chapter 2 summarizes the current state of knowledge by addressing relevant background literature. After reviewing the office development history and the conventional approach for office building fitout, it highlights the changing technological, organizational and environmental requirements on office buildings and furthermore, pinpoints the limitations of the conventional approach. After that, intelligent buildings and RFS are briefly introduced, and the existing researches on RFS fitout technology and application are presented. Finally, the research area is identified.

Chapter 3 describes the research methodology in detail including the research plan and design, data collection methods (questionnaires, semi-structured interviews, site observations and focus groups), questionnaire and interview development, data analysis methods, key research activities as well as validation of the research results.

Chapter 4 presents the questionnaire data analysis and findings. Questionnaire feedbacks are tabulated and analyzed and the industry practitioners’ recognition of RFS advantages and awareness of RFS fitout are explored and conclusions are drawn. In addition, potential issues hindering RFS application will be identified.

Chapter 5 puts forward the interview data analysis and findings. The potential issues obtained from the questionnaire are categorized into two groups and the real influence factors and problems will identified. Their conceptual solutions will be recognized as well.

Chapter 6 describes the site observation and focus group data analysis and findings. RFS products and application specifications are developed based on the data collected on the sites. Good practices and problems associated with RFS fitout are
explored as well. Then, focus groups are conducted to validate the RFS fitout advantages and interview findings.

Chapter 7 presents the LCC comparison between RFS and traditional fitout methods. Assumptions and elements of LCC are discussed at first and then the LCC comparison model is developed. A case study is undertaken to show the model application and justify the cost concerns of RFS fitout.

Chapter 8 contains discussions of the research findings. Firstly, the catalysts for RFS applications are analyzed and the real influence factors and problems are discussed, which expose the project level critical factors in RFS fitout design, construction, operation and maintenance. Then, a constructability study is made to integrate these factors into RFS project delivery, which highlights key issues influencing RFS implementation to be further investigated. Finally, guidelines for RFS fitout implementation are formulated as a final research outcome.

Chapter 9 presents the conclusions regarding the research objectives, contributions to the academic knowledge base, as well as the significance to practice. Study limitations and recommendations for further research are proposed in the end.

1.8 Summary

This chapter laid the foundations for the thesis. It first introduced the research background in which the current crux in the fitout of office buildings was revealed and RFS was introduced. Then, the research problem, questions and objectives were established. After that, the research methodology was briefly discussed, the key terms defined, the research limitation identified, before the outlining of the thesis structure. On these foundations, the study can proceed with detailed coverage of the research development process.
CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter presents the background literature relevant to the research questions and objectives developed in Chapter 1. The literature covers office building evolution and market, conventional fitout method, changing office building environments, intelligent building and existing research related to RFS fitout technology and application.

The retrospect of office evolution aims to show the importance of office buildings for society and modern business operation. The review of previous researches on current international and domestic office building markets manages to highlight the contribution of office building development to the Australian economy and expose the promising future of the office market. After that, the conventional approach for office building fitout, particularly on interior layout, partition and building service systems (e.g. HVAC system and PVD system), is summarized and the achievements will be used for the comparative study between RFS and the conventional approach in the following chapters.

After elucidating the conventional requirements on workplace environment and the corresponding fitout method, the changing organizational, technological and environmental requirements of office buildings were summarized in order to reveal the limitations of the conventional approach (Black et al., 1986). As a result, new office building fitout methods need to be conceived and applied to substitute for the traditional method in order to satisfy changing office requirements. Accordingly, intelligent buildings with cutting edge building technologies are introduced to
potentially accommodate the aforementioned changing requirements. The significance of RFS fitout is then highlighted considering its ability to house the intelligent building services.

The previous researches on RFS technologies and applications are summarized at the end of this chapter. Particularly, the underfloor HVAC system, PVD system, cost issues, retrofit with RFS and the status quo of RFS application in Australia are investigated and the advantages and potential barriers associated with RFS fitout are exposed, which underpin the subsequent research activities. Finally, the research areas of RFS are identified based on the above literature review.

2.2 Office Evolution and Australian Office Building Market

Office evolution is constantly progressing to meet the changing office activities and workplace environment (Joedicke, 1962). Today, responsive office buildings are indispensable to modern business operation (Andersen, 1999; Baier and Ellis, 1999). More importantly, the prosperous office building market has contributed a lot to the ever increasing Australian economy in the past ten years (Higgins, 2001).

2.2.1 Definition of Office and Office Building

An office has varied meanings. Duffy (1992) succinctly defined office as a place for work, emphasizing its function as a workplace. The Concise Oxford Dictionary gives more detailed definitions, in which an office is defined as “a place of authority or trust or service, a tenure of official position, a place for transacting business, a room in which any kind of administrative or clerical work is done, etc.” Similarly, Marmot and Eley (2000) argued that an office has at least three meanings: first, a role or job that a person had in an official capacity; second, all the people within an organization, namely office workers; third, a place where specific activities are carried out.

Duffy’s definition uncovered the truth of office functions with simple words. The other two definitions encompass several office meanings. Despite focusing on different aspects of office or things occurring inside it, the definitions are all relevant
to modern offices as places for disseminating information and are bound up with office workers and the routine office activities.

In this RFS research, the meaning of office is pertaining to an enclosed place where a number of people are engaged together and clerical activities on information, paper or computer are carried out. In line with the definition, office is first a place to work together. As per this definition, it is worthy of noting that an office has the same implication as an office building in this research although the latter may consist of many single or open-plan offices.

### 2.2.2 Evolution of Office Buildings and Fitout

Offices have a long history. According to the documented records, although the prototype of office building originated from approximate 6000 years ago, it modern embryo started to be developed only five centuries ago under the stimulation of capitalism (White and Romano, 1993). During that time, powerful banking and trading houses headquartered in business capitals such as Venice, Florence and London, forcing office into a fast developing era. To meet the growing need for business space in these cities, office buildings began to appear in numbers as early as the 1830s. These office buildings were mostly four- and five-story structures, which is almost insignificant by modern standards but imposing indeed in their days (MacCormac, 1992). In the late 19th and the early 20th century, steel-framed structures predominated but reinforced concrete structure was on the march, which strengthened office structures to support more than 10 stories (Condit, 1968). The advantages of this kind of office building more than offset its relative high cost and occasional discomforts. Furthermore, the design of the buildings gave employers a chance to demonstrate their wealth and power.

In the first half of 20th century, coupled with electric lighting, steam heat and original air conditioning mechanical systems were introduced into office buildings and made the office environment more habitable, which eliminated the most primitive artificial ventilation (vertical air shafts in toilet rooms and sometimes fresh air inlets behind the radiators). These facilities greatly bettered the workplace environment; as a result,
office buildings were designed to accommodate more office workers and activities (White and Romano, 1993).

During the postwar years, a generation of white collar workers reared in suburbia would in due course find its way back to the heart of the city. However, available office space was in short supply, driving office construction to new highs. In addition, the development of central air conditioning made it common and in fact almost mandatory during the 1960s, and encouraged the new office buildings to increase their floor sizes. Asphalt, rubber tile and carpet floor coverings were becoming popular, and fire-resistant, gypsum-based plasterboard, generally mounted on structural tile block or metal studs for reduced flammability, had appeared as a lower-cost partitioning material which allowed faster and cleaner revision of tenant layouts (White and Romano, 1993). In the 1980s, offices construction became almost paramount. A wide manufacturing recession happened in the developed countries, which made people begin to believe that the future of the world lay with the service industries. Therefore, large amounts of space would be necessary to accommodate this growth. A number of offices with a height more than 300 metres were built during this time all over the world. At the same time, personal computers, photocopiers, telefax and Internet gained ground to better the workplace environment and improve worker’s productivity. Another predominant phenomenon emerging in the last decade was that some of the office buildings took the form of smart buildings, in which building systems are integrated, pre-wired and centre-controlled by networks (Fujie and Mikami, 1991; White and Romano, 1993).

Today, office developments are characterized by how to make office environment more flexible and ergonomic rather than the simple emphasis on its structure and height as before. New office fitout approach is regarded as an important field in the current office development and research (Rus, 2000).

2.2.3 Australian Office Building Markets Analysis

Office building market is one of the main divisions of the Australian property market (Madsen, 2000). According to the revised Functional Classification of Buildings (FCB) by Australian Bureau of Statistics (ABS), office building is categorized under
non-residential building. In the past ten years, stimulated by the 2000 Sydney Olympic Games, the lower interest policy of the government, as well as the impending Goods and Services Tax (GST), the Australian office market went through a remarkably continuous increase except in the 1998 to 1999 financial year, which was attributed to the unprecedented Asian financial crisis in the 1997. Furthermore, although influenced by the tragedies of September 11, 2001 and the depressed US economy, the Australian office building market still presented striking growth, which is demonstrated in Figure 2.1.

![Figure 2.1 Characteristics of the Office Building Market in Australia](image)

Source: ABS 2004 – value of non-residential building approved

The increasing value of office approvals and the percentage of value of office building compared with non-residential buildings underpin office market as one of the main factors contributing to a stably developing property market in Australia. In the past ten years, Australian Gross Domestic Product (GDP) grew by an average around 3.5% per annum against a background of very low inflation, which was partly attributed to the well-running property market and in turn will consolidate the office market’s promising future (Higgins, 2001).

In today’s increasingly competitive global marketplace, a key location determinant is the quality and availability of office accommodation and supporting business infrastructure. Within the Asia Pacific region, Australia surpasses other countries with modern office buildings in planned cites complementing a low risk business environment that provides access to a knowledgeable and creative pool of skilled and multi-lingual labor (Higgins, 2001). However, as far as the real prime office market
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for Sydney CBD prime office market (the most expensive in Australia) is around A$684 per square meter. This represents only 67% of the cost of comparable space in Singapore, about 38% of that in Hong Kong, and about 24% of that in Tokyo.

- Excellent business infrastructure and delightful environment: Australia is world famous for its modern transport system and information technology-based office automation system application, together with agreeable climates and multicultural labor background, which will facilitate it as the financial and business centre in the Asia Pacific region. In fact, over recent years Australia has already been chosen as a base for related business functions including financial, administration and call centres.

On the other hand, the office refurbishment is also a large market in Australia. According to the statistical property data from ABS 2001, 151 leases were signed for prime office space above 1,000 square metres representing 522,800 square metres in 2000. These active leasing markets indicate a large new office construction market and more importantly, uncover a potential refurbishment market of existing offices (Ball, 2003). With the proliferation of IT and telecommunications, tenants prefer a flexible workplace environment that supports easy office relocation. The average lease term is approximate 6 years which is far less than the buildings’ life. Therefore, most of the prime office buildings in the financial and business cities in Australia are coming up for refurbishment at any time.

### 2.3 Conventional Office Building Fitout Approach

Requirements of office building environments determine the office interior layout style and building service fitout method. In the last century, along with the evolution of office buildings and the development of modern business and industry, the requirements of office environments have gone through many variations. Accordingly, the office building fitout approach was renovated over time. To this stage, the typical traditional office building fitout approach has been established.
2.3.1 Conventional Requirements on Office Building Environments

The human requirement is always on progress accompanying social, scientific and technological development (Duff et al., 1993). In the workplace, it is demonstrated by the ever-changing requirements of office building environments. If the long history before the 20th century is not considered, the conventional requirements on office building environments have so far gone through four typical stages, which are summarized in Table 2.2.

The first stage existed in the first half of the 20th century prior to the popularization of office work and business. At that time, the main function of office was to provide staff with a place to work which is strictly in line with its definition. White-collar work was not as prosperous as blue-collar work, and offices were not as urgently needed as is the situation today. So, the office building environment was designed only to meet the basic requirements (White and Romano, 1993). Accordingly, office buildings generally took the form of multi-story, masonry-walled, store-and-office buildings, with modest entrances between the storefronts, and narrow stair halls upstairs. The inner fitout was the primitive corridor office style, in which a long and bleak corridor with walls provided paths to each office (Duffy, 1992).

The second stage emerged when office work was popular from the middle of last century to the end of 1970s. The office inner fitout was the open-plan style for space saving, good work flow, ease of communication and excellent supervision (Duffy, 1992). So, the design of office buildings did not concentrate on the work environment and efficiency. With such a philosophy, offices were designed to keep people apart, and space planning was based on the ruthless divisions of hierarchy and status (Myerson and Ross, 1999).

The third stage came in the 1980s when the personal computer began its escape from the confines of the computer room and began to proliferate on office desks (Duff et al., 1993; Laing, 1997). Office appliances were largely invented to accommodate the office work needs. The massy wires and cables for computers, printers, telephones and photocopiers needed to be arranged safely and tidily. The general approach to deal with these wires and cables was to locate them in the cable carriers which were
built in walls. Office staff became more demanding for their work environment, such as light, thermal comfort and air quality, rather than work facilities. The central air conditioner was introduced into the workplace in most modern office buildings, and the thermostat was used to control the inner office temperature. Moreover, fire protective facilities were installed in every office to ensure workplace safety.

Table 2.2 Traditional Requirements on Office Building Environment

<table>
<thead>
<tr>
<th>Stage</th>
<th>Requirements on office building environment</th>
</tr>
</thead>
</table>
| Stage 1 – in the first half of 20th century (non-prevalence of business) | • A place to work;  
• The necessary office equipment e.g. desks, chairs, bookshelves, etc.  
• The necessary electrical appliances: telephones, typewriters, etc. |
| Stage 2 – before the 1980s (prevalence of business) | • Office space saving;  
• Good work flow;  
• Easy communication;  
• Excellent supervision. |
| Stage 3 – from the 1980s to the middle 1990s (prevalence of desk computers) | • Use of modern office equipment e.g. personal computers, printers, photocopiers, scanners etc.  
• Safe accommodation of the bulk cables and wires;  
• Better workplace environment;  
• Workplace safety. |
| Stage 4 – from the late 1990s to now (prevalence of intelligent buildings) | • Healthy office to meet the demands of workplace health, safety and comfort;  
• Responsive office to meet individual and organizational needs;  
• Flexible office to meet the development of new technologies. |

Apart from the above three stages of conventional office building requirements, the fourth stage came into being in the late 1990s in response to the changing IT and telecommunication technologies. The typical symbol is the prevalence of intelligent buildings. The office fitout emphasizes a responsive workplace environment, giving building users the least possible amount of constraint at their workstations and increasing social and economic productivity (Laing et al., 1998; Holman et al., 2003; Harrison et al., 2004). The typical requirements on modern office buildings are outlined in the above table and more details will be presented later.

2.3.2 Office Interior Layout

Two types of office interior layout are generally used today: the cellular office and the open-plan office (Duffy, 1992; Brooks, 1998). Each has its advantages and
disadvantages, but the open-plan layout style is more popular today (Roark, 1986). To demonstrate their characteristics, the two layout styles are examined separately.

**Cellular Offices**
The cellular office design (Duffy, 1992) is based on the assumption that the space is subdivided by unmovable partitions. There may be a central lift and service core, and offices are reached by a long central corridor. This kind of style can easily provide single offices, good privacy and adaptability to the individual’s control ability to the environment. However, space is wasted, partitions are expensive to move or unmovable, communication is bad, and supervision is impossible.

**Open-Plan Offices**
The available alternative to cellular offices hitherto is the open-plan offices in which many staff members share an open space and desks and equipments are arranged in ordered rows. Such offices are often very large: as staff work far from the windows, artificial light and ventilation are required. Compared with cellular offices, open-plan offices allow the more economic use of office space and more effective supervision (Thomson, 1986). Moreover, open-plan offices have good work flow, ease of communication, and ease of relocation in the layout. Due to these reasons, open-plan
offices are normally designed to accommodate routine tasks and lower grades of staff (Myerson and Ross, 1999). Furthermore, open-plan offices can be divided with movable partitions, which not only saves the fitout cost to a large extent but also accommodates frequent workplace relocations and maintenances speedy and economically. With so many advantages, open-plan offices are more popular than the cellular offices in today’s Australian office market. The disadvantages include a rigid classroom impression due to the ordered rows of desks and chairs, many distractions from surroundings and no control of personal environments (Duffy, 1992). Despite continuous complaints of acoustic and visual disruption, poor air quality and thermal comfort, and nightmarish way-finding, the vast open-plan, both partially and fully partitioned, continues to predominate because of perceived first cost advantage (Loftness et al., 1994).

While the 1970s were characterized by the construction of many offices with cellular and open-plan styles, the 1980s saw the erection of many headquarters facilities and the appearance of combi-office (Collard and DeHerde, 2004). Combi-office design attempts to combine the best features of op-plan and cellular office plan layouts. Dedicated workstations are used for workers in private cellular offices for a quiet and completely personal area where he or she can think. Communication equipment and shared technical equipment are located in a spacious area at the centre of the building. Each person thus works in more than one location. This kind of office layout first appeared in Scandinavia and Germany and has been most popular in the Nordic countries; however, it was not generally used in the USA and UK because it might potentially increase the average occupied space for each staff (Eley and Marmot, 1995; Duffy, 1999).

Other office concepts such as landscaped offices, group offices and combination open-closed plan offices were also practices in Germany, UK and USA (Duffy, 1992; Loftness et al., 1994; Collard and DeHerde, 2004). Duffy (1992) tried to promote landscaped offices, in which the disposition of groups and equipment does not have to be governed by building shape or by preconceived ideas such as straight lines of desks – only by working relationships and business needs. This kind of layout style can be easily relocated or repartitioned as well. However, it has not been accepted popularly because staff normally has diverse needs at the individual workstation. If
everyone does what he or she prefers without a holistic plan, the office layout will be messy. The other two office concepts are the combination of cellular offices and open-plan offices, and hence are not further explained to avoid tedious description.

2.3.3 Fitout of Office Building Services

Building services (Parlour, 1994; NATSPEC, 2003) generally consist of three main subsystems: hydraulic, mechanical and electrical systems, which are presented in Table 2.3. Office buildings reply on these services to provide an appropriate workplace environment. Although the three systems consist of a range of services, they basically deliver HVAC distribution service and PVD distribution service. Therefore, the two service systems under the traditional fitout method are chosen for further exploration.

<table>
<thead>
<tr>
<th>Hydraulic system</th>
<th>Mechanical system</th>
<th>Electrical system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water distribution</td>
<td>Heating</td>
<td>Power distribution system</td>
</tr>
<tr>
<td>Fuel gas</td>
<td>Ventilation</td>
<td>Signal and communication</td>
</tr>
<tr>
<td>Hydrants</td>
<td>Air conditioning</td>
<td>Telephone system</td>
</tr>
<tr>
<td>Hose reels</td>
<td>Ducting system</td>
<td>Controlling system</td>
</tr>
<tr>
<td>Sprinklers</td>
<td>Mechanical piping</td>
<td>Lighting</td>
</tr>
<tr>
<td>etc.</td>
<td>etc.</td>
<td>etc.</td>
</tr>
</tbody>
</table>

2.3.3.1 HVAC System Fitout

HVAC system is regarded as one of the most important services in modern office buildings (ASHRAE, 2000), maintaining desirable environmental conditions in workplaces. According to Haines and Wilson (1994), HVAC systems basically include centralized or decentralized systems, and normally consist of primary equipment (heating and refrigeration), air handing equipment (centrifugal/axial fans, dampers, coils, etc.), air distribution equipment (single- or dual-duct), piping system and air terminal units. Chadderton (1997) summarized 16 typical air conditioning systems, e.g. single-duct variable volume, single-duct variable volume with temperature, single-duct variable air temperature for multiple zone, single duct with fan coil units, dual duct with variable air temperature, etc.
The primary factors pertaining to HVAC system design and construction include performance limitations (i.e. temperature, humidity and space pressure), available capacity, available space, availability utility source, building architecture and construction budget (ASHRAE, 2000). After a full analysis of these factors, central plant or decentralized plant may be selected to locate the primary equipment. As the terminologies suggest, the difference between central plant and decentralized plant is the distribution of the primary equipment. For the centralized system, the primary equipment is located together in the basement or on the roof, inside or outside the building; for the decentralized system, the primary equipment is located throughout the building (Aronld, 1999a and 1999b).

Taking the central plant and all-air system as an example, the heating/refrigeration equipment in the plant room generates steam or cool air which is carried out through a single-duct or dual-duct system to fan rooms located in the basement for a multistory building or decentralized on each floor for a high-rise building. Then, the supply air is processed in air handling units, mixed with return air, humidified/dehumidified on each floor or in the office rooms, and finally delivered to the air terminal units located in each office.

A typical conventional fitout method for HVAC distribution in office buildings is illustrated in Figure 2.3 and Figure 2.4 (Wright, 1996). The first figure presents a ceiling-based HVAC distribution plan view on each floor. Steam, cool air or their mixture is conveyed to each floor through duct risers from central plant rooms. Then, the air is processed in air handling units and mixed with the return air on each floor. After that, the mixed air is carried to Variable Air Volume (VAV) boxes through main duct loops in the ceiling, and finally delivered to each diffuser in the offices through branch ducts. Each VAV box may control the supply air volume to one or several diffusers. Under special conditions, particular arrangements should be applied to control air quality in order to meet specific environmental needs. For example, additional heating or cooling may be necessary in meeting rooms or perimeter zones.
Figure 2.4 illustrates the section view of air distribution in offices. The air is introduced in from plant rooms through the main duct loop in the ceiling, which is further connected with VAV boxes and ceiling-based diffusers to control the supply air. Isolated from external influences, the interior zones have relatively constant conditions, so a VAV box providing simple temperature control is normally enough to cope with the interior environment needs.

In comparison, the perimeter zones are largely affected by varying external weather conditions such as wind, temperature and sun. Depending on the geographic area and season, it may require both heating and cooling at different times in a day in the
perimeter zone. So, in the exterior office rooms, VAV boxes with hot water coils may be selected to respond to these variations.

2.3.3.2 PVD System Fitout

The design of PVD system fitout needs to integrate the features of vertical building core design, office furniture distribution and specific equipment requirements in order to deliver power and data communication services to every point of use appropriately (Anderson, 1985). According to office equipment needs, designers first choose suitable cables and wires and estimate their quantity, and then determine the best power and data distribution method. It is important to first understand the various components of an integrated power and data distribution system and then decide the most appropriate PVD distribution method (Bownass, 2001).

In most existing office buildings, the PVD distribution applies the traditional method in which wires and cables are delivered from the building core through interiors, either in the ceiling or the floor, to workstations. Therefore, the building core design significantly affects the PVD distribution (Webster, 1986). For example, structural beams or components may limit power access at particular locations by blocking conduits that distribute wires and cables in floors or ceilings. Furthermore, the amount of available vertical space in the core limits the amount of cable risers, which further determines the amount of power that can be transmitted through the electrical system from the utility’s main feeder line to each floor.

Ceiling distribution systems use conduits, metal raceways, or flexible conduits cable to run wires and cables in the ceiling plenum (the space between the ceiling and the upper slab). Wires and cables are routed from the plenum to workstations through vertical hollow “power-poles” or through flexible “infeed” cables, which is called “power-poles” system as shown in Figure 2.5-A. Ceiling distribution can also incorporate a standard “poke-through” system to present PVD to the upper floors. Specifically, cables and wires are still distributed in the ceiling plenum but the upper floor slab is punctured to allow cable and wire access to the upper floor, as shown in Figure 2.5-B.
Floor distribution systems include a variety of methods. The most commonly used today include cellular floor system, underfloor duct system, flat wire system, and raised floor system, as shown in Figure 2.6.


Figure 2.6 Floor PVD Distribution Systems

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library
• Cellular floor and underfloor duct systems route cable and wire through steel and concrete channels in a grid system, providing access through outlets mounted in boxes fastened to the floor, and are a variation of the traditional separated ducts usually cast into a concrete floor. With the advent of composite decks of corrugated steel topped with concrete, manufacturers take to closing off some of the cells in the deck and using them as wire raceways for power and communication, and preset outlets are mounted into the ducts to provide access.

• Flat-wire systems, as its name implies, carry phone, electrical, and data transmissions through flat cables taped under carpet squares to outlets mounted flush with the floor. Installation is quite easy because the wire and its protective shields are simply taped to the floor and then covered with carpet tiles.

• Raised floor systems consist of removable floor panels set on adjustable pedestals mounted to the building basic floor, creating unrestricted space for wire and cable distribution. Outlets can be either flush mounted or typical doghouse style and located anywhere along the panels.

Each distribution has its pros and cons. For ceiling distribution, both power-pole system and poke-through system are acknowledged for easy and cost-effective means of rearranging power and communication outlets when ceiling plenum space is adequate (Dowall and Salkin, 1986). However, the power-pole system is often rejected by some designers as unsightly and the poke-through system is argued as inflexible, disruptive and expensive (Kleeman et al., 1991). For floor distribution, the cellular duct system is suited to steel structures; since the basic structure of the cells is a structural element of the building and an unavoidable cost anyway, the cost of a duct system in this case is minimized. Flat wire systems support easy and quick installation, minimally disruptive, and accommodate changes easily. Raised floor systems provide the most flexibility and minimal disruption for reconfiguration but may result in higher cost (Dowall and Salkin, 1986).

Selection of the most suitable ceiling/floor distribution system to suit a tenant’s needs requires facility planners to place relative values on such issues as flexibility, cost, and present and projected estimates of tenant’s electrical and communication requirements (Webster, 1986). Making good decision for a dynamic office environment is not easy, where high value is placed on the ability to reconfigure the
workplace quickly and with minimal disruption and as a result, the planner might choose raised floors with the higher cost. In addition to flexibility, if the office must be able to accommodate a heavy concentration of electrical and communication equipment powered by high-density wiring and cabling, the planner would also have to select RFS to satisfy this function.

2.4 Changing Offices and Limitations of Traditional Fitout Method

The development of IT and telecommunication technologies leads to a variety of changing factors in the office context, which further gives rise to new requirements on office building environments (Sullivan, 1996). However, the rigid equipment and service layout in conventional office fitout method cannot meet these changing factors and new requirements speedy and economically (Riewoldt, 1997).

2.4.1 Changing Factors in Office Buildings

The term “computer – intensive workplace” describes a totally different environment from that of 40 years ago when a telephone, electric typewriter, or shared word processing systems comprised the office technology. Office work and business operations have changed tremendously with the proliferation of new technology. Ellis (1986), Duffy et al. (1993), and Worthington (1998) put forward the following changing factors in modern office building environments.

Changing Organizations

Routine assumptions about the way office organizations should be structured are being overturned, often with paradoxical results: organizations want to enjoy simultaneously the benefits of being both small and large; the simple access to information resources characteristic of the early waves of the take-up of IT are being converted into a demand for the creative use of knowledge; traditional patterns of work, time, and location are being challenged and transformed (Duffy et al., 1993). The office is not merely a place of information and control. As routine operations are automated it becomes a place for stimulating the intellect and creativity. So, the workplaces have to be designed to accommodate much greater flexibility in the use
of space and time, to provide more rapid responses to business and operational needs, and to allow employers to adjust to employees’ increasing expectations of workplace quality (Ballesty, 2002).

**Changing Technologies**

Networks of smaller and more powerful workstations linked to central database are implemented. Cabling of considerably enhanced capacity will be more and more integrated with buildings in an increasingly structured and unobtrusive way. In consequence, the workplaces will be freed from the locational constraints of the traditional office; and more kinds of work will be possible in different workstations (Duffy et al., 1993; Coolodge, 1999).

**Changing IT and Intelligent Buildings**

An increasing dependence of building managers and building users on a greater variety of increasingly powerful and attractive electronic devices is predicted. Office usage of IT will converge with the use of electronics in managing building services. The office environment will be much more closely related to business success. Performance measures will become critical. While there will be continual changes and improvements in the design of workstations, it is equally likely that there will also be substantial differences in shared spaces, in the amount and type of meeting rooms, in greater user control, in the provision and management of more intelligent working environments (Ellis, 1986; Duffy et al., 1993; Ballesty, 2002).

**Changing Building Performance**

User demands for a better, more responsive, more controllable working environment will have a big impact on the design of building services resulting in much greater integration of design, construction and management. Building services will be more accessible to end users and will be used in a more sophisticated way, complementing and assisting natural systems (Worthington, 1998).

**Changing Perception on Sustainable Issues**

For many companies and organizations, the perception of sustainability were expressed through a discussion of energy efficiency, which is not enough now for a sustainability concept (DPW, 2000). A healthy workplace environment is being
accepted as a key characteristic of sustainable buildings. In reality, avoiding the waste of resources, minimizing occupancy costs, enhancing workplace health, etc. are closely related. Uncontrollable HVAC is also seen by employers and employees as irresponsible and the opposite of sustainability (Baier and Ellis, 1999). Physical consequences include the integration of the minimization of waste into the design, management and use of office buildings (Aye et al., 2000). Therefore, the design of office building services needs to support sustainable building performance.

In conclusion, more flexibility is expected for modern office business operation and more options are demanded for end users. More and more diverse technologies are anticipated to accommodate far more building intelligence. More natural environments are wanted but combined with more capacity in artificial building systems. More environmentally friendly buildings, more locational freedom, more discretion in the use of time are all in demand. Yet more choices are expected to be combined with more environmental responsibility. Driving rising expectations of more user choice and more stringent environmental standards are two closely interconnected realities: more powerful informational technology (IT) and more powerful and discriminating users (Loftness et al., 1997). As a result, the above changing factors require workplaces to be designed sustainable and motivational, which is dependent on design teams committed to the fundamental human-ecological needs of acoustic quality, thermal quality, air quality, visual quality, spatial quality and long term integrity. Further, the sustainable and motivational workplace environment is dependent on design teams being fully conversant with advances in building subsystems and their effective integration for meeting environmental, technological, and organizational goals (Laing et al., 1998)).

2.4.2 New Requirements on Office Building Environments

The above changing factors in office buildings reshape the traditional office and office business operation. How people work, where people work, control of time and place, as well as the quality of the office environment are totally changed. In response to the changing factors, several new requirements on the office building environment are emerging, as presented below.
Adapting Offices to Changing Organizational Needs
Organizational flexibility, perceived to be an important feature by many corporate owners and office tenants, demands an ability in these buildings to reconfigure quickly and economically. Office buildings need to be constructed with a degree of flexibility to cope with the office churn rate, the percentage of the organization that moves work location during a year (Harrison et al., 1998). Furthermore, organizations are evolving and their spatial needs evolving as well, which suggest that the workplace planning concepts could be changing in different divisions of the same organization, or during different stages of an organization’s development (Loftness et al., 1994).

Adapting Offices to IT and Telecommunication Development
New and emerging IT and telecommunication technologies have caused a fundamental shift in business activities away from simple clerical processes and towards more communication-based, managerial and creative work. As a result, new requirements of office buildings are emerging, such as office automation, modularity, integration and ergonomics, to make office work more efficient for the organization and more comfortable for the individuals (Riewoldt, 1997).

Making Offices More Responsive to Users’ Needs
Making the offices more responsive to users’ needs is conducive to workplace health, safety and productivity. Rigid office layout style and constant temperature cannot meet all users’ needs at the same time in the workplace. Regular office relocation should be made speedy and economically by the flexible office design. Adopting the adjustable floor-based HVAC system can better satisfy individual preference for workplace air and temperature. In order to reduce the Sick Building Syndrome (SBS), Fanger (2001) suggested five principles for the design of office space air conditioned environment, i.e. better indoor air quality increases productivity and decreases SBS; unnecessary indoor pollution sources should be avoided; the air should be delivered cool and dry to the occupants; personalized air such as a small amount of clean air should be delivered gently, close to the breathing zone of each individual; and individual control of the thermal environment should be proved.
Making Office Building System More Integrated

The building integration degree is the key factor for evaluating the intelligence of office buildings. The more integrated the building system is, the more reliability, flexibility and ergonomics the workplace can achieve (Arkin and Paciuk, 1997). Intelligent buildings present an integrated design and construction of building services such as HVAC system, PVD system, fire safety system, lighting system and security system in order to achieve more integrated control (Hartkopf et al., 1997; Parlour, 1997; Chilton and Baldry, 1997).

Increasing the Sustainability of Office Operation

Sustainable office operation not only creates a responsible workplace environment as previously mentioned, but also means lower running costs, waste generation and energy consumption. Reducing running costs can largely make the office building cost-effective, because running costs are always the most decisive part to the LCC of office buildings (Dell’Isola, 1982). Applying innovative and environment-friendly technology can help reduce waste and energy consumption and enhance office sustainability in the post-construction stage (Harrison et al., 1998).

Increasing Workplace Productivity

Workplace productivity is one of the most important indicators to evaluating the success of an office building project (Kleeman et al., 1991; Shumake, 1992). Modern office buildings are facing more and more competitive businesses. In order to attract the tenants and retain the leases, office should be constructed to accommodate diverse workplace requirements to enhance workplace productivity (Heerwagen, 2000). From this standpoint, office environment design is driven by productivity and cost, rather than cost alone. Management focuses on space savings after providing staff with quality space, technology and environmental conditions. A successful design and management must make a genuine commitment to enhancing productivity and workplace quality, not just reducing occupancy costs (Kroner et al., 1992). A key aspect of this success is listening to and working with employees to identify the settings and tools they need to be able to work productively.

In all, the office building is no longer built, rented, or sold as a generic product, with a “one-style-fits-all” design that is assumed to work for all types of tenants. The
fundamental lesson by the Responsible Workplace research (Duffy et al., 1993) also indicated that no one office prototype is likely to appeal equally to all, and diversity is both attractive and inevitable. Elements of office buildings, such as lighting, wiring, windows, heating and cooling systems, and layout have become more sophisticated to accommodate ever-changing technological, organizational, and environmental requirements. With the days of the permanent partition drawing to a close, this is a boon for office occupants to relocate workstations daily based on changing requirements. This leads to a dramatic increase in flexibility of office building fitout and the ability to build further on request (Cantwell, 2002).

2.4.3 Limitations of Traditional Fitout Method

The conventional offices are no longer flexible enough to accommodate advanced, rapidly changing, information technology-dependent modern office organizations (Duffy et al., 1993). Due to the ever-changing organizational, technological, and environmental requirements, the limitations of the conventional approach for office building fitout are exposed in the following aspects:

- The rigid masonry walls in conventional buildings cannot satisfy the needs for flexible office space planning (White and Romano, 1993). Walls made up of bricks or stones are usually unmovable. If the tenants want to re-partition their office spaces, they should demolish the dry walls first, which is time-consuming and expensive. The demolishment work will interrupt the office work nearby, resulting in complaints or charges (O’Daniel, 2001). Under these scenarios, the renovation on partitioning walls is imperative.

- The weakness of the conventional PVD fitout method is revealed gradually by the advancing IT and telecommunication technologies. Office environment needs to accommodate desktop computers and peripherals, scanners and plotters, facsimiles and more recently, Internet based facilities (Barber, 2001), which must have sufficient space for the cables and wires. Meanwhile, consecutive upgrades of office equipment need more space to change the PVD system quickly and economically and high churn calls for frequent workstation as well as PVD relocation, all of which are definitely troublesome in traditional fitout offices (Donovan, 2001).
• HVAC is neither ergonomic nor economical under the conventional configuration (Ylvisaker, 1990; Wright, 1996). Cooling units and fans are usually installed at the end of corridors, and air from the central plant and cooling tower is delivered to rooms through inlets in the corridor walls or perforated ceilings. The relocation and upgrade of HVAC system is hence time-consuming and cost-ineffective (Bauman, 1999). Very often the whole level of office space gets cold or heated air regardless whether it is required only for individual rooms or areas. Air is diffused with the same temperature, velocity and direction, without users’ own control. In open office space, pollutants may be circulated continuously through the system. Therefore, it cannot provide a comfortable workspace, and staff may develop fatigue in such unhealthy environment. One of the last ergonomic barriers to personal comfort is temperature (York, 1992a). With the current move towards distributed data processing, where most people have either a personal computer or an engineering workstation in their work areas, the heat generated in a particular location varies throughout the building. In fact, depending on the heat source, one can find an appreciable variable in temperature needs based on their respective metabolisms and the clothing they wear. One cannot expect a conventional VAV mechanical system with thermostats sprinkled throughout a building to keep everyone comfortable (McCarry, 1998).

As Loftness et al. (1994) summarized that “there exists a naive impression that the modularity and blanket conditioning and networking offered in present day open planning will accommodate all types of organizational change. As a result, new space planning concepts are introduced into buildings often without any modification of the building base systems – cooling, ventilation, lighting, networking, or ceiling/acoustics – with disastrous results.”

Under a conventional fitout method, developers take the backward fitout standards for granted, cannot see beyond the immediate efficiencies, and are still, perhaps understandably, ignorant of the future benefits. There is still too much indifference to the needs of the end users or the emerging requirements of organizations (Johnson and Clayton, 1998). A lot remains to be done and many deep rooted attitudes have to be changed. The new sustainable workplace has to offer the ability to respond to environmental pressures and to new ways of working. The objective of new style
offices is to avoid obsolescence by designing offices to be as habitable, as financially rewarding and as operationally effective as possible for everyone (Duffy et al., 1993).

Very few existing offices have been designed to support these new ways of working, their associated technologies and their patterns of work. Office buildings that will succeed are those that can provide workspace and infrastructures that allow tenants to enhance their business performance and contribute to a productive work environment. According to a recent survey exploring building features, amenities and services by BOMA and ULI (1999), the importance of and satisfaction with eight typical issues were outlined in Figure 2.7.

![Figure 2.7 Importance of and Satisfaction with Typical Building Issues](image)

Office users had a high recognition of the importance of the above 8 issues in the figure, with all ratings over 92%. Apparently, their satisfaction with these building services is much lower comparatively. The highest requirements are for tenant control of temperature and comfortable temperature – rated extremely high in importance and lowest in satisfaction.

The previous sections summarized the changing factors and new requirements in office building environments, and revealed the limitations of the traditional fitout method in meeting these changes. It is evident that conventional approaches for
office building fitout are increasingly incapable of meeting the changing requirements of the occupants and owners in the era of rapidly advancing technologies. The issues of making the workplace adaptive to changing technological, organizational, environmental needs as well as making the workplace more responsive to users’ individual requirements will be the most important workplace decisions. Under this scenario, office building service systems need to be upgraded and accordingly fitout renovation is urgently expected to find a more flexible and responsive style to accommodate emerging needs. In particular, the following two key fitout issues surface.

- New PVD distribution methods need to be explored. An office in a state of flux and yet heavily reliant on electrical and electronic equipment cannot easily function in a setting where power outlets and cable access are fixed and limited. The new PVD fitout methods need to be flexible enough to facilitate easy cable and wire relocation, upgrade and maintenance.

- New HVAC distribution methods need to be investigated. The traditional ceiling-based HVAC system results in a degree of complaints in workplace climate comfort and lack of temperature control. As the report (BOMA and ULT, 1999) noted, to make an immediate and positive impact on tenants’ perception of a building, owners and managers could focus on temperature-related functions by updating HVAC systems so that tenants can control the temperature in their suite or by helping tenants make better use of their existing system.

### 2.5 Intelligent Building and Raised Floor System

Intelligent buildings and raised floor system fitout are predicted to better serve the purpose of improving office productivity, comfort levels, and organizational flexibility in an aim to meet the ever-changing office building environment. In this section, the intelligent building and RFS are introduced.

#### 2.5.1 Intelligent Building

An intelligent building is one that creates an environment that maximizes the efficiency of the building occupants, while at the same time allowing effective
management of resources with minimum LCC (EIBG, 1994; Harrison et al., 1998; Smith, 1998). Intelligent buildings, also known as smart buildings, originated in the early 1980s in USA, where it was used to denote buildings incorporating sophisticated IT and telecommunications facilities. Hence, the development of intelligent buildings was closely linked to the growth of IT (Kell, 1996; Michael and Fellows, 2000). However, the conception of intelligent building is far beyond the convergence of high technologies. In fact, a high-tech building cannot be regarded as intelligent unless the technologies are better integrated to foster creativity, productivity, dynamic intellectual stimulation, information exchange as well as mental and physical good health. Arkin and Paciuk (1997) argued that building intelligence is not related to the sophistication of services in a building, but rather to the integration among the various service systems and between the systems and the building structure. Intelligent buildings also have to respond to new changes, and learn and adapt to new operating patterns through usage. As a result, “the intelligent buildings must be understood as a concept, not as a product. Needs are constantly evolving; Intelligent buildings is a direction, not a destination” (Moult, 1998).

Another important feature of intelligent buildings is cost-saving as indicated by the lower installation cost of building control systems, reduced churn costs, lower renovation costs as well as reduced energy costs (Ivanovich, 1999). These advantages will certainly add value to office buildings and make them more attractive to building owners and tenants. For a new building, the intelligent building technologies, data system, and telecommunication costs can be 20% of the total construction and fitout capital costs. The intelligent building system costs, as a capital expenditure, plus subsequent intelligent building technologies running costs can amount to about 15% of the total overhead costs of typical industries, such as banking, financial, accounting, communications and legal firms. However, intelligent buildings have a calculated payback period associated with the percentage of change requirements of the end-user systems connected to the building system. For example, a 10% rate of change in a system (PVD) would usually indicate a three-year payback of the initial outlay costs of the system. Industries such as the financial sector with a 50-60% churn rate will acquire more benefits if equipped with intelligent building system (Flax, 1991; Golder and Costantion, 2003).
Intelligent Building Features

A building innately does not have intelligence, but can be made intelligent with modern technologies and the integration of building components (Clemens-Croome, 1997). An intelligent building is the integration of a wide range of services and systems into a unified whole (Flax, 1991; Finley et al., 1991; Gann, 1992; Gerek, 1994; Ivanovich, 1999). Apart from the common elements in office building such as structure, finishes and services, Table 2.4 lists more features of intelligent buildings in the three categories of systems, structures and services:

Table 2.4 Features of Intelligent Buildings

<table>
<thead>
<tr>
<th>Building systems</th>
<th>Building structures</th>
<th>Tenants services</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Direct digital control system</td>
<td>• Structure design with flexibility</td>
<td>• Communal antenna broadcast distribution system</td>
</tr>
<tr>
<td>• Fire safety system</td>
<td>• External skin system</td>
<td>• Private automatic branch exchange</td>
</tr>
<tr>
<td>• HVAC system</td>
<td>• Intelligent flooring system</td>
<td>• Public address system</td>
</tr>
<tr>
<td>• Lifts and escalators</td>
<td>• Raised floor system</td>
<td>• Satellite services</td>
</tr>
<tr>
<td>• Lighting system</td>
<td></td>
<td>• Video conference</td>
</tr>
<tr>
<td>• LAN system</td>
<td></td>
<td>• Office automation</td>
</tr>
<tr>
<td>• Power system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Security system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Telecommunication backbone system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Similarly, the BOMA and ULI (1999) research revealed 5 typical intelligent building features: built-in wiring for internet, conduits for cabling, LAN/WAN connectivity, high-tech and energy efficient HVAC, and wiring for high-speed networks. This result conforms to the features in Table 2.4 presented by earlier researchers.

Advantages Associated with Intelligent Buildings

The advantages of intelligent buildings lie on the fact that these advanced components make office work more efficient and ergonomic, the occupants more comfortable and productive, the buildings more cost-effective and flexible, and the environment safer and healthier. All these advantages can be achieved on the premises that the intelligent building’s structure, skin, connectivity, service system and interior system work in orchestrated harmony as well as provide optimal performance for their functionality (Kell, 1996; Kua and Lee, 2002). Nowadays, the structure and skin may provide spatial adaptability with individual access to the natural environment, optimize design to reduce material use, as well as facilitate
better constructability and no-waste construction processes. The connectivity systems can highlight the importance of just-in-time connectivity vs. redundancy, user-based reconfigurable outlets, dynamically located shared services, flexible density of data, power and voice, as well as compatibility of different interfaces. The service systems can strengthen the applications of shared tenant services. The interior systems may provide a spatially flexible, individually conditioned and connected, healthy environment and meanwhile, ensure low energy use and other resource consumption (Loftness et al., 1997).

The Rise of Raised Floor System Fitout
Creating an integrated workplace is being recognized to be conducive to modern business operations (Eisenberg, 2000; Kroemer and Kroemer, 2001). An integrated workplace involves many concepts in the context of office environments and can be defined as a workplace in which the current and future needs deriving from the changing organization, improved environmental quality and technology advancement can be appropriately accommodated by flexible interior fitout and services (McGregor, 1994; Zhang et al., 2002).

However, the flexibility of workplace cannot be endowed by the conventional fitout technologies which are symbolized by dry wall partitions, ducted and ceiling-based HVAC, and conduits and cabling for power and data communication. Outdated partition methods cannot meet the different requirements of different workers based on their needs for both interaction and autonomy (Tanaka, 2002). With the service of these fixed methods and products, all too often occupants of office buildings have to adapt their business operations and office activities to suit the constraints imposed by the facilities, rather than the building adding value to their business. Consequently, office workers always have numerous complaints about the workplace temperature comfort and the lack of ability to control temperature (Boma and Uli, 1999). As such, the technology advancement inevitably creates problems and opportunities for the office work, whereas the ability to introduce new technologies into the workplace in an efficient and humane manner is being highlighted industry wide.

In all, the changing technological, organizational and environmental factors and new requirements on office building environments call for intelligent building services
and new fitout methods. The intelligent building services further point up the needs for innovative office building fitout methods to accommodate the ever-changing building technologies. Therefore, it is apparent that employing a new fitout method to cope with the current contradictions between reality and dream in office scenarios can never be overstated for improving workplace healthy, economy and productivity. To this end, an interior fitout using RFS has become highly desired.

### 2.5.2 Raised Floor System

The origin of raised floors can be traced back to 1954, when Tom Tremer, an American inventor, designed a special floor to accommodate the weighty mainframe computers under development at IBM’s test facility in Endicott, New York. Tremer’s floor offered a strong, level surface for the large computers and a way of storing the bulky cables (Ellison and Ramsey, 1989). When personal computers substituted mainframe computers, raised floors became the standard wire management option for computer rooms. Evidently, at this stage the function of raised floors was mainly limited on wiring and cabling for computer rooms. However, for this sole purpose, the cost of raised floor was much higher than other methods, such as power-pole, poke-through and cellular deck, which hindered its popularity. In the 1960s, raised floors extended their functions by integrating cable management, HVAC, plumbing and fire protection as a whole, which not only reduced the initial cost largely compared to the power-pole method, but also lowered the building LCC, which gave raised floors a much greater potential to develop.

![Figure 2.8 LCC Comparison between RFS and Power-Pole Fitout](image-url)
Figure 2.8 demonstrates the LCC comparison for an office building between the options of using RFS and power-pole system with or without HVAC (Ellison and Ramsey, 1989). This was a study on a 35,000 square feet, open plan office building project based on the LCC of 65% computer usage and 20% relocation annually over 10 years life span. It indicated that RFS is more favorable than power-pole system without HVAC; however, it is much more favorable than a power-pole system if the HVAC is included.

A typical RFS is composed of three parts: structural units, accessories and service units, as shown in Table 2.5. The structural units, consisting of panels and understructures, provide the basic frame of RFS, supporting diverse loads overhead. The panels will form the raised floor surface on which office activities are carried out. At the same time, these structural units will also create a plenum between the sub-floor and the raised floors for the distribution of building service units, and allow easy access to the maintenance of these units with minimum fuss. Accessories, such as floor coverings, perforated panels, dampers, ramps, steps and fascias, though not for load bearing purpose, are indispensable to achieve many flexible RFS functions, enhance structural integrity, and provide better workplace environments. The service units mainly include the underfloor HVAC system and the underfloor PVD system, both of which largely enhance the usability of RFS products for office buildings (Zhang and Yang, 2003a).

Table 2.5 Constitution of Typical Raised Floor System

<table>
<thead>
<tr>
<th>Structural Units</th>
<th>Components of Raised Floor System</th>
<th>Service Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Panels</td>
<td>• Floor coverings</td>
<td>• Underfloor HVAC system</td>
</tr>
<tr>
<td>• Understructures</td>
<td>• Cable grommets</td>
<td>➢ Air terminals</td>
</tr>
<tr>
<td>➢ Pedestals</td>
<td>• Cable carriers</td>
<td>➢ Fan coil units</td>
</tr>
<tr>
<td>➢ Stringers</td>
<td>• Floor service outlet / viewers</td>
<td>• Underfloor PVD system</td>
</tr>
<tr>
<td></td>
<td>• Perforated panels / dampers</td>
<td>• Fire protection system</td>
</tr>
<tr>
<td></td>
<td>• Ramps, steps and fascias</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Skirting boards</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Panel lifters etc.</td>
<td></td>
</tr>
</tbody>
</table>

How RFS can respond to the emerging demands of office buildings can be illustrated through two examples. The first is about flexibility. In most conventional buildings the relocation of power and communication wiring is usually accomplished by
cutting carpets, drilling holes on slabs, chasing walls and removing ceilings panels. The ongoing maintenance and retrofit costs are high and can directly affect rental returns. RFS can simplify the relocation process and reduce expenses (Syska and Hennessy, 1982; York, 1992a). The floor-mounted air diffusers and fan units require no ductwork and can be easily transferred to a new location. Conduit layouts and utilities can be accommodated within as little as 15cm of underfloor plenum. Another example is about ergonomics. In the traditional HVAC system, the temperature in an open plan office environment remains constant to all occupants, who may have individual preference for air temperature, direction and strength of airflow. In the RFS setting, with air from personal diffusers, each individual can control air quality on his/her own, thus maintaining a healthier work environment, reducing fatigue and enhancing productivity (Wright, 1996; Bauman, et al., 1999; Terranova, 2001).

Currently, the typical commercial flooring systems available for the cable and wire distribution include raised floors and cable-floors. Some countries also called raised floors as cavity floors or elevated floors. The major characteristics of the two flooring systems are presented in Table 2.6 and Figure 2.9.

Table 2.6 Major Characteristics of RFS and Cable-Floor System

<table>
<thead>
<tr>
<th></th>
<th>Raised Floor System</th>
<th>Cable-Floor System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System description</strong></td>
<td>• Panels are 600×600mm in size and interchangeable;</td>
<td>• Panels are 600×600mm in size and interchangeable;</td>
</tr>
<tr>
<td></td>
<td>• Finished floor height range from 60mm to 1500mm;</td>
<td>• Finished floor height is typically 56 and 68mm;</td>
</tr>
<tr>
<td></td>
<td>• Pedestals are made of galvanized steel with ±10-25mm adjustment</td>
<td>• Support cylinders are made of fire-rated polypropylene and not adjustable</td>
</tr>
<tr>
<td><strong>Applications</strong></td>
<td>• General office space;</td>
<td>• General office space;</td>
</tr>
<tr>
<td></td>
<td>• Computer/equipment rooms;</td>
<td>• Training rooms;</td>
</tr>
<tr>
<td></td>
<td>• Training and research rooms;</td>
<td>• Computer /equipment rooms;</td>
</tr>
<tr>
<td></td>
<td>• Commercial space; and</td>
<td>• High-rise residential; and</td>
</tr>
<tr>
<td></td>
<td>• Clean rooms</td>
<td>• Control rooms</td>
</tr>
<tr>
<td><strong>Underfloor air distribution (UAD)</strong></td>
<td>• UAD can be integrated into the RFS, which potentially enhances the cost benefits and largely improves the adaptability of RFS.</td>
<td>• UAD is not applicable due to the small floor cavity space.</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>• Enough space to accommodate large amount of cables and wires;</td>
<td>• Improved adaptability in retrofit projects owing to its low profile;</td>
</tr>
<tr>
<td></td>
<td>• Improved workplace environment owing to the use of UAD; and</td>
<td>• Ideal organization and separation of cables throughout the floor plan;</td>
</tr>
<tr>
<td></td>
<td>• Easy installation and relocation, and ‘plug and play’;</td>
<td>• Low capital cost; and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Easy installation and relocation.</td>
</tr>
</tbody>
</table>
2.6 Previous Research on RFS Fitout Technologies and Applications

York (1992) was convinced of the benefits and potential barriers of RFS implementation gradually during the process of his three-year duty as project director of a new building equipped with RFS in Herndon, Virginia, which was recognized as one of the most advanced buildings in the USA at that time. He concluded that using raised floors throughout the entire building was the key to accomplishing the project goals, because RFS can produce a high-capacity electrical closet, simplify wiring, eliminate wires from walls, accommodate changes easily and safely, present a perfectly level floor, and support underfloor conditioned air delivery. In terms of costs, he pointed out that buildings equipped with RFS could have a lower LCC although the first cost might be a little bit higher compared with the traditional fitout approach. The higher up front cost will be paid back by a number of cost savings attributed to the flexible construction, relocation and refurbishment, lower energy cost, as well as and improved health and productivity. Meanwhile, York also identified some potential barriers, i.e. no attainable source of advice, the perceived higher up front cost, and reluctance to do things differently. The weakness of this study comes from two aspects. Firstly, although York knew the RFS merits based on his own experience, the general awareness of RFS in the industry was not identified, which is normally decisive to the application process of a new building product.
Secondly, although York learned the aforementioned problems for RFS use in a new
building, the barriers for retrofitting an existing project has not been investigated in
his research.

At an earlier time, Ellison and Ramsey (1989) quoted some facility managers’
propositions that RFS was an economical way of levelling the original floor,
supported the integration and upgrade of building services, gave easy access to the
building mechanical systems, and simplified relocation and reconfiguration; whereas
costs were seen as the major impediment to the widespread of RFS. They listed key
considerations influencing RFS for office building use, i.e. client usage
considerations, building considerations and underfloor air considerations. They also
found that most industry practitioners in the USA did not know that integrating
underfloor air delivery with raised floors could add RFS adaptability and reduce
LCC. They further revealed that RFS users were normally primarily banks, insurance
companies and large corporations, all of which were more likely to examine LCC
rather than just consider the first costs of using RFS. Again, this study did not touch
the possible barriers for a retrofit project at all. Another possible weakness is that the
essential knowledge and team skills to enhance RFS constructability have not been
discussed in this paper.

Bloomfield’s lesson on a major defective raised floor in a shopping mall (1990a and
1990b) advised us that four major factors will directly result in the failure of raised
floors, i.e. poor integration of engineering and architectural design skills,
misinterpretation of materials and methods among the industry, disobedience of
product and application specifications, as well as lack of an effective yardstick and
job-specific methods for quality assurance and control. He insisted that the raised
floor contractors and manufacturers ought to take an interest in undertaking research
and development, and be able to offer informed advice to the project team. This
research pointed out the necessary knowledge and skills for RFS projects rather than
focusing on the RFS application in office buildings.

Siddens and Lovorn (2002) with two consulting engineers carried out a round-table
discussion about the proper implementation of RFS. They all agreed that raised
floors are the ideal multi-tasking system, serving both as a plenum for HVAC and
conduit for electrical wiring and data cabling. They also emphasized that a proper implementation of RFS should involve a closely coordinated effort by the design team to guarantee that specifications meet the needs of all systems. It goes without saying that the consulting engineers’ opinion is constructive to strengthening project team cooperation and communication, but they apparently tended to avoid discussing the specialist contractors, suppliers or manufacturers’ responsibility in the planning, design and construction of RFS projects.

The above findings indicate that little research was conducted to explore RFS applications as an integrated and innovative fitout method. No researchers have systematically studied the pros and cons associated with RFS fitout and issues influencing RFS implementation as an alternative fitout method. However, a few studies have been conducted to study the applications and pros and cons of RFS subsystems, particularly on underfloor HVAC and PVD systems, as presented below.

### 2.6.1 Underfloor HVAC System

Germany is one of the leader in the research and practice of underfloor air supply system which was used since the 1960s in rooms with high heat production rates and was introduced into offices in the middle of the 1970s. The moveable partitions extending from the floor upward vary from 1200 to 1800mm and offer an obstruction to the natural circular flow characteristic of overhead air conditioning system, which become a contributor to stagnation and hot and cold spots within the cellular and open-plan areas. Underfloor HVAC system produces an upflow movement of air, and hence can avoid this kind of problem (Sodec and Craig, 1990). Depending on the type of jet spread, the floor-based air diffusers can be free jet outlets and twist outlets. The twist outlet can produce a highly turbulent mixing action to facilitate a rapid thermal transfer between the primary and existing room ambient air and in the meantime create a high induction effect so as to not cause draft (Moog and Sodec, 1978). As to the location of floor-based air diffusers, considerations should be given to allow a minimum distance between the workplace and the outlets. The minimum distance is 800mm for the outlets of 150mm diameter and 1000mm for the outlets of 200mm diameter.
Sodec and Craig (1990) also studied the acoustic issues pertaining to the sound transmission between two adjacent rooms with floor outlets, as shown in Figure 2.10. The air diffusers and the floor plenum both have a certain attenuating effect. The total attenuation between two floor outlets in adjacent rooms depends on the distance between the air outlets. However, it is at least 29 decibels (dB). The loudness of a conversation is generally 50dB. This means that a sound pressure level of about 21dB passes through two air outlets into the adjacent room. Such a low sound pressure level can no longer be heard. Therefore, the conversation transmission through floor-based air diffusers is negligible.

Fitzner (1985) presented that using single-duct systems with a VAV system are preferred because it can save more energy. The air volume flow rates of the VAV system are varied by means of terminal units, which are installed in the floor plenum. One or more terminal units are required for each control zone. In the external zone, the terminal units are preferably combined with reheaters in order to increase the supply air temperature for the different zones in the winter. He also argued that although ducted methods are also applicable, the pressurized plenum is the most suitable supply air path to the underfloor air outlets for the following reasons:

- Low pressure requirement;
- Substantial reduction in the required supply air ductwork;
- Accessibility to each individual workplace;
- Flexibility to readapt the supply air system to owners’ requirement;
• Ability to adjust to changing area load factors; and
• Lower costs.

Bauman (1999), Brown (2000) and Badenhorst (2002) revealed that configuration of underfloor HVAC system may include the pressurized plenum, zero-pressure plenum and ducted air supply, and summarized their characteristics in Table 2.7

Table 2.7 Characteristics of Typical Underfloor HVAC Systems

<table>
<thead>
<tr>
<th>System description</th>
<th>Pressurized plenum</th>
<th>Zero-pressure plenum</th>
<th>Ducted air supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With a central air handler delivering air through the plenum and into the space through passive grills/diffusers. Air pressure is 12-50 Pa.</td>
<td>With air delivered into the conditioned space through local fan-powered (active) supply outlets in combination with the central air handler.</td>
<td>With air ducts through the plenum to terminal devices and supply outlets.</td>
</tr>
<tr>
<td>Advantages</td>
<td>• Additional fans are not needed to deliver air to the space;</td>
<td>• Occupants have more control over air distributed to their space;</td>
<td>• Removing floor panels does not disrupt system operation;</td>
</tr>
<tr>
<td></td>
<td>• System allows for complete “plug &amp; play”;</td>
<td>• Removing a floor panel does not disrupt system operation;</td>
<td>• It is easy to deliver concentrated cooling.</td>
</tr>
<tr>
<td></td>
<td>• System allows for lower initial cost.</td>
<td>• System allows for low plenum leakage.</td>
<td>• System allows for less fungus growth and less air leakage.</td>
</tr>
<tr>
<td>disadvantages</td>
<td>• Air leakage from the plenum becomes an issue;</td>
<td>• Additional fan is needed to deliver air to the space;</td>
<td>• Initial cost is increased due to the use of ducts;</td>
</tr>
<tr>
<td></td>
<td>• Removing a floor tile disrupts system operation</td>
<td>• Initial cost is increased due to extra equipment;</td>
<td>• Flexibility of relocation of diffusers is reduced;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• It may result in higher noise levels.</td>
<td>• Difficulty in laying the ducts in the plenum.</td>
</tr>
<tr>
<td>Applications</td>
<td>General office space, computer rooms, inner zones, etc.</td>
<td>Perimeter zones, computer rooms, etc.</td>
<td>Environments where high and diversified heat loads exist</td>
</tr>
</tbody>
</table>

Radtke (1981) studied the cost concerns of underfloor air distribution, and concluded that in the European practice the total cost of underfloor air distribution are at most 10% below the costs of conventional ceiling-based air conditioning system, where it is assumed that raised floors are not installed when using conventional systems.

In the 1990s, the research on the pros and cons of underfloor HVAC system was conducted extensively in the world. Underfloor air distribution system proponents noted that the repositioning of ceiling ducts and diffusers to accommodate revised office layout is costly and time-consuming, and placing air distribution beneath the floor makes these revisions easier and less expensive, as well as providing the
bonuses of greater HVAC efficiency and occupant comfort. For example, Drake et al. (1991), Loftness et al. (1995), Bauman et al. (1996), Brown (2000), Wand (2000), and Hui and Li (2002) pointed out that floor-based ventilation is much more effective at dissipating pollution and ensuring adequate thermal comfort for the individual. The typical propositions regarding the pros and cons of underfloor HVAC are summarized below.

Sodec and Craig (1990) revealed that advantages of underfloor air distribution are demonstrated in the following areas:

- Lower concentration of air pollution in the occupied zone;
- Lower refrigeration consumption owing to higher supply air temperature (not less than 18°C);
- Greater scope of ceiling design;
- No heating problems;
- Facilities for interchanging the outlets, thus providing a greater amount of flexibility in spatial planning;
- Partition walls and items of furniture can be installed right down to the floor level;
- Direct supply of fresh air into the occupied zone; and
- At floor-based outlets one has the ability to adapt the air flow in the occupied zone.

Based on experiments and site observations, Bauman (1999) and Webster et al. (2002) identified a range of benefits that underfloor air distribution can contribute to. They are summarized as below.

- **Improved thermal comfort for individual occupants.** In today’s work environment, there can be significant variations in individual comfort preferences due to differences in clothing, activities level and individual preferences. Recent laboratory tests show that the underfloor HVAC system can provide personal control of equivalent whole-body temperature over a sizable range of up to 5°C, which can make it easier to satisfy occupant thermal comfort preference.

- **Improved ventilation and indoor air quality.** Improvement in indoor air quality is expected by delivering the fresh supply air near the occupant at floor level,
allowing an overall floor-to-ceiling air floor pattern to more efficiently remove contaminants from the occupied zone of the space.

- **Adaptability to non-uniform loads and improved removal of local heat sources.** The floor-to-ceiling air flow pattern supports the efficient removal of heat loads from the space as the warm exhaust air rises up and out of the space with only partial mixing with the room air. Placing additional air diffusers or special cooling units in the underfloor plenum near the heat source can easily accommodate the locally high heat loads.

- **Reduced building energy use.** Cooling energy savings can be obtained by reducing air conditioning requirements outside of the occupied workstations and by allowing some amount of controlled thermal stratification in the space. Using fan-powered local supply units, the energy use associated with the small fans and their electric motors can be minimized by shutting off equipment in unoccupied workstations using occupancy sensors. In addition, under the right climatic conditions, higher supply air temperatures allow extended hours of operation of an outside-air economizer.

- **Lower life-cycle building costs.** First costs for underfloor HVAC system utilizing raised floors will probably, although not necessarily, be slightly higher than those for a conventional system. However, the cost of the raise floor can be at least partially offset by savings in installation costs for ductwork and electrical services, as well as from downsizing of some mechanical equipment. In new construction, UAD can lead to reduced floor-to-floor heights, reducing structure cost. Operating costs can be lowered due to the energy-saving. In addition, with most of the building services now located in the underfloor plenum, labor costs for maintenance and cleaning are reduced due to working at floor level instead of on ladders or scaffolds in the overhead plenum.

- **Improved flexibility in providing and maintaining building services.** Underfloor HVAC system provides maximum flexibility and significantly lower costs associated with the reconfiguration of building services. Floor-based supply outlets can be easily relocated using in-house personnel in response to changes in people or equipment.

- **Improved occupant satisfaction and increased productivity.** The satisfaction and productivity of occupants can be enhanced as a result of their having the ability...
to control their workplace environment individually. The workplace productivity can be improved by 3-7% depending on the nature of the task.

Bauman specifically emphasized the thermal mass benefit presented by the underfloor HVAC system. The thermal capacity of concrete, called thermal mass enables it to store and re-radiate heat provided it is ‘exposed’ to the heat source. The use of concrete in office buildings can make a meaningful contribution to energy efficiency (Glass, 2000). Using a thermal storage strategy in the concrete slab, underfloor HVAC system can contribute to energy and operating cost savings. In temperate climates, cooling night-time air can be brought into the underfloor plenum where it effectively cools the slab overnight. During the following day’s cooling operation, higher supply air temperatures can be used to meet the cooling demand, thereby reducing refrigeration loads for at least part of the day. This 24-hour thermal storage strategy benefits from low off-peak utility rates and extends the hours of economizer operation (Bauman and Arens, 1996). In order to allow enough space for maximum use of thermal mass in the underfloor HVAC system, the ceiling plenum can be totally removed as demonstrated by the two photographs in Figure 2.11.

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library

Source: Kingspan Access Floors Ltd, UK. Website: www.kingspanaccessfloors.co.uk.

Figure 2.11 Examples of Underfloor HVAC System with Exposed Ceiling

Meanwhile, Bauman and Webster pointed out some barriers (both real and perceived) to widespread adoption of underfloor HVAC technology, which includes new and unfamiliar technology, perceived higher costs, limited applicability to retrofit construction, lack of information and design guidelines, problems with applicable
standards and codes, limited availability of products, cold feet and draft discomfort, problems with dirt entering underfloor plenum, condensation problems and dehumidification in the underfloor air distribution system.

At an earlier time, Wright (1996) advocated the use of underfloor HVAC system for the following benefits.

- **Reduced fan power.** Although underfloor system may move more air than conventional ceiling system, their large cross-sectional flow areas can supply air with very low overall pressure drops. As a result, a fan does not have to work as hard as it would to force air through duct systems with higher pressure drops. However, systems with an underfloor duct network instead of an underfloor supply plenum require at least as much fan power as ceiling duct systems.

- **Higher chiller efficiency.** Underfloor systems can use warmer supply air 18°C, which permits a warmer cooling coil and warmer evaporator temperature compared with the overhead HVAC system. However, the system must be designed to take advantage of this opportunity. Many underfloor air systems blend conventional 12°C supplier with return air, thereby losing the opportunity for this improved chiller efficiency.

- **Extended economizer range.** The use of warmer supply air significantly expands the opportunity to use free cooling, or the direct use of outside air, without operating a chiller, especially in mild climates.

- **Better heat removal.** Because the airflow direction is from floor to ceiling, most of the heat from ceiling-mounted lights is removed before it can enter the occupied space. The effective cooling load is thus reduced, permitting warmer air to condition the area.

- **Self-balancing operation.** All diffusers in an underfloor air plenum operate at nearly the same pressure conditions. In addition to simplifying testing and balancing of the system, passive underfloor designs can eliminate the need for measurements with flow hoods and the balancing of VAV boxes and fan-powered mixing boxes.

- **Better pollutant removal.** The upward flow of supply air reduces lateral mixing in the conditioned space. Because many pollutant sources, such as copy machines,
are also heat sources, pollutants are drawn upward rather than being swirled around with the room air.

- **Floor slab as a thermal mass.** A concrete floor becomes an active thermal mass component for underfloor systems that don’t use ductwork, smoothing out the building’s daily cooling load profile. This can reduce peak cooling requirements and allow use of strategies such as night pre-cooling.

- **Elimination of ducts.** Since duct systems are generally expensive, leaky and difficult to clean and maintain, underfloor systems that can eliminate distribution ductwork avoid these problems and expenses.

As to the drawbacks, Wright pointed out two potential issues, i.e. reduced dehumidification capacity due to the use of warmer supply air and complaints about cold feet from building occupants. But he said that these problems can be minimized or eliminated with proper design and by integrating underfloor systems with measures such as outside air pretreatment. On the other hand, he also revealed two factors that have limited the adoption of underfloor HVAC system, i.e. few manufacturers offer raised-floor air distribution products, and relatively few mechanical engineers have experience in designing the systems.

Other researchers such as Arnold (1990), York (1994), Brown (2000), Terranova (2001), Thomas (2002) and Flint (2003) also conducted studies to explore the pros and cons associated with underfloor HVAC systems, and have reached similar conclusions.

### 2.6.2 Underfloor PVD System

In a dynamic office environment, high value is placed on the ability to reconfigure workplace facilities quickly and with minimal disruption, especially on the power, video/voice and data system (Kight, 1992). In addition to flexibility, if the office must be able to accommodate a heavy concentration of electrical and communication equipment powered by high-density wiring and cabling, the planner would also have to select appropriate RFS to satisfy this function (Dowall and Salkin, 1986). The pros and cons associated with underfloor PVD system are summarized as below.
Based on three years’ experience on a project, York (1992) concluded that underfloor PVD systems can lead to the following benefits.

- **Producing a high-capacity electrical closet.** The space between the raised floor panel and the floor slab serves as a high-capacity electrical closet, which can be adapted to both the technological advances and the future changing organizational needs on PVD facilities; easily accommodate distribution boxes, network boxes and the like.

- **Simplifying wiring.** In a clustered distribution system, in which each underfloor distribution point serves locations in a 6 to 10 meters radius from the distribution point, the feeder whips can be routed directly to each workstation and do not have to follow a set path such as they would with cellular deck or with above-ceiling wiring trays. To further simplify and speed up changes, the feeder whips should connect to the distribution boxes with either plug-in or screw-on connectors. Follow-on changes are as simple as plugging a lamp into a wall socket – no electricians, telephone technicians or network technicians required and more money saved.

- **Eliminating wires from walls.** With power, video/voice and data communications delivered to the workstations through boxes built into the raised floor, there is no need to run any wires in the wall. Outlets, switches and wires in the walls along with unsightly power poles, can be completely eliminated by using raised floors. The possible exception might be light switches for overhead lighting. However, these can be ganged on a core wall that would completely eliminate them from areas most likely to be changed in the future; or provide overhead lighting control in each enclosed area with motion detectors, which switch off the light when detecting unoccupied, and vice versa.

- **Easier and safer changes.** It is easier and safer to install the PVD system under the floor than above the ceiling gird. With the cable and wire system underneath the raised floor panels, construction and maintenance people are working on a safe and stable platform that makes them more relaxed and productive.

- **Lower labor costs.** The installation or relocation happens at the floor level rather than in the overhead ceiling or on high walls, which reduces workloads and at the same time improve the safety and productivity, and certainly lowers labor costs.
York also revealed that the biggest problems hindering underfloor cabling and wiring were the industry practitioners’ reluctance to accept new technology and concern of higher capital cost. However, he believed that the industry would accept underfloor PVD system and RFS once more successful projects were constructed and the cost could be reduced once the underfloor HVAC system was integrated into the RFS.

Anderson (1985) argued that the maximum flexibility of office space was virtually guaranteed with underfloor PVD system and RFS because services were available at any point through flush-mounted outlets; the costly electrified partitions could be eliminated; the labor cost for the wiring and cabling were reduced due to the floor-based work; the life cycle savings were impressive due to much lower costs for relocating telephone, cable distribution and power outlets.

Donovan (2001) stated that although not inexpensive, raised floors and underfloor PVD system gave the most versatility and flexibility of any system, wires and cables were easy to get to and to make the necessary removals, modifications or additions. Ranker (2000) explored the raised floor solution to a university’s connectivity challenges and found that the underfloor PVD system could be constructed in less time and with less disrupt to ongoing education, and could delivery more flexibility for workstation relocations. The only major drawback to the underfloor PVD and raise floors is the up-front cost.

Steloner (1998), Fortin (2000) and Crocker (2001) explored RFS contribution to cable management. They found that underfloor PVD system could lead to speedy construction, easy maintenance, flexible relocation and lower LCC, while the upfront cost of PVD system was a little higher than that of the conventional power-pole or poke-through method.

### 2.6.3 Cost of RFS

The Intelligent Building Institute (York, 1992), working with some of its member companies in determining costs of various types of buildings, has produced some startling results: a minimal first-cost premium for raised floor. Although adding
raised floor to the general office area costs in the vicinity of US$7 per square foot installed, it produces major cost savings in other costs of construction that come close to zeroing out the US$7 initial cost. Some of these savings are produced by the following:

- Avoiding the need for poke-through devices;
- Reducing rigid duct and conduit;
- Avoiding traditional fixed wiring methods;
- Eliminating the need for hand screeding floor slabs;
- Less complex concrete preparation and pour (as opposed to cellular deck);
- Savings in pre-engineering costs;
- Eliminating the need to electrify systems furniture and demountable walls; and
- Direct-path routing of electrical and communications wiring.

The Intelligent Building Institute study shows that using raised floor with an intelligent wiring system increases the building costs a mere 3.3% above the costs of a traditional building using poke-through wiring. Assuming a cost of approximately US$88.20 per square foot for a basic conventional building, a raised floor building with intelligent wiring distribution would only cost an additional US$2.94 per square foot. Although one would be paying the raised floor company US$7 per square foot, they would be paying US$4.06 less in other costs. Complete payback in operating costs would occur in two to three years.

Although the additional construction costs of a raised floor building are lower than one might expect, the most important savings advantages can be found in the LCC savings. The following saving in life-cycle costs, which have been achieved by real people in real buildings (Ellison and Ramsey, 1989; York, 1992a; Reitz, 2002), shows the advantages of raised floors:

- Energy costs reduced by 15-30%;
- Operating and facility staff reduced by 25-50%;
- Costs of telecommunications churn reduced by 40-70%;
- Floor plan modification costs reduced by 40-70%;
- Costs of PVD changes to individual workstations reduced by 50-80%;
• Time and costs of moving such components as plotters, printers, engineering work stations and personal computers reduced by 80-90%;
• Absenteeism reduced by 5-10%;
• Employee disruptions and dead time reduced by 50-80%;
• Disaster recovery minimized; and
• Demolition costs and dry wall dirt eliminated.

As one of the most famous raise floor manufacturers in the world, Tate (2002) presented that the RFS fitout could contribute to the office buildings and modern business in the following aspects:

• Cheaper to build
  ➢ Reduce total first construction costs by up to 10%;
  ➢ Reduce slab-to-slab height by up to 300mm per story;
  ➢ Reduce HVAC plant costs by up to 10%;
  ➢ Reduce main structure, elevator shaft and foundation costs;
  ➢ Achieve 15% faster build and completion time; and
  ➢ Achieve faster return on investment due to earlier rental.
• Cheaper to operate
  ➢ Facilitate rapid office space reconfiguration;
  ➢ Achieve 75% lower office churn costs;
  ➢ Reduce the cost of HVAC churn;
  ➢ Reduce wiring and cable reconfiguration costs by up to 85%;
  ➢ Reduce PVD cabling costs by up to 35%;
  ➢ Reduce fan energy usage by 32-48%; and
  ➢ Reduce energy consumption by up to 20%.
• Cheaper to staff
  ➢ Improve air quality reducing employee absenteeism by up to 30%; and
  ➢ Improve productivity through enhanced working environment by up to 7%.

AET (2000) concluded that the RFS fitout cost savings were gained in 9 aspects: reduced height of construction, reduced interior finishing costs, reduced program time, reduced financing costs, reduced cost of reconfiguration, tax advantages, reduced operation costs, user comfort, and design flexibility.
2.6.4 Retrofit with RFS

Loftness et al. (1997) pointed out that for a majority of the industrialized world, the density of existing buildings and infrastructures is more than adequate for the population base of those nations. However, the age and condition of those buildings results in their inability to meet modern workplace demands and in premature obsolescence. Indeed the level of investment and multi-disciplinary engineering evident in new buildings is so low that both inflexibility and obsolescence are equally likely in a very short time. Instead what is needed are flexible infrastructures capable of changing locations and density of service as organizations and technologies change. So, re-valuing existing buildings and reinvesting inside buildings are imperative to ensure technological and organizational reconfigurability with workplace quality and craftsmanship (Highfield, 2000).

RFS also has promising applications in retrofit projects, because the current retrofitting technologies for office buildings has many limitations, such as rigidity in spaces provided, time-consuming processes and long term cost disadvantage (Zhang and Yang, 2003b). Moreover, it lacks a systematic arrangement of integrating many desirable building components and considerations ranging from flexible data/communication connections to air quality (Yang and Peng, 2001). Following the booming economy, many office buildings were built during 1970s to 1980s in Australia with conventional design for fitout and service utilities and little considerations for office automation, connectivity and other induced innovations (ETSU, 1986). In these traditional office buildings, most of the sub-systems are unchangeable, or changeable only on the condition of substantial extra costs or damages to the old systems to some extent (Highfield, 2000).

In a micro retrofit case, the upgrade of PVD cables embedded in conduits in walls is an evident example. Renovating cables to meet new office automation requirements often requires demolishing part of these dry walls, thus incurring extra costs and disruption of work routines. However, with RFS technology all cables are embedded in ducts systematically. Renovating the cable system simply requires removing the panels, unplugging cables, adding new cables, and re-plugging cables in the new
location. Upgrading cables for computer networks and telecommunications can also be readily accommodated (Davis, 1996).

RFS in a macro retrofit relates to the flexibility to change the functions of office buildings. For example, to divide a large open office into several smaller single offices, or to change several office rooms into a meeting room may be time-consuming and costly in the traditional office building because of the relocation of all the sub-systems; however, it is indeed very easy and cost-saving in the RFS environment together with modular and reconfigurable office partition and furniture systems (Winsor, 2001).

Nowadays, the development of office automation systems and facilities management systems will undoubtedly lead to the retrofit of old office buildings (Loftness et al., 1997). Trends in the US and Europe have already indicated such a resurgence. Given time and more exposure, RFS will prove to be a new and viable option for retrofitting Australian commercial buildings (Yang and Zhang, 2003).

2.6.5 Status Quo of RFS Application in Australia

RFS is used widely throughout many countries and is nearly a standard in the UK and USA (York, 1992; Tate, 2000). The status quo of RFS application in the Australian industry is unclear, because few researches have been conducted in this field. However, according to a preliminary discussion with managers from one Australian raised floor manufacturer and one air distribution supplier, the RFS market in Australia presents four features.

- The Australian RFS market is not as prosperous as the oversea market such as UK and USA despite the fact that RFS was introduced into Australia in the early 1980s and much research and development in RFS technologies have been conducted.
- As far as the existing projects are concerned, RFS is mainly used in computer and equipment rooms to accommodate the bulky cable and wire distribution, rather than adopted in general office space to better workplace environment and improve building sustainability.
• With respect to the two main RFS subsystems in the existing projects, underfloor PVD is generally applied in both computer rooms and general office space; however, underfloor HVAC is seldom identified in general office space.
• Most RFS projects are located in the two largest cities – Sydney and Melbourne rather than in other cities.

2.6.6 Summary of RFS Fitout Advantages and Potential Barriers

The previous literatures with respect to RFS fitout technologies and applications have already introduced some advantages and barriers associated with RFS fitout implementation. They are summarized to make preparation for revealing the research areas in the next section.

Advantages
The general studies of RFS fitout in the above section have shown that floor-based servicing is more preferable for the flexible office, since networking, ventilation and thermal conditioning are delivered to the individual, either at floor level or at desktop from the floor. The many advantages of RFS fitout are attributed to the innovative technologies. The main advantages of RFS fitout are recalled in Figure 2.12.

Figure 2.12 Advantages of RFS Fitout in Office Buildings
The previous research also studied the two main subsystems of RFS, i.e. underfloor air delivery (UAD) and underfloor cable and wire distribution. With the UAD, building clients have the ability to improve indoor air quality and ventilation, individualize climate control, support flexible maintenance, relocation and reconfiguration, reduce building energy use and LCC, and increase workplace productivity (Ylvisaker, 1990; York, 1994; McCarry, 1998; Wand, 2000; Bauman and Webster, 2001). As far as the underfloor PVD system is concerned, people know that the renovated cable and wire system can meet the present and future needs for system integration, technology upgrade, service maintenance, office relocation and reconfiguration, organizational changes, etc. at minimum costs (Anderson, 1985; York, 1993; Standish and Silver, 1997). The above two updated subsystems were integrated with raised floors to form RFS. Supported by the literatures findings (Ellison and Ramsey, 1989; York, 1992a; Standish and Silver, 1997; Bauman, 1999; Terranova, 2001), RFS through its leading edge subsystems, can demonstrate many salient advantages for the fitout of office buildings as summarized in Table 2.8.

Table 2.8 Advantages Associated with the Two Main RFS Subsystems

<table>
<thead>
<tr>
<th>Subsystems</th>
<th>RFS fitout advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Individual advantages</td>
</tr>
<tr>
<td>Underfloor HVAC system</td>
<td>• improved thermal comfort;</td>
</tr>
<tr>
<td></td>
<td>• improved ventilation &amp; air quality;</td>
</tr>
<tr>
<td></td>
<td>• flexible individual control;</td>
</tr>
<tr>
<td></td>
<td>• reduced running energy;</td>
</tr>
<tr>
<td></td>
<td>• reduced first costs by lower floor-to-floor height.</td>
</tr>
<tr>
<td>Underfloor PVD system</td>
<td>• easy layout;</td>
</tr>
<tr>
<td></td>
<td>• plug and play;</td>
</tr>
<tr>
<td></td>
<td>• higher integration;</td>
</tr>
<tr>
<td></td>
<td>• higher reliability;</td>
</tr>
<tr>
<td></td>
<td>• pleasing-to-the-eye and aesthetic.</td>
</tr>
</tbody>
</table>

Potential Barriers

Although providing so many advantages for the quality enhancement of office buildings, RFS has not received wide implementation in Australia since it was introduced into this continent at the end of 1980s. The contradiction between RFS
merits and a scarcity of its adoption by new-built or retrofit projects in the last 20 years indicates that there might be some barriers associated with RFS use in the Australian construction industry. Based on the initial literature study, these barriers may come from different aspects, and some are objective whereas others subjective. They are identified and analysed as follows.

**Subjective factors:**
- Public awareness of RFS: RFS is a relatively new fitout technology for workplaces, and there is a lack of “role models” for the industry practitioners to follow. For many existing applications, little information on their evaluation and performance is made available to potential owners, developers and occupants. So the project stakeholders are not fully aware of the advantages and disadvantages, products, specifications, let alone maintenance issues (Standish and Silver, 1997).
- Professional prejudice: new ideas and approaches are often easily met with skepticism and resistance (Terranova, 2001). Too often, when a RFS plan is suggested to owners, they ask “how much more will this cost us?” and “who else have used RFS?” The decision to reject is often made without attempting to find further facts (such as LCC and feasibility studies).
- Nature to follow tradition: developers and contractors, who are more skilled in the traditional fitout approach, are afraid of losing their technical superiority and existing markets. By human nature, they prefer to recommend office building owners or occupants to use their preferred (old) technology for workplace fitout (Finley *et al.*, 1991).

**Objective factors:**
- Physical constraints of buildings for retrofit projects: when retrofitting aged buildings, especially those low-volume buildings without ceiling-based air conditioning system, the ceiling to floor height may be restrictive to RFS installation specifications (Ellison and Ramsey, 1989).
- Constructability issues: owing to industry peoples’ unfamiliarity of RFS implementation, there exists much confusion pertained to the specification, procurement, accessibility, adaptation, team skills, system integration,
Chapter 2: Literature Review

maintenance, and reconfiguration issues associated with RFS application (CIIA, 1996; Nima et al., 2001).

2.7 Identification of the Research Area of RFS

RFS is being continuously developed in response to the changing requirements of office environment. Changing the fitout style from the conventional approach to RFS is a viable direction, which may add flexibility, ergonomics and other values to office buildings and at the same time lower the LCC. With these potential merits, the technology for RFS is being highlighted in the USA, UK and Germany currently. According to the government development policies of Australia, including “follow-the-sun operating environment”, RFS should present a sound alternative in Australian office buildings and other commercial buildings. However, over the past decade, RFS applications in office building have not received whole-hearted adoption by new-built or retrofit projects in Australia. This unreasonable phenomenon indicates a degree of problems hindering the RFS fitout implementation in the Australian construction industry.

As we all know, two general problems associated with new technology application in its beginning are its low industry awareness and its differences to the current standard method. As per the above literatures, it can be concluded that while the advantages of RFS and its subsystems such as underfloor HVAC system and PVD system have been explored technologically by many researchers, no research has been conducted to justify the advantages of RFS as an integrated fitout method and based on the acknowledgement of its efficiency from real users. The general awareness of these advantages in the industry, particularly in Australia, is not clear. Furthermore, RFS popularization replies on the industry practitioners’ encouragement; however, their level of knowledge and experience on RFS fitout implementation is not known. At this stage, there is not any robust research on the RFS implementation in Australia. Specifically, the general recognition of RFS including RFS advantages and fitout knowledge, the industry practitioners’ knowledge in RFS fitout implementation, the barriers hindering RFS fitout
implementation in office building projects, as well as the current status and future of RFS adoption have not been identified in the Australian construction industry.

The above literatures and analysis expose a research problem – how can the RFS implementation for the fitout of office buildings be promoted in the Australian construction industry considering the industry practitioners’ recognition of RFS? As presented in Chapter 1, the research problem gives rise to two research questions: (1) how to justify the advantages of RFS fitout compared with the traditional method and improve public awareness of RFS fitout if the Australian industry practitioners lack information in this regard? And (2) how to integrate the barriers and their solutions into the RFS fitout project delivery if some barriers hindering RFS implementation do exist?

2.8 Summary

This chapter reviewed the relative literatures about the importance of office building market, conventional office building fitout method, changing office building characteristics and requirements, intelligent buildings, RFS features and existing research on RFS technology and application.

Office and office development were recalled first to identify the general office building market in Australia, and further to emphasize that the importance of study on renovation in a workplace fitout. Then, the conventional approach for office building fitout was introduced. Conventional requirements on workplace environment were determined and the corresponding building system, fitout method, and specifically the HVAC and PVD systems were summarized. After that, the varying factors in the workplace environment were explored and the emerging requirements were highlighted, which were supposedly contributing to the rise of intelligent buildings and innovative office fitout methods. Before introducing RFS, succinct literature was provided for intelligent building, its significance and advantages. One important characteristic of intelligent buildings is that the office environment can be adapted to the ever-changing and advancing organizational, technological and environmental requirements, especially the HVAC quality, control
and relocation, PVD layout and reconfiguration, etc. Under this scenario, RFS showed it could accommodate most of these changes. The pros and cons of RFS fitout were further studied and summarized in both RFS technologies and applications. The status quo of the RFS market in Australia was summarized. Based on the above literature reviews, the research areas were clearly identified.

The next chapter will develop the methodology used for this research.
CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

This chapter aims to define the research design and methodology. The methodological procedure adopted needs to be capable of providing in-depth, relevant, up-to-date and reliable information. According to Bell (1993), research styles can be Action, Ethnographic, Surveys, Case Study and Experimental. Yin (1994) suggested that determination of the most appropriate style to adopt depends on the type of research operation and the degree of control that the research can exercise over the variables involved and whether the focus of the research is on past or current events.

This research aims to encourage the implementation of RFS for the fitout of office buildings in Australia through justifying the RFS fitout advantages, improving public awareness of RFS, exploring the barriers in RFS implementation and integrating their solutions into the project delivery process. In light of these objectives, the researcher has chosen the survey research approach. The survey includes two stages: questionnaire and interview. The questionnaire is designed to explore the industry practitioners’ awareness of RFS fitout knowledge and advantages, and to identify the potential issues associated with RFS implementation. The interview is conducted to explore RFS fitout advantages and justify these problems and explore industry people's recognition of RFS advantages. However, the research approaches and strategies obviously do not exist in isolation and therefore can be “mixed and matched”, which is often beneficial to the research (Saunders et al., 2000). Site observations and focus groups are also chosen to collect data to generate RFS specifications, validate the survey findings and further explore RFS advantages. LCC
comparison is used to ascertain the cost concerns of the RFS fitout compared with the traditional method. Hence, the research methodology is a multi-method approach.

This chapter provides discussions on the processes by which the research objectives are achieved. It examines in detail the issues pertaining to the research design and methodology, data collection and analysis methods, key research activities and validation methods.

### 3.2 Research Plan

Formulating a research strategy is the first step adopted. The research strategy is a general plan of how the research questions previously set will be answered. There are several research strategies available. Fellows and Liu (2003) have grouped these strategies under eight headings, namely pure research, applied research, quantitative research, qualitative research, instrumental, descriptive, exploratory, explanatory and interpretive studies. Hussey and Hussey (1997) gave a much clearer classification. That is, according to purpose, it can be exploratory, descriptive, analytical or predictive research; according to process, it can be quantitative or qualitative research; according to logic, it can be deductive or inductive research; and according to outcome, it can be applied or basic research. These strategies should not be thought of as being mutually exclusive; rather, it is possible to combine these strategies within the same piece of research.

However, it is impossible to determine which method is superior in abstract terms because each method has its own strengths and limitations. Research strategy should be chosen based on the research objectives (Sekaran, 2003). It is therefore necessary to review the research problem and questions being undertaken to determine the strategy to be employed.

**Research problem:**

*How can the RFS implementation for the fitout of office buildings be promoted in the Australian construction industry considering the industry practitioners’ recognition of RFS?*
Research questions:

(1) How to justify the advantages of RFS fitout compared with the traditional method and improve public awareness of RFS fitout if the Australian industry practitioners lack information in this regard?

(2) How to overcome the barriers in the RFS fitout project delivery if some barriers hindering the RFS implementation do exist?

The research aims to explore how to justify the RFS advantages and improve public awareness of RFS fitout, and more importantly identify the barriers associated with RFS fitout implementation and explore appropriate solutions. Based on the preceding interpretation and the research nature, the research strategy needs to be an exploratory research as per research purpose and qualitative and quantitative research combined as per research process.

With the aid of the questionnaire survey, the awareness of RFS in Australia will be recognized and the potential issues hindering RFS fitout implementation will be identified; then, based on the questionnaire results, interviewees will be chosen for face to face interview to justify the RFS advantages, expose the real influence factors and real problems and explore appropriate solutions. After that, site observations and focus groups are carried out to obtain data to develop RFS specifications, validate the survey findings and explore RFS advantages. LCC comparison is undertaken to ascertain the cost concerns of RFS fitout, and then a RFS fitout constructability study is conducted to help arrive at the final research outcome.

3.3 Research Design

Research design is concerned with making the research problems researchable by setting up the study in a way that will produce specific answers to specific questions (Oppenheim, 1998). It is the overall configuration of a research project, specifying what kinds of evidence is to be gathered from where and how such evidence is to be interpreted in order to provide valid answers to research questions. The research design involves a series of rational decision-making choices. There are several issues
pertinent to the research design: namely the purpose of study, its location (i.e. the study setting), the type it should conform to (type of investigation), the extent to which it is manipulated and controlled by the researcher (extent of research interference), its temporal aspect (time zone), and the level at which the data will be analysed (units of analysis) (Sekaran, 2003). The following subsections presents decisions made by the researcher on the key research design issues.

### 3.3.1 Purpose of Study

Studies may be either exploratory in nature or descriptive, or may be conducted to test hypotheses. Exploratory studies are a valuable means of finding out “what is happening; to seek new insights; to ask questions and to assess phenomena in a new light” (Robson, 1993). It is a particularly useful approach if not much information is available and researchers wish to clarify their understanding of a problem (Saunders et al., 2000). There are three principal ways of conducting exploratory research, i.e. a search of the literature, talking to experts on the subject and conducting focus group interviews. Considering the RFS research, there is not too much literature available and the research aims to tell the Australian people about new office fitout methods, prove RFS advantages, identify barriers hindering RFS implementation, as well as seek the corresponding solutions.

As the purpose of this research is to explore the factors influencing the RFS application in the Australian construction industry through justifying the advantages of RFS fitout and exploring and overcoming barriers associated with RFS fitout implementation, it is exploratory in nature. It is therefore *Exploratory Study* that has been used as the main research strategy.

### 3.3.2 Type of Investigation

A researcher should determine whether a causal or non-causal study is needed to answer the research question. The former type of study is done when it is necessary to establish a definitive “cause – effect” relationship. The researcher is keen on delineating one or more factors that are undoubtedly causing the problem. However,
if the researcher is merely interested in delineating the important factors that are associated with the problem, then a correlational study is called for. In the social science and organizational studies, it is not just one or two variables that cause a problem. Sekaran (2003) pointed out that given the fact that most of the time there are multiple factors that influence one another and the problem in a chainlike fashion, the researcher might be more interested in identifying the crucial factors that are associated with the problem, rather than establishing a cause-effect relationship.

According to the literature study and the following survey in this research, a number of factors can potentially influence the application of RFS for office building fitout in Australia. However, this research aims to identify the significant influence factors and keys issues associated with RFS fitout implementation. Hence, it is obvious that the type of investigation adopted in this research framework is **Non-Causal** or **Correlational Study**.

### 3.3.3 Extent of Researcher Interference with the Study

According to Sekaran (2003), the extent of researcher interference has a direct bearing on whether a causal or correlational study is undertaken. A correlational study is conducted in the natural environment of the organization with the researcher interfering minimally with the normal flow of events. In causal studies conducted to establish cause-effect relationships, the researcher tries to manipulate certain variables so as to study the effects of such manipulation on the dependent variable of interest. In other words, the researcher deliberately changes certain variables in the setting and interferes with the normal flow of events they usually occur in the organizations.

In this research, questionnaires, interviews, site observations and focus groups are carried out in sequence in a natural and open-minded environmental, which allows the respondents to express their real opinions with minimum interference from the researcher. Therefore, the extent of the researcher interference with the study is **Minimal**.
3.3.4 Study Settings

There are two types of study settings: namely contrived and non-contrived. Correlational studies are invariably conducted in non-contrived setting, i.e. in the natural environment where events normally occur. On the contrary, rigorous causal studies are done in artificial, contrived settings (Sekaran, 2003).

As mentioned previously, all the research activities are conducted in a natural environment and the type of investigation of this research is correlational. Accordingly, the appropriate study setting is **Non-Contrived**.

3.3.5 Unit of Analysis

Hussey and Hussey (1997) defined the unit of analysis as the kind of case to which the phenomena in the research problem refers. The unit of analysis may be an individual, an event, an object, a group of individuals or a relationship. Kervin (1992) suggested that as a rule it is best to choose a unit of analysis at the lowest level possible where the decisions are made. The best guide for choosing a unit of analysis is the research problem and questions, as they explicitly refer to the focus of the study (individual, organization or event) and what the researcher intends to uncover.

In this research, the research questions are primarily concerned with the Australian people’s awareness and knowledge of RFS, and the barriers and constructability issues for the RFS implementation in office buildings. Data is collected through questionnaires, interviews, site observations and focus groups, to examine the issues associated with RFS fitout implementation among the Australian construction industry. Obviously, the unit of analysis is the **Industry**.

3.3.6 Time Horizon of Study

A study can be done in which data is gathered just once, perhaps over a period of days or weeks or months, in order to answer the research questions. This kind of study represents a snapshot of one point in time and is called cross-sectional study. In some cases, however, the researcher might want to study people or phenomena at
more than one point in time in order to answer the research questions. This kind of study is called longitudinal study (Saunders et al., 2000; Sekaran, 2003).

The research data is collected over months from industry practitioners, existing office building sites and construction sites on an equal basis. Therefore, this research is a Cross-Sectional study.

### 3.4 Research Methodology

Research methodology includes the research plan and process, as well as research techniques. Only by using appropriate methodologies and methods of research, applied with rigour, can the body of knowledge for construction be established and advanced with confidence (Fellows and Liu, 2003). In this section, the methods adopted are introduced.

#### 3.4.1 Research Process

The general research plan and design have been explained in the previous sections. This section introduces the detailed techniques adopted in this research. A model reflecting the research process is developed in Figure 3.1. The model consists of four columns, i.e. data collection methods/research instruments, analyses and outcomes, discussions and summary, and objectives. The data collection methods include literature review, questionnaires, semi-structured interviews, site observations and focus groups. An overview of the research process is presented below.

Based on a comprehensive review of research on the office building development, traditional fitout approach, intelligent buildings and RFS, the literature study identified four issues to be explored in the questionnaire survey. They were the industry practitioners’ general recognition of RFS (e.g. fitout advantages and products), their knowledge in RFS fitout implementation, the current status and future of RFS application in Australia, and the barriers associated with the fitout implementation.
Following literature findings, a questionnaire survey was conducted to explore the above four issues. Data obtained from the questionnaires was analyzed using descriptive statistics through two comparative methods. The first one was to explore the different opinions regarding RFS fitout between the industry practitioners with or without RFS experience. The second one was to explore the different opinions between the industry practitioners with different expertise. Potential barriers identified from the open-ended questions will form the basis of the interview study.

The semi-structured interview surveys aimed to further explore the industry practitioners’ opinion on the RFS fitout advantages and more importantly to unearth real issues associated with RFS fitout implementation. The research categorized these potential barriers into potential influence factors pertaining to RFS fitout planning and potential problems associated with RFS operation and maintenance, and invited interviewees’ comments in order to pinpoint the significant influence factors and real problems.

Next, site observations were conducted to obtain first hand data for developing specifications of RFS products and applications, justifying RFS fitout advantages, exploring good practice and validating the real issues concluded by the previous survey study. The focus groups were undertaken to validate the real problems and obtain RFS occupants’ opinions on the benefits enabled by RFS fitout such as flexibility, ergonomics, time-saving and improved workplace productivity. The cost reality of RFS fitout was examined through a life cycle cost comparison between the RFS fitout and the traditional fitout method using case study.

After that, discussions on the significant influence factors and real problems will present project level critical factors associated with RFS fitout design, construction, operation and maintenance. A constructability study will be undertaken to integrate the real issues and critical factors into the RFS fitout project delivery appropriately. Finally, guidelines are formulated based on the previous survey findings, discussion results and constructability study. The research outcomes will be sent to industry practitioners for validation in the end.
Figure 3.1 also indicates the alignment among the research activities and the objectives.

Based on the above explanation, it is evident that the advantages enabled by the RFS fitout were justified through three steps: preliminary exploration through questionnaire, further exploration through interview and final validation through focus groups, which finally reaches the research objective 1.

For the research objective 2, the questionnaire first concluded a relatively low level of awareness of RFS fitout among the Australian industry practitioners. In order to improve it, the specifications of RFS product and fitout applications suited for a variety of application scenarios were developed through site observations.

The potential issues hindering RFS applications were identified from the questionnaire at first, and then refined to SIFs pertaining to the RFS fitout planning and real problems associated with RFS service operation and maintenance in the interview. Finally, these SIFs and real problems were validated through site observations and focus groups, which reach the research objective 3. After that, constructability study was conducted to integrate the key factors into the RFS fitout project and guidelines were developed to improve the RFS fitout implementation, which achieve the researches objective 4 and 5.
Chapter 3: Research Methodology

Figure 3.1 Research Model and Process

Data collection methods/research instruments
- Literature Reviews
- Questionnaire
- Semi-structured interview
- Site observations & focus groups
- LCC comparison

Analyses and Findings
- Changing office building environment
- Traditional fitout method and limitations
- Review of existing RFS research
- Identification of research areas
- Industry general recognition of RFS
- Industry confidence in RFS future
- Industry knowledge of RFS implementation
- Preliminary barriers hindering RFS application
- Justification of RFS fitout advantages
- Identification of SIFs from non-SIFs
- Identification of real problems from false ones
- Conceptual solutions to the real issues
- Data collection for RFS specifications
- Exploration of good practices
- Exploration of problems in RFS application
- Exploration of opinions on RFS advantages
- Exploration of opinions on real problems
- Establishment of a LCC comparison model
- Case study for cost benefit justification

Discussions and Formulation
- Justification of RFS fitout advantages
- Formulation of RFS products specification
- Formulation of RFS application specification
- Discussion of SIFs and real problems
- Discussion of solutions
- Constructability study
- Guideline formulation and validation

Objectives
- Objective 1
- Objective 2
- Objective 3
- Objective 4
- Objective 5
3.4.2 Data Collection Methods

As above mentioned, the data collection methods in this research include literature review, questionnaire survey, semi-structured interview, site observation and focus group. Details about them are presented below.

3.4.2.1 Literature Review

The literature review is a clear and logical presentation of the relevant research work done thus far in the area of investigation, and is the documentation of the relevant studies citing the author and the year of the study. The sources of the literatures include books, journals, newspapers, magazines, conference proceedings, postgraduate dissertations, governmental publications, as well as other reports related to the topic to be studied. The purpose of the literature review is to identify and highlight the important variables, and to document the significant findings from earlier research that will serve as the foundation on which the theoretical framework for the current investigation can be built. A point to note is that the literature review should bring together all relevant information in a cogent and logical manner instead of presenting all the studies in chronological order with bits and pieces of uncoordinated information (Hart, 1998; Sekaran, 2003).

The literature review in this research was conducted primarily on four aspects, which were highly correlational and supportable, as presented in Chapter 2. Since the research studied a new office building fitout technology, this chapter first reviewed the office building evolution and the domestic office market. Then, it introduced the conventional office building fitout approach. After that, it revealed the changing factors in office buildings, enumerated new technological, organizational and environmental requirements for workplace environments, and disclosed the limitations of the conventional fitout approach at length. Based on the above analysis, the intelligent building concept, the RFS and its characteristics were introduced briefly. Finally, the previous research on RFS technologies and applications were summarized and the research areas were determined.
3.4.2.2 Questionnaire

A questionnaire is a prepared written set of questions to which respondents record their answers, usually within rather closely defined alternatives. Questionnaires are an efficient data collection mechanism when the researcher knows exactly what is required and how to measure the variables of interest (Sekaran, 2003). Questionnaires can be administered personally, mailed to the respondents, or electronically distributed. When the survey is confined to a local area, and the organization is willing and able to assemble groups of employees to respond to the questionnaires at the workplace, personally administered questionnaire is the best way to collect data. The researcher can collect all the responses within a short period of time, clarify the respondents’ question on the spot, and more importantly have the opportunity to introduce the research topic and motivate the respondents to answer frankly. However, chances for this kind of survey are hard to find, as organizations are often unable or disinclined to allow work hours to be spent on data collection.

The mail questionnaire, as the term indicates, is a survey in which the questionnaires are sent out by the researcher and answered by the respondents without the researcher’s intervention (Dane, 1990). Compared with personally administered questionnaires, mail questionnaires can cover a wider geographical area in the survey. Furthermore, Oppenheim (1992) summarized that mail questionnaires can be conducted at low cost both for data collection and processing, and avoiding researcher’s bias. However, the return rates of mail questionnaires are typically low (Dane, 1990; Bourque and Fielder, 1995). A 30% response rate is considered acceptable (Fellows and Liu, 2003; Sekaran, 2003). Nevertheless, some effective techniques can be employed for improving the response rates to mail questionnaires. Sending follow-up letters, enclosing some small monetary incentives with the questionnaire, providing the respondents with self-addressed, stamped return envelopes, and keeping the questionnaire brief will help enhance the return rates.

In this research, a mail questionnaire was designed to obtain information about industry practitioners’ awareness on RFS and its application for office building fitout in Australia; more importantly, the open-ended questions inside the questionnaire helped to identify the potential issues associated with RFS fitout implementation.
The survey questions consisted of “5A” sections: **Awareness, Advantages, Accessibility, Adaptability and Adoption** of RFS.

Sekaran (2003) highlighted that where gathering “specialised informed inputs” on the topic area researched is essential and any type of probability sampling across a cross section of people is purposeless and not useful, it may become necessary to obtain the needed information from specific targets that possess the knowledge and can provide the information sought. This type of sampling is called judgement sampling which involves the choice of subjects who are in the best position to provide the information required. In this study, the above approach – judgement sampling – was adopted. This method is appropriate because the deployment of RFS implementation is indeed a big challenge in the fitout plan not only for new buildings but also for retrofit projects. On the one hand, this kind of significant decision-making can only be authorised by the people with middle-to-top level positions in companies which are naturally developers and owners. On the other hand, the implementation of RFS needs the knowledge, skill and information support from professional industry practitioners, particularly contractors, consultants as well as real estate agents.

Accordingly, the implementation of RFS fitout may involves a variety of stakeholders, e.g. owners, occupants, developers, architects, engineers, contractors, commercial real estate agents, etc. Based on this understanding, these parties were selected as the target respondents for the questionnaire. Owners and occupants were grouped under the category of clients because they both had the hands-on experience of using RFS in their premises. Architects and engineers were grouped under the category of consultants because they are the people actually delivering the design of the RFS fitout. The questionnaire respondents were selected from the last updated database available in the School of Urban Development, Queensland University of Technology. This database has been used by research projects that were successfully carried out in the relevant field, such as Shirazi (2001) and Budiawan (2002). Samples chosen from this database are unbiased and of good representative of the Australian construction industry stakeholders.
The survey was limited in three cities, Sydney, Melbourne and Brisbane. This decision was based on:

- When the research was conducted at QUT at 2002, only Sydney, Melbourne and Brisbane have a few projects using RFS technology.
- Based on the RFS practice in the world, it was mainly used in the high-technology office buildings which normally located in metropolitan cities. Sydney, Melbourne and Brisbane can represent the typical metropolitan cities in Australia.

### 3.4.2.3 Semi-Structured Interview

Interviews can be unstructured, semi-structured or structured (Kahn and Cannell, 1957; Saunders et al., 2000). Semi-structured interviews are designed to have a number of interview questions prepared in advance but such prepared questions are designed to be sufficiently open that the subsequent questions of the interviewer cannot be planned in advance but must be improvised in a careful and theorized way (Wengraf, 2001). Compared with unstructured ones, semi-structured interviews can focus on what the interviewer expects to acquire; compared with structured ones, semi-structured interviews require as much preparation before the session, more discipline and creativity in the session, more time for analysis and interpretation after the session, but can acquire more valuable information (Sakaran, 2003).

On the other hand, interviews can be conducted either face to face or by telephone or online, depending on the level of complexity of the issues involved, the likely duration of the interview, the convenience of both parties, and the geographical area covered by the survey. Face-to-face interviews allow the researcher to adapt the questions as necessary, clarify doubts, and ensure that responses are properly understood by repeating or rephrasing the questions. Its main disadvantage is the geographical limitations (Frey and Oishi, 1995). Telephone interviews can cover large geographical areas easily but may be not easy for the researcher to put his/her idea clearly and further be denied by the respondent without warning. Computer-assisted interviews can be stated simply as quick and more accurate information gathering, plus faster and easier analysis of data; however, it entails heavy initial investment on computer facilities and the response rate is relative low currently.
(Fowler and Mangione, 1990; Sekaran, 2003). In this research, a semi-structured face-to-face interview approach was employed for the following reasons.

- Most interview questions are structured, based on the potential issues obtained from the questionnaire survey. However, there might have other issues that have not been exposed by the previous questionnaire survey. Using semi-structured interviews can allow the interviewees to add any other potential problems as per their knowledge and experience.

- Since most of the interview questions are obtained from the questionnaire, it could be difficult for the interviewees to understand the real meaning of each question in such abstract terms. The face-to-face approach can allow the researcher to explain the real meaning of each question to the interviewees and let them make rational decisions and comments.

- With semi-structured interviews, the researcher can give the interviewees chances to freely present their own opinions on the questions and the possible solutions. And the researcher can clarify ambiguities in questions or answers immediately during the interviews.

- By semi-structured face-to-face interviews, the researcher can not only ask the interviewees to assess the perceived RFS fitout advantages, but also allow them to comment where and how these advantages are demonstrated according to their experience and knowledge.

The interviewees consisted of clients, developers, consultants, contractors and manufacturers. Compared with the respondents of questionnaire, the interviewees excluded commercial real estate agents as they are not familiar with RFS at all, and included manufacturers as they are the actual propeller of RFS in the market. All these interviewees were industry practitioners related to RFS fitout implementation. However, different from the appointment standard of questionnaire respondents, the interviewees selected must have robust knowledge and extensive experience of RFS fitout. Meanwhile, considering that most questionnaire feedbacks came from Brisbane (35%) and Sydney (49%), industry practitioners from these two cities were selected for the interviews. Most interviewees were selected from the questionnaire respondents who have robust knowledge and extensive experience of RFS fitout, while some were recommended by RFS building owners, developers and contractors.
3.4.2.4 Site Observations

Site observations are conducted when things or people can be observed in their natural environment or in the lab setting, and their activities or other items of interest can be noted and recorded (Saunders et al., 2000; Sekaran, 2003). The researcher may collect the needed data in that capacity without becoming an integral part of the organizational system, or may also enter the organization or the research setting and become a part of the work team. The former researcher is called a nonparticipant-observer, and the latter is called a participant-observer. The advantages of observational studies include ease of getting reliable data, and ease of observing the effects of site environmental influences. The disadvantages include the long period of personnel present on site, slow and expensive data collection.

Similar to the classification of interviews, site observations can be unstructured, semi-structured or structured. When the observer has a predetermined set of categories of activities or phenomena planned to be studied, it is a structured observational study. On the contrary, when the observer has no definite ideas of the particular aspects that need focus at the beginning of the study, and records practically everything that is observed, it is an unstructured observational study (Sekaran, 2003). In this research, a structured site observational study was employed for the following purposes:

- To validate the significant influence factors and real problems concluded by the questionnaire and interview surveys.
- To collect data relating to RFS products and applications in order to develop RFS specifications.
- To explore good practices for RFS fitout design and construction.
- To explore problems associated with RFS fitout implementation.

The sites included one manufacturer, four existing office building sites with RFS fitout and two office building construction sites with RFS fitout, which will be presented in detail in Chapter 6.
3.4.2.5 Focus Groups

Focus groups consist typically of 8 to 10 members with a moderator leading the discussions for about 2 hours on a particular topic, concept or product, in order to obtain their impressions, interpretations and opinions. The researcher plays a vital role in steering the discussions in a manner that would draw out the information sought, and keeping the members on track. It provides an opportunity for a flexible, free-flowing format for the members to comment on a specific topic at a particular location and at a specified time. It is relatively inexpensive and can provide fairly dependable data within a short time frame. In this research, three focus groups were conducted during the site observations for the following purposes.

- To obtain occupants’ opinions regarding real problems associated with RFS service operation and maintenance;
- To obtain occupants’ opinions regarding the advantages associated with RFS fitout implementation;
- To validate the survey findings regarding the SIFs and real problems.

3.4.3 Survey Development

The survey in this research includes questionnaires, interviews and focus groups. The development of these research instruments are interrelated, as presented below.

3.4.3.1 Questionnaire Development

Chapter 2 presented the existing literature related to RFS fitout technology and its application in overseas countries, and highlighted four unidentified but important issues with respect to the RFS fitout implementation in Australia as follows:

- The industry practitioners’ general recognition of RFS (including knowledge and awareness of RFS advantages);
- The industry practitioners’ knowledge in RFS fitout implementation;
- The current status and future of RFS application in Australia; and
- The barriers associated with RFS fitout implementation.
In quest of the above four issues, the questionnaire aimed to (1) identify the general recognition level of RFS in the industry; (2) identify the industry practitioners’ knowledge of RFS implementation; (3) to explore the status quo and future of RFS applications in the mind of industry practitioners; and (4) explore barriers associated with RFS fitout implementation.

The questions for the questionnaire consist of five groups: Awareness, Advantage, Accessibility, Adaptability and Adoption. The questions were designed to explore the 4 issues that were highlighted from the literature review. The questionnaire research plan is shown in Figure 3.2.

Figure 3.2 Questionnaire Research Plan

The five “A-” sections focus on different aspects of RFS implementation for the office building fitout and will be used to analyze and answer the aforementioned issues. Basically, Awareness, Advantage and Adaptability sections aim to explore the industry practitioners’ general recognition of RFS advantages and knowledge. Accessibility, Adaptability and Adoption sections aim to seek the industry practitioners’ knowledge in RFS implementation. Accessibility, Adaptability and Adoption sections aim to unearth barriers hindering RFS implementation. Adaptability and Adoption sections aim to investigate the status quo and future of RFS adoption in the mind of industry practitioners. The supplement at the end of the questionnaire is designed to explore the participants’ background for the survey statistic purpose.

The questionnaire was developed using a multiple-choice format. Some of the multiple-choice questions include answers to be solicited on a 7-point bipolar Likert scale with 1 representing the “least” and 7 the “most”, while others are designed with several pre-described answers. The questionnaire also includes one open-ended question to allow the respondents with RFS experience to write down the problems
they have come across in the operation of their RFS facilities. The specific content of
the questionnaire is presented in Appendix 1.

Example Questions

A 7-point bipolar Likert scale question:
Please identify your opinions to the questions below:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Rating (1-least, 7-most)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much are you interested in new information about RFS for office building fitout?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
</tbody>
</table>

A multiple choice question:
Please identify the advantages of RFS for office building fitout:
[a] Flexibility                                     [b] Ergonomics
[f] Others (please specify):

Pilot Study

As mentioned above, the questionnaire aims to explore the four issues raised from
the literature study, based on which the questions in the questionnaire were designed.
The appropriateness and adequacy of the proposed questions were justified through
the pilot study, which was carried out from December 2002 to February 2003.

In the pilot study, the preliminary version of the designed questionnaire was sent to
three academic staffs in this field from the Queensland University of Technology and
two industry people from the Department of Public Works, Queensland Government,
to test whether the questions were intelligible, easy to answer, or unambiguous, and
to seek possible improvement. A series of discussions were held separately with each
of the persons mentioned. The results of the discussions proved to be useful and led
to minor refinements of the questionnaire in the following aspects.

- Present an extra “others” as the last choice in most questions in order to allow
  respondents to add any possible answers which are not given in the questionnaire;
- Shorten the questionnaire length and make it more succinct and clear;
- Put the questionnaire background part in the questionnaire cover letter rather than
  in the questionnaire itself;
• Revise the rating scales for the cost, time and productivity comparison between the RFS and traditional fitout method.

Following these advices, the questionnaire development was finalized and tested again with two of the above five participants, making sure that all the issues had been clarified and resolved. By March 2003, the questionnaire was ready to be disseminated to the industry practitioners.

At the end of the research, another questionnaire was sent by electronic mail to the 19 interviewees who had been engaged for the semi-structured interviews in order to acquire their opinions on the research outcomes. This involved five key issues with significant influences on RFS fitout project delivery and guidelines for RFS fitout implementation. The feedbacks were used to validate the research outcomes. The questionnaire content is presented in Appendix 15.

3.4.3.2 Interview Development

As per the questionnaire findings, the industry people generally had low awareness of RFS fitout advantages and many potential issues were identified to be associated with RFS fitout implementation. Hence, semi-structured interviews were employed to (1) further explore the industry practitioners’ recognition of RFS advantages; (2) justify the significant influence factors (SIFs) and real problems associated with RFS fitout implementation; and (3) explore conceptual solutions to accommodate the above real issues in the RFS fitout project delivery.

In response to the interview purposes, the pre-described interview questions consisted of three sections. Section 1 presented 5 typical RFS benefits, i.e. flexibility, ergonomics, workplace productivity, time-saving and fitout cost-saving, to the interviewees and explored their comments. The interviewees were also encouraged to propose other advantages that have not been listed in the interview questions. Section 2 and Section 3 collectively consisted of 5 parts which further included the 44 issues raised from the questionnaire feedback. Specifically, Section 2 involved the potential SIFs that can affect the RFS fitout planning while Section 3 included the potential problems that can occur in the RFS service operation and maintenance. Again, the
interviewees were encouraged to propose other issues which had not been listed in the predefined questions.

All the questions were developed with four choices, i.e. *agree*, *disagree*, *it depends* and *no comments*. Considering the time limit and the numbers of questions, the researcher allowed the interviewees to choose one answer and then make a brief comment. Interviewees were also encouraged to present their opinions on how to solve the issues appropriately in the real projects. Each interview was expected to last 1 to 2 hours. The specific content of the questions is presented in Appendix 4.

**Example Questions**

**Section 1: Exploration of RFS Fitout Advantages**

A range of advantages associated with RFS fitout were identified in the research literature; however, they were not highly recognized by industry practitioners according to the earlier questionnaire survey. This might be due to the lack of RFS practices in the Australian construction industry. As per your experience and knowledge, please comment on the following issues.

<table>
<thead>
<tr>
<th>Perceived RFS fitout advantages</th>
<th>Agree</th>
<th>Disagree</th>
<th>It depends</th>
<th>No comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Flexibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Ergonomics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Workplace productivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other Advantages:

Comments:

**Section 2: Exploration of Potential Influence Factors**

A range of factors was identified from the previous questionnaire survey with potential influence to RFS fitout implementation. Please present your opinions on the following issues.

**Part 1 – Structural Constraints**

<table>
<thead>
<tr>
<th>Potential Influence Factors</th>
<th>Agree</th>
<th>Disagree</th>
<th>It depends</th>
<th>No comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) The initial building structural regularity restricts building retrofit with RFS.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) The space volume (distance between slab and slab) is a problem.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Transitions to lift system, existing doors, stair landings and toilets are problems.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Solutions to the above issues:

Other potential issues and solutions:

3.4.3.3 Focus Group Development

Through the questionnaire and interview, the real problems in the post-construction stage were recognized. In order to validate these problems, focus groups were employed to further investigate the occupants’ opinions with respect to these problems. At the same time, their understanding of the benefits resulting from their day-to-day experience could be obtained to justify the RFS advantages.

Focus groups were organized in three of the four existing office building sites during the site observations. Each focus group lasted approximately 2 hours. The group members were all occupants of the existing office buildings with RFS services. As per the purposes of focus groups, the focus group questions included two sections, as presented in Appendix 10. Section 1 presented the 15 problems identified from the previous survey and invited respondents to validate them based on their daily experience in their RFS facilities. Section 2 included one open-ended general question in quest of the real RFS users’ opinion on the perceived RFS advantages. Details of the focus groups will be presented in Chapter 6.

Example Questions

Section 1: Exploration of Real Problems

A range of real problems associated with RFS service operation and maintenance were identified in the earlier survey research. In order to validate these findings, please comment on the following issues from the viewpoints of an occupant of RFS facilities.

<table>
<thead>
<tr>
<th>Real problems resulting from the earlier survey research</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Excessive cable and wire distribution prevents even spread of underfloor cool air.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) UAD does not allow an easy solution to deal with hot spots in computer rooms.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Cool air in the UAD is often leaking from the interstice between panels.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments:
3.4.4 Data Analysis Methods

After data was collected from the questionnaire survey and interview survey, the data analysis process was started. Data analysis usually involves reducing accumulated data to a manageable size, developing summaries, looking for patterns, and applying statistical techniques (Emory and Cooper, 1991). In this research, a range of preliminary processes such as editing data, handling blank responses, coding data, categorising data files and entering data are undertaken prior to analysing the data, in order to ensure consistency of data and to allow results to be meaningfully interpreted.

Questionnaire Data Analysis

The analysis of questionnaire feedbacks was carried out using the Statistical Package for Social Science (SPSS for Windows) Version 11.5 and Microsoft Excel for Windows Version 2002. The main analytical technique was descriptive statistics. Specifically, the comparison of mean value of each variable was used for questionnaire data analysis.

The questionnaire survey aimed to explore the general recognition level of RFS in the industry, to seek the industry practitioners’ knowledge of RFS fitout implementation, to explore their views on the future of RFS fitout in Australia, and to identify barriers associated with RFS fitout implementation. The first three purposes were examined through the observation of the dichotomous and numerical scale questions using descriptive statistics. Buckingham and Saunders (2004) presented that descriptive statistics is appropriate to explore a phenomenon with no attempt to analyse why this phenomenon happens. It is evident that the questionnaire survey aimed to explore the industry practitioners’ general views on the RFS fitout rather than to explain why they have different views on these respects in the follow research. Hence, the employment of mean value comparison is appropriate to meet the survey purposes.

Different rating scales were adopted in the questionnaire survey, so different rating methods were needed to quantify or code the feedback data when the SPSS was used to analyze the data. For the numerical scale questions, the respondents feedback
rating was between 1 and 7. For the dichotomous scale questions, “Yes” was coded with “1” and “No” coded with “2”. The coding method for the dichotomous scale did not represent the real value of the data. Rather, it was used just for statistical purposes. For the category scale questions, the given multiple choices were accounted and regarded as dichotomous scale questions individually (Miller et al., 2002). Similarly, the “Yes” and “No” coding method was applied. The statistic results were used for comparisons between respondents with or without RFS experience. Some data was also used for comparisons among different industry professionals.

It should be noted that the results of the 5 pilot studies were not considered in the final questionnaire analysis because a few changes have been made to the first draft of the questionnaire, based on the feedback from the pilot study respondents. For example, the rating scales for some questions have been changed. Meanwhile, 49 valid responses were received, representing a response rate of 39%, which is appropriate for carrying out the analysis of the questionnaire.

The last but the most important goal aimed to identify possible barriers hindering the application of RFS fitout in Australian office buildings. These potential issues were proposed by the respondents when they answered the open-ended questions in the questionnaire. These issues formed the basis of the following interviews, site observations, focus groups, and constructability study, in which they were refined and justified and solutions were found to overcome them in the process of delivering RFS fitout projects.

**Interview Data Analysis**

The interview data analysis is a rich and complex process. Using the pre-planned questions as the analytic blueprint places an a priori structure on the outcome of the analysis (Cavana et al., 2001). The researcher utilized tape recorders to collect the interviewees’ opinions. The data analysis process included the following procedures.

- Transcribe the information in the cassettes into raw data on the basis of individual interviewee;
- Source code all the raw data and then categorize the relevant information into each question;
• Read through each respondent’ comments along with his/her choice to each question;
• Summarize their choice in tables using Excel for Windows and abstract and compare their comments, particularly the solutions to each problem.
• Reach a conclusion to each question and its possible solutions.

**Site Observation and Focus Group Data Analysis**

Since the data collection method for site observations was taking pictures with the aid of digital camera, pictures would be employed as the main tool to convey the findings that researchers had discovered on the sites. Those pictures reflecting innovative design and construction were gathered and presented to demonstrate the good practice for RFS fitout delivery, whereas those pictures reflecting problems were collected to highlight the improper issues associated with RFS fitout implementation. In addition, the data relating to RFS products and application were categorized, compared and summarized in order to develop the RFS specifications.

The data analysis method for focus groups is similar to that of the earlier semi-structured interview. The group members’ comments on particular potential problems associated with RFS service operation and maintenance were transcribed, categorized and analysed with Excel, and the descriptive statistics (percentage) were used to expose the highly recognized problems. Then, their comments on the potential RFS merits were summarized, which contribute to the justification of RFS advantages with compelling examples derived from daily occupancy experience.

**3.4.5 Key Research Activities**

The data collected from the literature review, questionnaires, semi-structured interviews, site observations and focus groups are analysed, and the findings underpin the basis for the following key research activities.

**LCC Comparison Study**

Cost is always one of the most important factors influencing owners and developers’ decision-making on the application of new technologies. RFS has been used for the fitout of office buildings in the past decade. However, the literature review shows
that while many studies have explored the benefits enabled by RFS fitout such as flexibility and improved workplace environment, no dedicated research has been done in Australia construction industry in this regard. As a result, the industry practitioners are not knowledgeable enough with respect to the cost reality of RFS fitout. It is critical to conduct a cost comparison to ascertain the cost reality between RFS and the traditional fitout method.

The literature review highlighted the typical differences between the RFS fitout and traditional fitout methods, which might result in fitout cost differences. Meanwhile, although many respondents argued that RFS could lead to higher capital cost investment, the questionnaires, interviews, site observations and focus group discussions revealed that RFS fitout could contribute to lower running costs due to its great benefits, e.g. flexibility to churn, improved workplace productivity, reduced absenteeism, lower energy consumption, etc.

Since the model aimed at ascertaining the cost difference between RFS and traditional fitout method rather than calculating the capital cost and running cost pertaining to each fitout method, only the elements with different cost occurrences were considered in the constitution of the model. As such, the cost elements under each group needed to be identified prior to the model development. By calculating the cost difference of each element identified and adding them up, the total capital cost difference and total running cost difference between the two fitout methods were reached. Then, a LCC comparison model was established by comparing the total running cost difference with the total capital cost difference based on reasonable assumptions. Considering time value of money and the period of project life cycle, the LCC benefit of RFS fitout can be justified.

Based on a proposed RFS fitout project, a case study was undertaken to demonstrate the application of the LCC comparison model, which finally justified the LCC benefits of RFS fitout. With the aid of single parameter and multiple parameters sensitivity analysis, the key factors influencing the LCC benefits of RFS fitout were exposed in the end. The specific LCC model development and the case study are presented in Chapter 7.
Summary of Catalysts for RFS Implementation

Although a range of factors influencing RFS fitout implementation and a series of real problems associated with RFS service operation and maintenance were identified by the earlier research instruments, many catalysts were, in the meantime, also seen to stimulate RFS applications in the Australian construction industry. Based on the findings of questionnaire, interview, site observations, focus groups and LCC comparison, the catalysts not only included the justified benefits brought by RFS fitout and the industry practitioners’ confidence in its promising future; more importantly, they revealed the improved adaptability of the new technology and the positive factors in the relatively low industry practitioners’ awareness of RFS.

Discussion of Barriers

The justified barriers including significant influence factors and real problems were discussed in the context of RFS fitout project delivery process, which highlighted the impacts of these significant influence factors on RFS fitout design, construction, operation and maintenance and in the meantime, identified the causes for the post-construction problems. The conceptual solutions to these barriers were reconsidered in order to pinpoint the key issues associated with RFS fitout project delivery, which finally exposed a range of project level critical factors pertaining to RFS fitout design, construction, operation and maintenance.

Constructability Study

In tune with the constructability principles concluded by the CIIA (1996), a RFS fitout constructability study was conducted to integrate the significant influence factors and project level critical factors into the project delivery process, in an aim to minimize the negative impacts of these factors and create an optimal environment for RFS implementation. Despite its coverage of all principles, the constructability study mainly focused on the exploration of integration of constructability, early construction knowledge inputs, team skills, design and construction programs, alignment of RFS fitout risks and benefits with project objectives, etc. And finally, key issues with significant influences on the RFS fitout project delivery were highlighted and further investigated.
Chapter 3: Research Methodology

Formulation of Guidelines
Based on the findings of previous research instruments, particularly constructability study findings, viable guidelines for RFS fitout implementation in the Australian construction industry were formulated as a final outcome of the RFS research. Covering the whole project life cycle, the guidelines consist of five sections, i.e. feasibility stage, conceptual design stage, detailed design stage, construction stage and post-construction stage, each of which present the objectives, team roles and critical details in this project stage. To facilitate the application of the guidelines, a framework was presented, covering the main research findings.

3.4.6 Validation of Results
Validation of the results can be undertaken in a variety of ways. For quantitative studies, statistical inference is employed to determine the applicability of the results to the issues under investigation, thence, the drawing of conclusions (Fellows and Liu, 2003). Considering that this research was of applied research nature rather than social research and the main research outcomes (e.g. significant influence factors, real problems, guidelines, etc) were achieved through qualitative analysis on the potential issues highlighted from the surveys, the validation of results are conducted in two stages.

The questionnaire and interview surveys identified a series of significant influence factors pertaining to RFS fitout planning and real problems associated with RFS service operation and maintenance. Before the theoretical study of these factors and problems, they had to be validated to form a sound basis for the following study. This is the first stage validation, as shown in Figure 3.3. This validation process was conducted with the aid of site observations and focus groups as indicated below:

- The problems associated with RFS construction and performance on the existing office building sites and construction sites were identified and analyzed to validate the significant influence factors pertaining to RFS fitout planning.
- The real problems associated with RFS service operation and maintenance were validated through focus group discussions in which the RFS occupants were asked to pinpoint the problems based on their experiences of RFS facilities in their office buildings.
Chapter 3: Research Methodology

The second stage validation was undertaken at the end of the research. Once the key issues influencing the project delivery of RFS fitout were identified and the guidelines to support RFS fitout implementation were developed, a questionnaire covering them was developed to explore the industry practitioners’ comments and validate these findings. The questionnaire was sent to the previously engaged interviewees who were all industry practitioners with robust knowledge and extensive experience of RFS fitout. Through this way, the validity of the key issues influencing the RFS fitout implementation and the guidelines for the RFS fitout project delivery was tested.

3.5 Summary

This chapter presented the relevant literatures for methodological issues and described the specific methodologies adopted in this research. The research design and plan were developed first, in which the main elements such as the purpose of study, type of investigation, extent of researcher interference, study setting, unit of analysis and time horizon of study were defined. Then, the methodology adopted in this research was presented in detail, which covered the research process model, data collection methods, survey development, data analysis methods, key research
activities and validation of research findings. All of these formed a comprehensive methodological approach that underpins and consolidates this exploratory research.

The next chapter will present the questionnaire data analysis and findings.
CHAPTER 4
QUESTIONNAIRE DATA ANALYSIS AND FINDINGS

4.1 Introduction

An apparent contradiction was mentioned in Chapter 2. That is, the highly perceived RFS advantages against the scarcity of RFS application for office building fitouts in Australia. This reality indicates the existence of barriers hindering RFS implementation in the construction industry. However, there is no a systematic research exploring the RFS implementation in Australia. Specifically, neither the industry practitioners’ awareness of RFS advantages nor their knowledge in RFS fitout project delivery were identified; the potential barriers associated with RFS fitout design, construction, operation and maintenance were not recognized; their confidence in the future of RFS as an alternative to the traditional fitout method is not clear either. Accordingly, a questionnaire survey presented to the industry practitioners (with or without RFS experience) was undertaken in an aim to ascertain all these critical issues as the first step of this RFS research.

This chapter presents the questionnaire data analysis and findings. Data obtained was edited in order to make sure that each of them was usable and could be easily scored. Not applicable (N/A) or missing values were excluded from the analysis. The valid data was tabulated and analysed using SPSS and Excel. Based on the comparisons between respondents with or without RFS experienced and among different industry practitioners, a qualitative analysis and interpretation is presented in this chapter in an aim to explore the questionnaire purposes. The findings of the survey are summarized in the end, which forms the basis of this exploratory research.
4.2 Questionnaire Purposes

As per the literature findings, a mail questionnaire survey was conducted for the following purposes:

- To identify the general recognition level of RFS in the industry;
- To explore barriers associated with RFS fitout implementation;
- To identify the industry practitioners’ knowledge of RFS implementation; and
- To explore the status quo and future of RFS applications in the mind of industry practitioners.

4.3 Sample Characteristics

Research projects take place in the contexts of the researcher’s interest, expertise and experience; of human contacts; of the physical environment (Fellows and Liu, 2003). Hence, despite the best intentions and vigorous precautions, it seems inevitable that circumstance, purpose and characteristics of samples will impact on the work and its results. Therefore, it was considered necessary to first describe the characteristics of the samples prior to performing the main data analysis.

4.3.1 Questionnaire Response Rate

The survey questionnaire was administered by mail in April 2003 to 126 participants from three metropolitan cities in Australia, i.e. Sydney, Melbourne and Brisbane. The participants include 42 clients (owners and occupants), 27 developers, 8 consultants (architects and consulting engineers), 27 contractors and 22 commercial real estate agents. The reason for putting owners and occupants together is that the two groups both had the hands-on experience of using RFS in their premises. The questionnaire package comprised a cover letter, the questionnaire, and a postage paid and self-addressed envelope.

After an elapsed time of two and a half months, of the 126 questionnaires mailed to the participants, a total of 53 forms were returned, representing a response rate of 42%; however, 2 feedbacks are unclaimed letters and another 2 are invalid responses.
due to incomplete answers to the questions. Therefore, only 49 forms were useable, representing a valid response rate of 39%. The distribution of the valid respondents is outlined in Table 4.1. Although 5 pilot studies had been carried out prior to the final questionnaire survey, they are not considered in the questionnaire data analysis.

Table 4.1 Distribution of Questionnaire Respondents

<table>
<thead>
<tr>
<th>Category of Respondents</th>
<th>No. canvassed</th>
<th>No. returned</th>
<th>No. unclaimed</th>
<th>No. invalid</th>
<th>No. valid</th>
<th>Valid response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clients</td>
<td>42</td>
<td>14</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>Developers</td>
<td>27</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>41</td>
</tr>
<tr>
<td>Consultants</td>
<td>8</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>88</td>
</tr>
<tr>
<td>Contractors</td>
<td>27</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>11</td>
<td>41</td>
</tr>
<tr>
<td>Commercial Real Estate Agent</td>
<td>22</td>
<td>9</td>
<td>0</td>
<td>1</td>
<td>8</td>
<td>36</td>
</tr>
<tr>
<td>Total</td>
<td>126</td>
<td>53</td>
<td>2</td>
<td>2</td>
<td>49</td>
<td>39</td>
</tr>
</tbody>
</table>

4.3.2 Respondents’ Profile

As indicated in Table 4.1, the respondents comprise of 12 clients, 11 developers, 7 consultants, 11 contractors as well as 8 commercial real estate (c.r.e.) agents. The profile of the respondents is indicated in Figure 4.1.

A further analysis of the feedback by locations against the category of respondents is persuasive to the rationalization of the places for the subsequent interview survey. The numbers of the feedbacks from Sydney, Brisbane and Melbourne are 24, 17 and 8, representing response rates of 49%, 35% and 16% respectively. Details are summarized in Figure 4.2.
Chapter 4: Questionnaire Data Analysis and Findings

4.4 Questionnaire Data Analysis

According to the questionnaire purposes, the data analysis is undertaken through two methods in order to organize different comparisons and reach more in-depth results as to the RFS implementation for office building fitout in Australia.

First, a comparative method is used for the data analysis and is implemented between the experienced group and the inexperienced group throughout all sections, for the purpose of finding the differences in terms of their understanding of RFS and barriers hindering RFS application, as well as their opinions on the RFS status quo and future. The experienced group involves respondents who actually used, designed, and constructed RFS. Reversely, the inexperienced group includes all other respondents. This kind of category facilitates the direct comparison of the prospective from the experienced and inexperienced groups, which is perspicuous and convictive. The analysis process is organized in the sequence of the questionnaire contents.

Then selective data is compared among different categories of respondents by professionals, in an aim to explore their significant different recognition and opinions.
with respect to RFS and its corresponding barriers, knowledge of RFS implementation as well as RFS current status and future. Selecting important data for comparison can help to single out key issues and minimize long-winded descriptions.

4.4.1 Data Analysis between Experienced and Inexperienced Groups

According to the statistics of the questionnaire feedback, 24 respondents have experienced RFS whereas 25 respondents have not. Table 4.2 presents the questionnaire feedback comparisons between the experienced group and inexperienced group. The general rating scales were presented in Chapter 3. More details are presented here. Variable 2-4, 14, 15, 21 and 22 used the numerical scale, Variable 1 and 11 used the dichotomous scale, whereas other variables used the categorical scale. For the numerical scale questions, the respondents feedback rating is between 1 and 7. Particularly, although Variable 8-10 used the categorical scale, they can also be expressed as ordinal measurement scales to ease the subsequent data analysis considering the wording of the questions according to Zikmund (2000). The coding method for the dichotomous scale does not represent the real value of the data. Rather, it is used for statistitical purposes.

The mean value or percentage of all variables for each group is summarized in Table 4.2. The method of measurement is also listed for reference. Encompassing 60 variables, a total of 22 questions are applicable to the comparison between the two respondent groups. To the Likert scale questions, the mean value is the average value of the respondents’ feedbacks and calculated by summing up the values to a particular variable and then dividing the result by the number of corresponding respondents. Taking Variable 2 as an example, the mean value for the experienced group is 5.83, which is obtained by summing up each experienced respondent’s feedback rating and then dividing the result by 24. By the same token, the mean value for the inexperienced group is 3.52, which is calculated by summing up each inexperienced respondent’s feedback rating and then dividing the results by 25.
### Table 4.2 Feedback Comparisons between Experienced and Inexperienced Groups

<table>
<thead>
<tr>
<th>Code</th>
<th>Variable Names</th>
<th>Measure</th>
<th>Mean or Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experienced</td>
</tr>
<tr>
<td>1</td>
<td>Heard of RFS</td>
<td>yes/ no</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>Familiarity with RFS and its components</td>
<td>Likert 1-7</td>
<td>5.83</td>
</tr>
<tr>
<td>3</td>
<td>Satisfactory with current office environment</td>
<td>Likert 1-7</td>
<td>5.30</td>
</tr>
<tr>
<td>4</td>
<td>Interest in new RFS information</td>
<td>Likert 1-7</td>
<td>4.38</td>
</tr>
<tr>
<td>5</td>
<td>Identification of RFS advantages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>Flexibility</td>
<td>yes/ no</td>
<td>0.96</td>
</tr>
<tr>
<td>5.2</td>
<td>Ergonomics</td>
<td>yes/ no</td>
<td>0.33</td>
</tr>
<tr>
<td>5.3</td>
<td>Fitout cost-saving</td>
<td>yes/ no</td>
<td>0.38</td>
</tr>
<tr>
<td>5.4</td>
<td>Workplace productivity</td>
<td>yes/ no</td>
<td>0.25</td>
</tr>
<tr>
<td>5.5</td>
<td>Time-saving</td>
<td>yes/ no</td>
<td>0.21</td>
</tr>
<tr>
<td>6</td>
<td>Demonstration of flexibility</td>
<td>yes/ no</td>
<td>0.46</td>
</tr>
<tr>
<td>6.1</td>
<td>Construction</td>
<td>yes/ no</td>
<td>0.88</td>
</tr>
<tr>
<td>6.2</td>
<td>Reconfiguration</td>
<td>yes/ no</td>
<td>0.67</td>
</tr>
<tr>
<td>6.4</td>
<td>Relocation</td>
<td>yes/ no</td>
<td>0.46</td>
</tr>
<tr>
<td>7</td>
<td>Demonstration of ergonomics</td>
<td>yes/ no</td>
<td>0.63</td>
</tr>
<tr>
<td>7.1</td>
<td>Adjustable HVAC</td>
<td>yes/ no</td>
<td>0.58</td>
</tr>
<tr>
<td>7.2</td>
<td>Self-controlled environment</td>
<td>yes/ no</td>
<td>0.33</td>
</tr>
<tr>
<td>8</td>
<td>Fitout cost comparison</td>
<td>Likert 1-6*</td>
<td>3.05</td>
</tr>
<tr>
<td>9</td>
<td>Installation time comparison</td>
<td>Likert 1-6*</td>
<td>2.67</td>
</tr>
<tr>
<td>10</td>
<td>Workplace productivity</td>
<td>Likert 1-6*</td>
<td>3.18</td>
</tr>
<tr>
<td>11</td>
<td>Access to adequate RFS information</td>
<td>yes/ no</td>
<td>0.79</td>
</tr>
<tr>
<td>12</td>
<td>Team skills for RFS construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.1</td>
<td>Client</td>
<td>yes/ no</td>
<td>0.89</td>
</tr>
<tr>
<td>12.2</td>
<td>Architect</td>
<td>yes/ no</td>
<td>0.95</td>
</tr>
<tr>
<td>12.3</td>
<td>Engineer</td>
<td>yes/ no</td>
<td>0.74</td>
</tr>
<tr>
<td>12.4</td>
<td>Project manager</td>
<td>yes/ no</td>
<td>0.84</td>
</tr>
<tr>
<td>12.5</td>
<td>Quantity surveyor</td>
<td>yes/ no</td>
<td>0.58</td>
</tr>
<tr>
<td>12.6</td>
<td>Cost consultant</td>
<td>yes/ no</td>
<td>0.68</td>
</tr>
<tr>
<td>12.7</td>
<td>Construction consultant</td>
<td>yes/ no</td>
<td>0.53</td>
</tr>
<tr>
<td>13</td>
<td>Project delivery methods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.1</td>
<td>Design/bid/build (D/B/B)</td>
<td>yes/ no</td>
<td>0.50</td>
</tr>
<tr>
<td>13.2</td>
<td>Design and build (D&amp;B)</td>
<td>yes/ no</td>
<td>0.31</td>
</tr>
<tr>
<td>13.3</td>
<td>Const. mgmt./general contractor</td>
<td>yes/ no</td>
<td>0.44</td>
</tr>
<tr>
<td>13.4</td>
<td>Lump sum (except D/B/B and D&amp;B)</td>
<td>yes/ no</td>
<td>0.63</td>
</tr>
<tr>
<td>14</td>
<td>Supplier’s involvement in fitout design</td>
<td>Likert 1-7</td>
<td>3.71</td>
</tr>
<tr>
<td>15</td>
<td>Supplier’s delivery of RFS construction</td>
<td>Likert 1-7</td>
<td>3.59</td>
</tr>
<tr>
<td>16</td>
<td>Areas of RFS being interested in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.1</td>
<td>RFS products</td>
<td>yes/ no</td>
<td>0.46</td>
</tr>
<tr>
<td>16.2</td>
<td>RFS design</td>
<td>yes/ no</td>
<td>0.38</td>
</tr>
<tr>
<td>16.3</td>
<td>RFS contracting strategy</td>
<td>yes/ no</td>
<td>0.21</td>
</tr>
<tr>
<td>16.4</td>
<td>RFS installation</td>
<td>yes/ no</td>
<td>0.33</td>
</tr>
<tr>
<td>16.5</td>
<td>RFS maintenance</td>
<td>yes/ no</td>
<td>0.46</td>
</tr>
<tr>
<td>16.6</td>
<td>RFS reconfiguration</td>
<td>yes/ no</td>
<td>0.38</td>
</tr>
<tr>
<td>16.7</td>
<td>Associated fitout technologies</td>
<td>yes/ no</td>
<td>0.54</td>
</tr>
</tbody>
</table>
# Table 4.2 (Continued)

<table>
<thead>
<tr>
<th>Code</th>
<th>Variable Names</th>
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<th>Mean or Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Experienced group</td>
</tr>
<tr>
<td>17</td>
<td>RFS application areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17.1</td>
<td>Office space</td>
<td>yes/no</td>
<td>0.88</td>
</tr>
<tr>
<td>17.2</td>
<td>Computer/equipment room</td>
<td>yes/no</td>
<td>1.00</td>
</tr>
<tr>
<td>17.3</td>
<td>Clean room</td>
<td>yes/no</td>
<td>0.17</td>
</tr>
<tr>
<td>17.4</td>
<td>Residential room</td>
<td>yes/no</td>
<td>0.13</td>
</tr>
<tr>
<td>17.5</td>
<td>Commercial building (except offices)</td>
<td>yes/no</td>
<td>0.21</td>
</tr>
<tr>
<td>18</td>
<td>Subsystems integrated with RFS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18.1</td>
<td>HVAC</td>
<td>yes/no</td>
<td>0.83</td>
</tr>
<tr>
<td>18.2</td>
<td>Lighting system</td>
<td>yes/no</td>
<td>0.25</td>
</tr>
<tr>
<td>18.3</td>
<td>PVD</td>
<td>yes/no</td>
<td>0.96</td>
</tr>
<tr>
<td>18.4</td>
<td>Fire safety system</td>
<td>yes/no</td>
<td>0.46</td>
</tr>
<tr>
<td>19</td>
<td>Physical constraints for retrofits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19.1</td>
<td>Floor to ceiling height</td>
<td>yes/no</td>
<td>0.88</td>
</tr>
<tr>
<td>19.2</td>
<td>Ceiling-based HVAC system</td>
<td>yes/no</td>
<td>0.38</td>
</tr>
<tr>
<td>19.3</td>
<td>Power pole PVD system</td>
<td>yes/no</td>
<td>0.17</td>
</tr>
<tr>
<td>19.4</td>
<td>Fire safety system</td>
<td>yes/no</td>
<td>0.17</td>
</tr>
<tr>
<td>20</td>
<td>Main non-physical factors hindering RFS use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.1</td>
<td>Higher initial cost</td>
<td>yes/no</td>
<td>0.88</td>
</tr>
<tr>
<td>20.2</td>
<td>Unfamiliarity with RFS products</td>
<td>yes/no</td>
<td>0.46</td>
</tr>
<tr>
<td>20.3</td>
<td>Unfamiliarity with RFS procurement</td>
<td>yes/no</td>
<td>0.33</td>
</tr>
<tr>
<td>20.4</td>
<td>Safety problems</td>
<td>yes/no</td>
<td>0.17</td>
</tr>
<tr>
<td>20.5</td>
<td>Reluctance to accept new technology</td>
<td>yes/no</td>
<td>0.46</td>
</tr>
<tr>
<td>21</td>
<td>Probability of using RFS in the future</td>
<td>Likert 1-7</td>
<td>4.63</td>
</tr>
<tr>
<td>22</td>
<td>Promising application for office fitout in Au.</td>
<td>Likert 1-7</td>
<td>5.29</td>
</tr>
</tbody>
</table>

* 1 = ‘50~100% lower’, 2 = ‘≤50% lower’, 3 = ‘equal’, 4 = ‘≤50% higher’, 5 = ‘50~100% higher’, 6 = ‘>100% higher’

# 1 = ‘50~100% shorter’, 2 = ‘≤50% shorter’, 3 = ‘equal’, 4 = ‘≤50% longer’, 5 = ‘50~100% longer’, 6 = ‘>100% longer’

To the dichotomous scale questions, the value listed in Table 4.2 indicates the percentage of respondents holding a positive answer to this variable. The percentage value is obtained by counting up the number of respondents choosing “Yes” and then dividing the result by the number of the total respondents in this group. Taking Variable 5.1 as an example, the percentage value for the experienced group is 96%, which is obtained by counting up the “Yes” respondents and then dividing the result by 24. Similarly, the percentage value for the inexperienced group is calculated.

## 4.4.1.1 Exploration of Awareness

Four questions were designed in the first section of the questionnaire and accordingly Variable 1-4 are analyzed to ascertain the general awareness of RFS and interest in new information about RFS among project stakeholders.
First of all, both the experienced group and the inexperienced group had a unanimous agreement that they had heard of RFS. The value of 100 percentages indicates that all respondents answered the questions based on their knowledge, which hence substantiates the exploration of the questionnaire purposes.

However, the feedback on the familiarity shows that the experienced group was more familiar with RFS and its components than the inexperienced group, with the mean score 5.83 against 3.52. This is reasonable since the former had experience on the RFS design, construction, operation and maintenance whereas the latter could only understand RFS and its components based on their general knowledge in the building and construction context. Meanwhile, since all respondents have heard of RFS, the second part of Question 2 is not applicable and unpresented in Table 4.2.

Furthermore, the different level of satisfaction with the current workplace environment is also highlighted. Specifically, strong evidence has shown greater satisfaction with the current workplace environment among the experienced group than that among their counterparts, with the satisfaction level 5.30 against 4.00. This result reveals that RFS is indeed conductive to the improvement of the workplace environment.

At the end of this section, the respondents were asked about their interest in new RFS information. The feedback shows that the experienced group (mean score 4.38) had slightly more interest than the inexperienced group (mean score 3.96). However, the general level of interest in both groups is moderate, which discloses inadequate incentives for industry practitioners to consider RFS in their projects.

4.4.1.2 Exploration of Advantages

A total of 6 questions and 15 variables were involved in this section to identify the advantages of RFS in the perception of respondents. As above mentioned, the experienced group’s recognition about RFS advantages can be supposed to be more objective than the inexperienced group, provided that the experienced respondents
made their choices based on their hands-on RFS practice and the inexperienced respondents on their own grounds which might not relate to RFS directly.

Although most of the comparative data is presented in Table 4.2, a further illustration in a figure facilitates the transversal comparison among all the listed perceived advantages. Figure 4.3 shows the comparison between the two groups of their recognition of RFS advantages. First of all, 96% of respondents in both groups agreed with the flexibility enabled by RFS. This high level acknowledgement indicates that *industry practitioners have generally accepted the fact that RFS can bring flexibility into buildings and modern business.*

![Figure 4.3 Recognition of RFS Advantages in Experienced and Inexperienced Groups](image)

In comparison, *a generally low recognition applies to other perceived RFS advantages.* In detail, the agreement level of ergonomics, fitout cost-saving and workplace productivity are all less than 50% in both groups, which reveals two important issues. Firstly, most experienced respondents did not agree with these perceived benefits. Secondly, this result is inconsistent with the conclusions as to the RFS benefits derived from the previous literature reviews indicating that RFS could contribute to all these respects. When it comes to time-saving, the experienced group generally did not agree with this benefit either although more than half of the inexperienced group conceived it. In particular, some experienced respondents pointed out that RFS could contribute to a lower running cost, easy access to underfloor services maintenance, more user-friendly environment, etc.

As far as the demonstration of flexibility is concerned, there is a strong agreement in both groups that RFS can best support office reconfiguration, followed by

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maintenance, relocation and construction. Considering the high acknowledgement of flexibility outlined by the former question and the high awareness of RFS demonstrations inferred by this question, a conclusion that *RFS enabled flexibility has been substantiated in the mind of industry practitioners* is reached.

With respect to the demonstration of ergonomics, the adjustable HVAC and self-controlled environment were respected, with a response rate of 63% and 58% respectively in the experienced group, whereas the open communication and the self-controlled environment were regarded with a response rate of 68% and 56% respectively in the inexperienced group. All the agreement levels are moderate, which further confirms that *the RFS endowed ergonomics has not been broadly appreciated by industry practitioners*. This result is consistent with the above findings of the recognition analysis on the RFS advantages.

In addition, respondents were asked to compare the fitout cost, installation time and workplace productivity between the two fitout methods. Table 4.2 shows that the fitout cost of RFS was perceived to be less than 50% higher than the traditional fitout method, with a mean score of 3.61; however, the real experience revealed that the two methods were nearly all square, with a mean score of 3.05. This result reveals that *the fitout cost of RFS is indeed not as high as perceived*.

Interestingly, the experienced group generally suspected that the workplace productivity could be improved with the adoption of RFS, with a mean value of 3.18; the inexperienced group deemed that RFS could contribute to it, with a mean value of 3.64. The moderate acknowledgement is inconsistent with the literature review findings that RFS could enhance workplace productivity, which might be due to two reasons. Firstly, workplace productivity is hard to evaluate. Secondly, even though there is an improvement of the workplace productivity, it is hard to justify that RFS is the leading accelerant. In any case, however, *RFS is assumed to be conducive to workplace productivity*.

Finally, the feedback on the installation time shows there was not a consensus among the respondents. The experienced group believed that the installation time of RFS could be less than 50% shorter than that of the traditional fitout method.
Comparatively, the inexperienced group perceived that the time was less than 50% longer. This result is contradictory to the above recognition on the time-saving as one of the RFS advantages, which indicates that most respondents did not have a clear idea in this respect.

4.4.1.3 Exploration of Accessibility

Section 3 investigated the accessibility issues of RFS through a review of team skills, project delivery methods, knowledge involvement, public interest in RFS items, etc. A total of 5 questions and 21 variables were observed.

First of all, respondents were asked whether they have access to adequate information or knowledge on RFS application for office building fitout. The result shows that the experienced group clearly had more access than the inexperienced group, with a percentage of 79 against 44.

In terms of the constitution of team skills for RFS projects, there is a similar order of rating among both groups, with architects, clients, engineers and project managers being the most necessary while construction consultants the least, which is revealed in Figure 4.4. The apparent disagreement between the two groups lies in the appointment of construction consultants. Compared with a low agreement in this regard in the inexperienced group, more than half of the respondents with experience appreciated the contribution of construction consultants to RFS projects.

![Figure 4.4 Recognition of Team Skills in Experienced and Inexperienced Groups](image-url)
In regard to project delivery methods, there is not a general agreement in the two groups. The inexperienced group seemed to have equivalent rating on all the provided choices, reflecting their low recognition of the impacts of the project delivery methods on the RFS implementation. Meanwhile, the respondents in the experienced group seemed to agree with the design/bid/build and lump sum (except design/bid/build and design and build) contracts. Their low agreement to the design and build (D&B) and construction management/general contractor (CM/GC) contracts is apparently contradictive to the project constructability principles (Griffith and Sidwell, 1997). The result indicates that most respondents did not know the impacts of various contract forms upon the project delivery with innovative technologies. From the constructability perspective, both D&B and CM/GC methods can bring contractors or subcontractors on board during the design process and as a result facilitate the cooperation and integration of design and construction.

Since RFS is as yet a non-standard application in the industry, the involvement of RFS suppliers or manufacturers was perceived to be able to facilitate RFS implementation. However, the feedback shows that most respondents in both groups held a negative agreement with the suppliers or manufacturers’ delivery of RFS fitout design. A similar opinion applies to the consideration of the suppliers or manufacturers’ delivery of the RFS fitout contracts, with a mean value less than 4.00 in both groups.

At the end of this section, respondents were asked to choose the areas of their interest for RFS information. The result shows that more than half of the respondents in the experienced group were interested in the associated fitout technologies such as underfloor HVAC and PVD, while more than half of their counterparts were interested in RFS products, design and installation besides the associated fitout technologies. However, the two groups had very low interest in the RFS contracting strategy.

4.4.1.4 Exploration of Adaptability

Section 4 investigated the respondents’ propositions of the RFS adaptation, the underfloor service integration, as well as the main physical constraints reducing the
RFS adaptability in retrofit projects. A total of 3 questions and 13 variables were concerned in this section.

As per Table 4.2, the application of RFS in computer/equipment rooms and office spaces were recognized by an absolute majority of respondents in both groups, with all percentages over 84, indicating that the general use of RFS was recognized popularly. Meanwhile, there is very low awareness of RFS applications in clean rooms and commercial buildings (except office buildings) although many RFS products were designed for the two environments as well.

As far as the underfloor service integration was concerned, again, an absolute majority of respondents in both groups were of the opinion that the PVD system should be integrated into the RFS. As to the use of underfloor HVAC, more than 80% of respondents in both groups agreed with it although the consensus on it is not as strong as that to the underfloor PVD. Other services were also recognized by a smaller proportion of respondents, such as lighting service, fire safety service as well as underfloor water and piping system.

As part of the exploration of barriers hindering RFS implementation, respondents were asked to highlight the possible physical constraints in retrofit projects using RFS. A broad agreement hits on the floor to ceiling height, with a percentage of 88 in both groups. Meanwhile, the ceiling-based HVAC system was conceived by the inexperienced group while only a small number in the experienced group perceived it as a problem. The power-pole system and fire safety system were not seen as problems by most experienced respondents. Particularly, the existing building structure is seen by many respondents as a hard nut to crack.

**4.4.1.5 Exploration of Adoption**

The last section studied RFS adoption issues, e.g. the possible non-physical problems influencing RFS adoption, the respondents’ general attitude towards RFS and their possibility of using RFS in the future. Although 5 questions are listed in this section, only 3 of them are applicable to both groups. Consequently, the comparisons only relate to the 3 questions and 7 variables.
Respondents were asked to identify the main non-physical factors hindering the RFS implementation in office buildings. As per Table 4.2, out of the five pre-described choices, *the higher initial cost was of the first constraint perceived by both groups*. Meanwhile, approximately half of the experienced respondents also revealed that the unfamiliarity with RFS products and reluctance to accept new technology were the barriers. In comparison, the inexperienced group perceived the unfamiliarity with RFS products and procurement as barriers; however, they did not deem that the reluctance was a problem. Particularly, safety issues were not regarded as a constraint by most participants.

Respondents were further required to express their probability of using RFS as long as their recognized barriers would be properly solved in the future. The feedback shows that *the experienced group had a more clear inclination than the inexperienced group*, with a mean score of 4.63 against 3.56. The experienced group’s positive answer justifies the value of RFS; meanwhile, the inexperienced group’s low tendency of using RFS indicates that *there is not enough incentive to stimulate the RFS market in Australia*.

At the end of the questionnaire, respondents were asked to forecast the future of RFS application for office building fitout in Australia. Interestingly, *both groups had an affirmative perspective in this regard*. Among the inexperienced group, *the inconsistency of the feedbacks on their use of RFS and the future of RFS infers barriers retarding RFS application to a certain degree*.

**4.4.2 Selective Data Analysis among Different Categories of Respondents**

Different categories of respondents may have diverse viewpoints on the same issues pertaining to the RFS implementation and their various opinions are conducive to exposing RFS merits and potential problems. The data for the comparisons were calculated and summarized in Appendix 2. In order to explore the significantly different perspectives, only selective data is compared in depth among the different categories of respondents with the aid of SPSS.
**Familiarity and Interest**

To learn different respondents’ familiarity with and interest in RFS, a numerical scale rating is used from 1 to 7, representing the extent from the least to the most. A boxplot was used to present different feedbacks and describe the corresponding features visually in Figure 4.5. Since the top of the box represents the upper quartile (75\textsuperscript{th} percentile) of the variable distribution and the bottom of the box represents the lower quartile (25\textsuperscript{th} percentile), 50\% of the cases lie within this box range. The median value is represented by the bold line inside the box.

The industry has different levels of familiarity with RFS. In detail, *consultants perceived themselves to be the most familiar with RFS* (median score 7) among all respondents, which might be attributed to their professions as consulting engineers. *Clients and contractors, as the actual users and builders of the RFS facilities, had the second level of familiarity with RFS* and interestingly, their familiarity distributions are exactly the same with an interquartile range from 5 to 6 and a median score of 6. Meanwhile, *developers* had the widest range of interquartile, whereas their median score is only 3, indicating that they *were generally unfamiliar with RFS*. Comparatively, *commercial real estate agents were the most unfamiliar with RFS* as illustrated by the lowest location of the interquartile range.

![Boxplot](image.png)

**Figure 4.5 Different Respondents’ Familiarity with and Interest in RFS**
In terms of interest in new information of RFS, the industry showed a moderate interest; consultants, clients and contractors were generally more positive than developers and commercial real estate agents in this regard. Likewise, consultants ranked the highest with a median score of 6, followed by clients and contractors with a median score of 5. However, the long whiskers in their distributions reveal that a proportion of them were uninterested in new information of RFS, which might be due to their latent awareness or unwillingness to use RFS. Comparatively, developers selected a medium rate to depict their interest, which expressed their eagerness to know RFS but reluctance to bear the risks possibly brought by the RFS implementation. Commercial real estate agents were the most indifferent to RFS applications, with a median score of 4 and an interquartile range from 3.5 to 4.

In conclusion, consultants, clients and contractors perceived themselves to be familiar with RFS and interested in new information of RFS. They are eager to be continuously informed of new upgrades of RFS technologies such as underfloor air delivery. In comparison, developers and commercial real estate agents were not that acquainted with RFS, and the latter is even not interested in new RFS information either. Hence, developers need to be further educated with RFS knowledge and commercial real estate agents need to be recognized by the industry for their role of recommending RFS facilities to potential and quality business tenants.

**General Advantage Awareness**

RFS is recognized for its advantages to accommodate the organizational, technological and environmental requirements emerging in modern office buildings. Feedbacks as to the recognition percentages of diverse RFS advantages from different categories of respondents were summarized in Figure 4.6. The overall opinion is presented in this figure as well.

First of all, the figure shows that different categories of respondents had a unanimous agreement that RFS gave flexibility to the workplace environment, with all percentage scores over 86, which substantiate flexibility as the most distinguished advantage brought by the RFS fitout. In comparison, other perceived merits were lowly recognized by most respondents. Likewise, respondents had a similar consensus regarding the RFS fitout cost-saving. However, the agreement level is
quite low, with a response rate around 40%, indicating that the fitout cost might be an important factor hindering RFS implementation.

As to other perceived RFS merits, such as ergonomics, productivity and time-saving, a diversity of understandings were borne in the mind of different categories of respondents. A total of 55% of developers assumed RFS endowed ergonomics whereas only 13% of commercial real estate agents believed it. Clients, contractors and consultants held “middle to low” consent in this regard. Likewise, most categories of respondents had “middle to low” agreement with the time-saving, while commercial real estate agents had a high rating and consultants had a low rating in this regard. Comparatively, consultants had a relatively high agreement as to the RFS endowed productivity, with a percentage of 71. However, their idea was strongly refuted by a majority of respondents in other categories.

**Information Access, Team Skills and Project Delivery Methods**

Different categories of respondents have given different assessment on their access to adequate knowledge pertaining to the RFS implementation. Figure 4.7 reveals that most clients (83%), consultants (86%) and contractors (82%) viewed themselves having access to information or knowledge about RFS application. In contrast, developers appeared to lack access in this regard. Significantly, commercial real estate agents assumed that they did not have sources to RFS information at all.
A knowledgeable project team is indispensable to the success of a project. In order to investigate the important team skills for a RFS fitout project, different categories of respondents’ recognitions are compared in Figure 4.8. Commercial real estate agents did not answer this question since none of them had access to RFS information.

Figure 4.8 Recognition of Team Skills among Different Categories of Respondents

According to the 4 voluble lines, clients, architects, engineers and project managers were regarded as the most important team skills in a RFS project team, with all preference rates over 60%. In comparison, quantity surveyors, cost consultants and construction consultants were put in the second level, with most preference rates around 50%. However, consultants were the exception, with a high appreciation of quantity surveyors, cost consultants and construction consultants, as well. On the contrary, clients had a low recognition of quantity surveyors, which is unreasonable since clients are always cost conscious. Moreover, contractors had an extremely low appreciation of construction consultants, which might be due to their high
confidence of having access to adequate knowledge and information on the RFS planning and construction, as indicated in Figure 4.8. In particular, some contractors deemed that innovative leader, RFS manufacturers, and professional HVAC and fire consultants were necessary team skills for RFS projects as well.

Project delivery methods are critical to the success of a RFS project due to its novelty and contravention compared with traditional fitout methods. Figure 4.9 discloses the respondents’ preference of project delivery methods for RFS fitout procurements. The result shows that most categories of respondents had a low preference to the D&B method. Similarly, the CM/GC method was poorly appreciated as well. In contrast, the D/B/B and other type of lump sum methods were general recognized by most respondents. This fact indicates that most industry practitioners were unaware of the significant effects that both the D&B and CM/GC methods can have upon the procurement of innovative building technologies.

![Figure 4.9 Preferences of Project Delivery Methods among Different Categories of Respondents](chart)

**Figure 4.9 Preferences of Project Delivery Methods among Different Categories of Respondents**

**Constraints Hindering RFS Implementation**

The constraints pertaining to RFS implementation can be physical or non physical barriers, and appear before or during the RFS operation and maintenance. The feedbacks from different categories of respondents on physical constraints hindering RFS implementation is illustrated in Figure 4.10.
The floor to ceiling height is seen as a constraint by most respondents, with all response rates over 75%. Other constraints such as ceiling-based HVAC system, traditional PVD system and fire safety system were admitted in a variety of degrees. Specifically developers and contractors generally saw ceiling-based HVAC system as constraints, while consultants did not see this as important. Commercial real estate agents generally perceived the traditional PVD system as constraints while most other categories had a low recognition of it. Particularly, consultants did not perceive it as a constraint at all. With regard to fire safety system, most respondents except developers had a low awareness of it. Overall, the most recognized physical constraint is the floor to ceiling height, followed with ceiling-based HVAC system, fire safety system and traditional PVD system. Consultants did not regard them as constraints except floor to ceiling height; however, developers worried about most of them. In addition, some consultants, contractors and clients pinpointed other physical constraints, e.g. transition problems from raised floor panels to lifts, existing doors, stair landings and toilets, etc. and inappropriate height from panels to window sills and heads.

Five non-physical constraints were investigated, as shown in Figure 4.11. A high capital cost was generally proposed by most categories except commercial real estate agents. The commercial real estate agents’ low awareness might be due to their lack of RFS experience. So, it can be concluded that the high capital cost is a real constraint. Unfamiliarity with RFS products was highly perceived by commercial real estate agents and developers, and moderately recognized by clients.
and consultants. Contractors had a low agreement in this regard. Most categories of respondents except commercial real estate agents moderately recognized unfamiliarity with RFS procurement as a non-physical constraint. With respect to the safety issues such as an unsafe feeling when walking on the RFS, most respondents did not see it as being of real concern. A low recognition in this respect from clients further refuted the unnecessary concern. With respect to the reluctance to accept new technologies, consultants and developers generally knew it existed, while contactors had a lower agreement. This might be due to their different experiences in the RFS practice.

![Figure 4.11](Image)

Figure 4.11 Recognitions of Main Non-Physical Constraints among Different Categories of Respondents

Furthermore, clients and consultants posed other possible constraints, such as the additional hole needed during the operation, travel of sound, lack of RFS knowledge among project team members, and carpet maintenance. Developers highlighted one significant obstacle, i.e. who is going to pay the increased capital costs for RFS fitout?

At last, one open-ended question was designed to draw out other barriers hindering RFS implementation that the respondents had experienced. Consultants, clients, contractors and developers put forward a number of issues which were not presented in this questionnaire. These issues include physical or non-physical constraints and also relate to different aspects of RFS fitout, i.e. structural constraints, RFS service integration, industry practitioners’ knowledge, cost concerns, post-construction issues. All these issues together with the above identified problems are summarized in the next section and further investigated in the subsequent interview survey.
Familiarity with RFS Constructability Issues

A total of 8 issues relating to RFS constructability were raised with respondents to explore their understanding. These issues were basically constructability principles though not all these were involved. However, the familiarity observations of RFS constructability issues were only applicable to those respondents who had real RFS experience. Since commercial real estate agents had no RFS experience, they were not required to answer these questions.

Figure 4.12 presents the mean values of all constructability issues answered by different categories of respondents. The rating scale is from 1 to 7 representing the least to the most familiar with the listed issues. The mean values reveal that consultants and contractors were moderately acquainted with most of the constructability issues, whereas clients and developers were unfamiliar with most of these areas. Overall, respondents believed that they were slightly familiar with RFS construction and RFS reconfiguration and maintenance. Comparatively, they had moderate knowledge about RFS cost estimates and budget and project team skills but they lacked information as to the RFS specifications, available resources for RFS procurement as well as contracting strategies.

Future of RFS Application

Figure 4.13 outlines opinions on the future of RFS application in Australia among different categories of respondents. It is evident that all categories of respondents believed that RFS has a promising future for office building fitout in Australia. The
boxplot distributions and the median line locations indicated that consultants and clients had an high agreement with RFS promising future while developers, contractors and commercial real estate agents were not as enthusiastic about it.

![Boxplot distributions](image)

Figure 4.13 General Assessments on the Future of RFS Application among Different Categories of Respondents

*With respect to the probability of using RFS in the future, a discrepancy existed among the respondents.* As per the boxplot distributions, consultants were inclined to use RFS in the future while clients had an above average tendency in this regard. However, the long and lower outer lines for the minimum values (representing level 1) in the batch pertaining to consultants and clients’ feedback distributions indicates that some of them might be unwilling to use RFS. In comparison, developers, contractors and commercial real estate agents still had low interest in using RFS in the future even though the potential constraints and barriers could be solved properly.

Generally speaking, the overall high acknowledgement of a promising RFS future seems to be in contradiction with the moderate to low willingness to use RFS among clients, commercial real estate agents, developers and contractors. This inconsistency indicates that the aforementioned physical and non-physical constraints can potentially dominate people’s decision-making on using RFS in their facilities. Consequently, in order to promote the RFS implementation in the Australian construction industry, these issues need to be aggregated for further investigation.
4.5 Findings of Questionnaire Data Analysis

The questionnaire findings are achieved through using the data analysis results to explore the four purposes of the survey. Specifically, the questionnaire identified clients, developers, consultants, contractors and commercial real estate agents’ general recognition of RFS and its application for office building fitout in Australia. Then, two comparisons were carried out to scrutinize the common and different ideas from respondents. A further analysis of the results of the two comparisons can reach the questionnaire findings. As per the four questionnaire purposes, the general findings are organized through the method outlined in Figure 4.14. Once the industry practitioners’ general awareness of RFS and their knowledge in RFS fitout implementation are understood, the research can go to the next stage to explore ways to answer the two research questions and five research objectives.

![Diagram of Questionnaire General Findings](image)

**Figure 4.14 Process of Questionnaire General Findings**

**Purpose 1: General Recognition**

The general recognition of RFS among the industry practitioners can be outlined through a retrospection of the comparisons pertaining to *Awareness, Advantage and Adaptability* of RFS.
Familiarity

• All industry practitioners have heard of RFS; however, only those who have used, designed or constructed RFS fitout possess working knowledge on RFS components and its applications. As RFS practice is not widely implemented in Australia and only a limited number of industry practitioners have relevant experience, it indicates that the majority of Australian industry practitioners are not familiar with RFS and its applications.

• Among different categories of respondents, consultants were the most familiar with RFS and its components, clients and contractors were fairly familiar with them, developers were fairly unfamiliar with them, and commercial real estate agents were not familiar with them at all.

Interest

• Respondent with experience were slightly more interested in new RFS information than their counterparts.

• Consultants showed the highest interest in new RFS information, followed by clients and contractors with moderate interest and developers and commercial real estate agents without interest.

Advantages

• The experienced group’s opinions were perceived to be more convincing than the inexperienced group’s. However, no evident divergences were found between the two groups except for time-saving, indicating an approximate consensus of RFS merits among industry practitioners. Flexibility is highly acknowledged as the distinguishing advantage; ergonomics, cost-saving and productivity were not broadly appreciated. The inconsistent responses in terms of time-saving reveal the industry practitioners’ little knowledge of this factor.

• Among different categories of respondents, flexibility was generally acknowledged while fitout cost saving is hardly appreciated. As to ergonomics, productivity and time-saving, there is no consensus.

• Reconfiguration and maintenance were deemed as the demonstration of flexibility, and a self-controlled environment was regarded as the demonstration of ergonomics.
Adaptability

• RFS applications for the fitout of office buildings and computer/equipment rooms were highly recognized, while other applications were rarely perceived.
• Underfloor HVAC and PVD systems were well known, while the integration of other services into RFS was generally unappreciated.

Purpose 2: Potential Barriers Associated with RFS Implementation

The potential barriers associated with RFS implementation can be physical or non-physical. The physical barriers were explored in the Adaptability section, the non-physical constraints were investigated in the Adoption section. In addition, an open-ended question was designed in the Adoption section as well in an aim to expose other physical or non-physical problems associated with RFS application in the real projects, which however were not pre-described in the questionnaire.

Physical barriers

• The floor to ceiling height was generally recognized as an issue hindering RFS application in retrofit projects. Ceiling-based HVAC system, traditional PVD system and fire safety system were regarded as constraints only by respondents without experience, to some extent indicating that most of the perceived barriers might not be real issues. However, they do influence RFS decision-makings.
• Among different categories of respondents, the floor to ceiling height was generally deemed as a constraint. Developers and contractors held that ceiling-based HVAC system was a barrier, which however was not supported by almost all consultants and most clients and commercial real estate agents. Traditional PVD system and fire safety system were only regarded as constraints by commercial real estate agents and developers. Moreover, consultants, clients and contractors pinpointed some physical constraints in retrofit projects besides the provided choices, e.g. transition to common areas, etc.

Non-physical barriers

• Higher capital cost was perceived as the key barrier by both experienced and inexperienced respondents. Unfamiliarity with RFS products was highly regarded as well. Moreover, reluctance to accept new technology was recognized by
approximately half of experienced respondents; unfamiliarity with RFS procurement was mentioned by approximately half of inexperienced respondents.

- Among different categories of respondents, high capital costs were proposed by all respondents except commercial real estate agents. Unfamiliarity with RFS products and procurement were perceived by most developers and commercial real estate agents. Reluctance to accept new technologies was highly counted by consultants and developers. In addition, clients, consultants and contractors proposed some possible barriers, e.g. travel of sound, additional hole drilling, etc.

Besides the constraints identified above, 54 potential issues associated with RFS implementation were abstracted from the open-ended question (see Appendix 3). These issues were proposed by different respondents and hence some of them may overlap. With an eye to keep the original meaning of these problems, these issues were mapped and comprehended into 44 issues. For example, in Appendix 3 Issue (6) – “traditional cable and wire distribution method on each floor” and Issue (21) - “the initial design of wire distribution in each level restricts RFS adaptability” have the similar meaning with respect to the influence of traditional cable and wire distributions on RFS applications. They both indicate that the existing cable and wire distribution in the old buildings restrict the use of RFS fitout in the building retrofit. Therefore, they were grouped together and coded Issue B6. More details introducing the consolidation and combination of the 54 issues into the 44 issues are presented in Appendix 3.

**Purpose 3: Knowledge of RFS Fitout Implementation**

The knowledge of RFS fitout implementation includes team skills, project delivery methods, constructability, etc. With a study of Accessibility and Adoption sections, the industry practitioners’ general knowledge in this respect can be identified.

**Access to RFS information or knowledge**

- Respondents without experience lacked access to information or knowledge in RFS implementation, compared with the experienced group.
- A majority of consultants, clients and contractors thought that they had access, compared with commercial real estate agents who had no access at all.
Team skills
• Clients, architects, engineers and project managers were generally regarded as important team skills for RFS projects by respondents with or without experience.
• The above finding is applicable to different categories of respondents. However, a big divergence on the necessity of quantity surveyors, cost consultants and construction consultants, was identified. Consultants had a high appreciation of them, whereas clients and contractors held an opposite viewpoint. Construction consultants for knowledge inputs were unappreciated generally.

Project delivery method
• The D/B/B and lump sum methods (except D/B/B and D&B) were more preferable than the D&B and CM/GC methods among all respondents.
• Among different categories of respondents, there is not consensus on the project delivery method; however, the D&B and CM/GC methods were not generally acknowledged.
• With respect to manufacturers’ involvement in RFS projects, both experienced and inexperienced respondents had a relatively negative attitude towards their delivery of RFS fitout design and construction.

Constructability
• Consultants and contractors were more familiar with RFS constructability than developers and clients.
• Consultants were unfamiliar with RFS specifications and contracting strategies while contractors lacked knowledge in RFS specifications, team skills and RFS reconfiguration and maintenance. Developers and clients were unacquainted with most issues, particularly RFS specifications, contracting strategy, available resources for procurement issues and team skills. All these indicate that Australian industry practitioners generally did not have a holistic knowledge of RFS constructability.

Purpose 4: Status Quo and Future of RFS
The feedbacks of Awareness, Adaptability and Adoption, to a large extent, reveal the status quo and future of RFS implementation in Australia.
Status Quo of RFS

- Consultants, contractors and clients perceived themselves to be familiar with and interested in RFS, which gives the industry some hope for the future of RFS implementation in Australia.
- RFS fitout in office buildings and computer/equipment rooms was highly recognized, and underfloor HVAC and PVD systems were well known as well.
- Many barriers hindering RFS implementation existed.
- RFS was generally perceived to be capable of improving workplace environment by all experienced respondents except contractors, as shown in Appendix 2.

Future of RFS

- All respondents had a positive attitude towards the promising future of RFS application in Australia.
- From the viewpoints of different professionals, all respondents believed in a sound RFS future as well.

Use of RFS

- Respondents with experience showed a positive tendency to use RFS, while respondents without experience presented a relatively negative attitude.
- Among different categories of respondents, consultants and clients have shown an above average probability of using RFS in the future, with a mean value of at least 5 (with 1 representing the lowest and 7 representing the highest). Comparatively, developers, contractors and commercial real estate agents have an average probability in this regard, with a mean value of 4 respectively.
- The inconsistency between the general belief in RFS future and the low probability of using it indicates potential problems and justifies the necessity of further investigation of the potential barriers.

The above four findings indicate that the industry practitioners without RFS experience generally had low awareness of RFS and lacked knowledge in RFS implementation. Considering that RFS is not popular for use in office buildings at this stage as revealed in Chapter 2 and professionals with robust RFS fitout
knowledge and extensive experience only occupy a small proportion of the whole industry practitioners, it can be concluded that the Australian construction industry lacks awareness and knowledge in RFS implementation for office building fitout. This questionnaire finding closely aligns with the first research question. Hence, the importance and necessity of justifying the advantages of RFS fitout compared with the traditional fitout method and improving public awareness of RFS fitout are highlighted. In addition, the questionnaire revealed the existence of potential issues hindering RFS fitout implementation, which forms the basis for the exploration of the second research question.

Accordingly, the comprehensive research methodology described in Chapter 3 needed to be undertaken to justify the RFS fitout advantages, improve public awareness of RFS, explore the barriers associated with RFS fitout implementation and integrate their solutions into RFS fitout project delivery appropriately.

4.6 Summary

The questionnaire feedbacks were analysed with the aid of two comparisons. The first comparison was conducted between the experienced group and inexperienced group and looked through most aspects of the six sections, in an aim to recognize the different opinions pertaining to RFS implementation among industry practitioners with and without experience. The second comparison is a selective one and undertaken among different categories of respondents, i.e. clients, developers, consultants, contractors and commercial real estate agents, in an aim to identify their significantly different idea upon the RFS implementation in Australia.

Findings of the respondents’ feedback answered the four purposes of the questionnaire, which form the basis of the two research questions and highlight the following research direction. Particularly, a total of 44 potential issues were exposed for further investigation in the subsequent interview survey.
CHAPTER 5
INTERVIEW DATA ANALYSIS AND FINDINGS

5.1 Introduction

The questionnaire feedback in Chapter 4 uncovered 44 issues that may have potential influence on the RFS implementation in the Australian construction industry. Based on the nature and relationship with RFS fitout project delivery, these issues can be categorized under five aspects, i.e. structural constraints, RFS service integration, industry practitioners’ knowledge, cost concerns, and post-construction issues. The issues under the first four aspects are potential influence factors pertaining to the RFS design and decision-making, and so deserve deep consideration in the strategic planning of a project using RFS fitout. Those issues occurring in the RFS post-construction stage are potential problems likely to emerge in the process of the RFS service operation and maintenance. Identifying the real significant influence factors and real problems is all-important to facilitate the RFS implementation in the Australian construction industry. Another important task in the interview is to obtain the industry practitioners’ recognition of RFS fitout advantages in order to clarify the many uncertainties exposed by the earlier questionnaire survey.

This chapter reports on the findings of the second part of the survey, namely semi-structured interviews with a number of construction industry practitioners with robust RFS knowledge and experience. It first introduces the interview purposes and the diversity of respondents. Then, the main data collected from the interviewees’ feedback is presented and analysed. The interview final results are summarized at the end of this chapter.
5.2 Interview Purposes

The semi-structured interview survey was conducted on the top of the questionnaire survey in an aim to achieve the following three purposes:

- To further explore the industry practitioners’ recognition of RFS advantages;
- To justify the significant influence factors (SIFs) and real problems associated with RFS fitout implementation; and
- To explore conceptual solutions to accommodate the above real issues in the RFS fitout project delivery.

At length, the interview presented all the issues identified from the questionnaire to respondents and asked them to comment on these issues. Their feedbacks could be Agree, Disagree, It depends or No comments. Interviewees were also encouraged to propose possible solutions and considerations to those SIFs and real problems that they assumed. The data collected were analysed in the same sequence of the pre-described questions in the interview, as shown in Appendix 4.

5.3 Respondents’ Profiles

All interviewees were practitioners in the construction industry and were chosen based on the questionnaire feedbacks and their experiences and positions. A total of 20 interviews were conducted and 22 interviewees were involved as indicated in Figure 5.1.

![Figure 5.1 Respondent Distributions by Professionals](image-url)
The professions of the respondents are classified into five categories: Clients (18%), Developers (14%), Consultants (45%), Contractors (14%) and Manufacturers (9%). In particular, the clients include facility managers not only from occupants but also from building owners who own and occupy the buildings. The developers encompass the public and private developers. Consultants cover mechanical engineers, electrical engineers, architects and other building service engineers. Most of them are principal engineers and architects. Manufacturers involve one raised floor manufacturer and one underfloor air service manufacturer in Australia.

All the respondents have actually used or experienced RFS in their professions. Figure 5.2 shows the distribution of the respondents’ work experience in their professions. It is grouped into 5 different categories. Group 1 represents those having experience from 6 to 10 years, Group 2 from 11 to 15 years, Group 3 from 16 to 20 years, Group 4 from 20 to 25 years, and Group 5 represents those with over 26 years experience. The average respondent’s work experience in the construction industry is 20 years, indicating that the interview feedback was based on considerable RFS experience.

![Figure 5.2 Respondent Distributions by Experience](image)

Meanwhile, since most questionnaire feedbacks were from Sydney and Brisbane, the interviews were organized in the two cities. In particular, 5 of them were conducted in Brisbane and 15 of them in Sydney. On the other hand, there were 20 rather than 22 interviews in total because two of the 20 interviews were conducted with two respondents at the same time. The interview surveys were conducted between June
and August 2004. Prior to talking with the interviewees, the interview questions were sent to them by email for their early perusal and preparation.

### 5.4 Interview Data Analysis

RFS faced many barriers on the way to being accepted by the industry, as indicated by the 44 issues identified from the questionnaire survey. These issues might be SIFs or non-SIFs and real or false problems, which are grouped under 5 sections, as mentioned previously. The list of these issues is presented in Table 5.1 with their codes included, which will be referred to in the following interview data analysis and presentation. Prior to the analyses of the feedbacks on these potential issues, the interviewees’ perspectives on the RFS fitout advantages are studied to ascertain the reality based on their hands-on experience.

#### 5.4.1 General Impressions on RFS Endowed Advantages

The general impression on the perceived RFS fitout advantages are summarized in Figure 5.3. The results show that 90% of interviewees agreed with RFS’s contribution to flexibility in the office building project. They put forward that the flexibility was best demonstrated in workplace relocation, service maintenance and technology upgrades. This result is consistent with the questionnaire feedback, in which 96% of respondents acknowledged RFS enabled flexibility.

![Figure 5.3 Response regarding RFS Endowed Advantages](image-url)
Table 5.1 Potential Issues Influencing RFS implementation in Australia

<table>
<thead>
<tr>
<th>Groups</th>
<th>Issues</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural constraints</td>
<td>(1) The initial building structural regularity restricts building retrofit with RFS;</td>
<td>A1</td>
</tr>
<tr>
<td></td>
<td>(2) The space volume (distance between slab and slab) is a problem;</td>
<td>A2</td>
</tr>
<tr>
<td></td>
<td>(3) Transitions to lift system, existing doors, stair landings, etc. are problems;</td>
<td>A3</td>
</tr>
<tr>
<td></td>
<td>(4) Inappropriate height to existing windows, cabinets, etc. is a problem;</td>
<td>A4</td>
</tr>
<tr>
<td></td>
<td>(5) The existing overhead HVAC system configuration influences RFS application;</td>
<td>A5</td>
</tr>
<tr>
<td></td>
<td>(6) The existing cable and wire distribution method influences RFS application;</td>
<td>A6</td>
</tr>
<tr>
<td></td>
<td>(7) The existing structural beams influence RFS application.</td>
<td>A7</td>
</tr>
<tr>
<td>RFS service integration</td>
<td>(8) It is hard to deal with hot air delivery for UAD;</td>
<td>B1</td>
</tr>
<tr>
<td></td>
<td>(9) It is hard to deal with air dehumidification for UAD;</td>
<td>B2</td>
</tr>
<tr>
<td></td>
<td>(10) Water distribution is hard to be incorporated in underfloor plenum;</td>
<td>B3</td>
</tr>
<tr>
<td></td>
<td>(11) The fire safety system is hard to be accommodated in the RFS fitout;</td>
<td>B4</td>
</tr>
<tr>
<td></td>
<td>(12) Existing cables and wires are not compatible with new PVD systems;</td>
<td>B5</td>
</tr>
<tr>
<td></td>
<td>(13) It is hard to locate ambient lighting if using RFS fitout without ceiling;</td>
<td>B6</td>
</tr>
<tr>
<td></td>
<td>(14) The mutual harassment exists among power, data and other signal distributions.</td>
<td>B7</td>
</tr>
<tr>
<td>Industry practitioners’ knowledge</td>
<td>(15) The integration of RFS with building structure and services has not been fully considered by most architects and consulting engineers;</td>
<td>C1</td>
</tr>
<tr>
<td></td>
<td>(16) Poor design is one of the main factors resulting in low construction productivity;</td>
<td>C2</td>
</tr>
<tr>
<td></td>
<td>(17) No evidence and cases show the links between UAD and productivity;</td>
<td>C3</td>
</tr>
<tr>
<td></td>
<td>(18) Most clients do not understand UAD although they know raised floors;</td>
<td>C4</td>
</tr>
<tr>
<td></td>
<td>(19) Contractors have a low familiarity with RFS products and installation;</td>
<td>C5</td>
</tr>
<tr>
<td></td>
<td>(20) Most QSs do not care life cycle cost and are not interested in new systems.</td>
<td>C6</td>
</tr>
<tr>
<td>Cost concerns</td>
<td>(21) The most significant obstacle is the capital cost of RFS;</td>
<td>D1</td>
</tr>
<tr>
<td></td>
<td>(22) Owners only stress capital cost rather than LCC;</td>
<td>D2</td>
</tr>
<tr>
<td></td>
<td>(23) Poor design is one of the main reasons resulting in cost overrun;</td>
<td>D3</td>
</tr>
<tr>
<td></td>
<td>(24) Maintenance costs are not actually as low as expected;</td>
<td>D4</td>
</tr>
<tr>
<td></td>
<td>(25) RFS costs significantly more compared with traditional fitout method and for most clients, it is not paid back nearly soon enough;</td>
<td>D5</td>
</tr>
<tr>
<td></td>
<td>(26) Building is owned by the developers while fitout is occupants’ responsibility.</td>
<td>D6</td>
</tr>
<tr>
<td>Post-construction issues</td>
<td>(27) Excessive cable and wire distribution prevents even spread of underfloor cool air;</td>
<td>E1</td>
</tr>
<tr>
<td></td>
<td>(28) UAD does not allow easy solutions to deal with hot spots in computer rooms;</td>
<td>E2</td>
</tr>
<tr>
<td></td>
<td>(29) Cool air in the UAD is often leaking from the interstice between panels;</td>
<td>E3</td>
</tr>
<tr>
<td></td>
<td>(30) Draught arises due to UAD method;</td>
<td>E4</td>
</tr>
<tr>
<td></td>
<td>(31) The floor surface composed of panels is uneven;</td>
<td>E5</td>
</tr>
<tr>
<td></td>
<td>(32) The connectivity between panels and walls is poor;</td>
<td>E6</td>
</tr>
<tr>
<td></td>
<td>(33) The connectivity between different floor levels is not aesthetic;</td>
<td>E7</td>
</tr>
<tr>
<td></td>
<td>(34) Panels do not present well and limit the underfloor ongoing accessibility;</td>
<td>E8</td>
</tr>
<tr>
<td></td>
<td>(35) It is not actually flexible to relocate cables, wires and outlets;</td>
<td>E9</td>
</tr>
<tr>
<td></td>
<td>(36) Additional hole drilling results in costs and mess;</td>
<td>E10</td>
</tr>
<tr>
<td></td>
<td>(37) Much travel of sound appears;</td>
<td>E11</td>
</tr>
<tr>
<td></td>
<td>(38) Holes in panels induce stress concentrations leading to further cracks;</td>
<td>E12</td>
</tr>
<tr>
<td></td>
<td>(39) Panels tend to be moving due to poor installation;</td>
<td>E13</td>
</tr>
<tr>
<td></td>
<td>(40) Panels are hard to relocate for its distortion;</td>
<td>E14</td>
</tr>
<tr>
<td></td>
<td>(41) Dust is often built up during construction and operation;</td>
<td>E15</td>
</tr>
<tr>
<td></td>
<td>(42) Water always leak into floor outlets and underfloor plenum;</td>
<td>E16</td>
</tr>
<tr>
<td></td>
<td>(43) Lifting of facial components on panel creates trip hazards;</td>
<td>E17</td>
</tr>
<tr>
<td></td>
<td>(44) Panels with cable passes expose holes to pedestrian traffic when fitout changes.</td>
<td>E18</td>
</tr>
</tbody>
</table>
In addition, more than 55% of interviewees argued that RFS fitout could improve office ergonomics, workplace productivity and time-saving compared with the traditional fitout method. They specified that ergonomics was demonstrated on the improved workplace environment and individual control ability, workplace productivity was indicated by less sickness and less maintenance interruption, and time-saving was reflected on flexible construction and maintenance. On the other hand, approximately 15% of interviewees had no comments because of lack of knowledge and experience in this respect. These results are inconsistent with the questionnaire feedback in which respondents had a relatively low agreement of the three RFS merits. The reasons might come from three aspects. Firstly, the researcher could interpret the meaning of these terminologies to the interviewees with face-to-face interviews. Secondly, the researcher could enlighten and stimulate the interviewees to comment on all the perceived RFS merits at length and at their best. Thirdly, the questionnaire results might not reflect the respondents’ true understanding of RFS merits for some reason.

With respect to the fitout cost saving, 55% of interviewee thought that the RFS fitout cost was higher than that of the traditional method. Comparatively, only 20% of interviewees believed that RFS fitout had a lower capital cost investment, which is consistent with the questionnaire result. Meanwhile, 25% of interviewees had “No Comments” or chose “It Depends” in this regard.

In conclusion, almost all interviewees agreed with the RFS enabled flexibility, and more than half of them agreed with RFS enabled ergonomics, workplace productivity and time-saving. In addition, most of them thought that RFS fitout would result in higher capital cost than traditional fitout method.

5.4.2 Structural Constraints

Building structure is defined as the assemblage of those parts which exist for the purpose of maintaining shape and stability (Shaeffer, 1980). As per the definition, building structure reflects the building physical conditions and hence it largely determines the feasibility of using RFS for the fitout of office buildings. Structural constraints were recognized in the questionnaire as one of the main factors affecting
RFS application, particularly for retrofit projects. A total of 7 issues were identified and the interviewees’ general opinions on these issues are summarized in Table 5.2.

Table 5.2 Feedback on Structural Constraints

<table>
<thead>
<tr>
<th>Code</th>
<th>Agree</th>
<th>Disagree</th>
<th>It depends</th>
<th>No comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Percentage</td>
<td>No.</td>
<td>Percentage</td>
</tr>
<tr>
<td>A1</td>
<td>15</td>
<td>75</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>3</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A3</td>
<td>10</td>
<td>50</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>A4</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>A5</td>
<td>2</td>
<td>10</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>A6</td>
<td>3</td>
<td>15</td>
<td>16</td>
<td>80</td>
</tr>
<tr>
<td>A7</td>
<td>9</td>
<td>45</td>
<td>6</td>
<td>30</td>
</tr>
</tbody>
</table>

First of all, the restriction of the initial building structural irregularity on the building retrofit with RFS was explored. A majority of respondents agreed that the initial structure is a critical factor influencing the RFS application in office buildings. A typical example stated that:

“The shape of the building makes it very difficult to use RFS sometimes. Due to the curves of the shape, the layout is not straight, so you got to spent much time and money in installing the raised floors very precisely.”

The fact that nobody chose “Disagree” further confirms the significance of structural regularity for a retrofit project. Meanwhile, one interviewee argued that it won’t be a problem if the initial building structure design has considered RFS features in advance. However, he admitted that most developers are reluctant to do so because:

“Once the building shape is designed with perfect regularity for easy accommodation of RFS, you never get chance to revise it, because it is building shape and the structure design is normally a one-off project.”

With the understanding of the existing building structure restrictions, most respondents thought that an integrated design incorporating RFS features and the building structure conditions is the only way to put RFS in successfully.

For Issue A2, a majority of feedbacks reveal that whether the space volume is enough depends on many factors, e.g. the designed finished floor height (FFH) of RFS, use of underfloor HVAC system, keeping the ceiling air system, etc. A typical section drawing of an office is shown in Figure 5.4.
The ceiling space needs to house the structural beam, air ducts, cable and wire distribution, fire safety services, etc. An equation reflecting the causality between the allowable FFH of RFS and space volume can be written in Equation (5-1):

\[ FFH = H - X_1 - X_2 - X_3 - X_4 - Y_1 - Y_2 - L \] (5-1)

Where, FFH: the finished floor height of RFS;
H: the distance between slab and slab;
X₁: the thickness of the slab;
X₂: the sectional height of the structural beam;
X₃: the sectional height of air ducts;
X₄: the thickness of the ceiling panels;
Y₁: the interstice height between the structural beam and the air ducts;
Y₂: the interstice height between the air ducts and the ceiling panel; and
L: the distance between ceiling panel and raised floor panel top surface.

As per the above equation, the allowable FFH of RFS is mainly determined by the distance between slab and slab, which means if designers plan to design an appropriate FFH to accommodate underfloor services, the building should hence have a correspondingly appropriate slab to slab distance.
The use of UAD determines the appropriate FFH, which further decides whether the space volume is enough. If the UAD method is used, a deep floor plenum is expected. As per the interviewees’ opinions, 300mm is generally perceived as the minimum FFH to cope with the UAD. Therefore, to give enough space for UAD, a FFH must be not less than 300mm, as shown in Equation (5-2).

\[ FFH \geq 300mm \]  

(5-2)

Accordingly, the distance between slab and slab needs to meet Equation (5-3).

\[ H \geq (X_1 + X_2 + X_3 + X_4 + Y_1 + Y_2 + L) + 300mm \]  

(5-3)

For a typical multi-level or high rise office building, the thickness of the slab is around 120mm; the height of the structural beams is around 500mm; the height of air ducts is around 300mm; the thickness of the ceiling panel is around 30mm; the interstice height between the structural beam and the air ducts is around 100mm; the interstice height between the air ducts and the ceiling panel is around 150mm; and the distance between ceiling and raised floor surface is not less than 2400mm as per the Building Code of Australia (BCA). Then, if the clients want to keep the ceiling air system while applying UAD for the special reasons such as using a ceiling and underfloor mixed system and keeping the ceiling air system as a backup, the distance between slab and slab must be not less than 3900mm.

If the air conditioning is removed and the ceiling is kept solely for concealing the overhead service systems, the ceiling space can be reduced. The space height between the ceiling panel and the structural beam is allowed 200mm and the distance between slab and slab must be not less than 3550mm. If the clients want to remove the whole ceiling and expose the upper slab, the distance between slab and slab must be not less than 3320mm. Of course, if there is a flat structural beam or no structural beam in the building, the distance between slab and slab can be even shorter.

On the other hand, if UAD is not used, a RFS with 150mm FFH is enough to accommodate the underfloor cable and wire distribution according to the interview
feedback. Hence, the ceiling air system should be kept there without major changes. FFH is not less than 150mm, as shown in Equation (5-4).

\[ FFH \geq 150\text{mm} \quad (5-4) \]

Then, the distance between slab and slab needs to meet Equation (5-5).

\[ H \geq (X_1 + X_2 + X_3 + X_4 + Y_1 + Y_2 + L) + 150\text{mm} \quad (5-5) \]

Accordingly, the slab and slab distance must be not less than 3750mm. This value and the ceiling space in retrofit projects are both constant. Whether a RFS with 150mm FFH can be put into the building depends on the initial floor to ceiling height.

\[ L_{ini} = L + FFH \quad (5-6) \]

Where, \( L_{ini} \): the initial floor to ceiling height in a building to be retrofitted.

Therefore, the initial floor to ceiling height must be not less than 2550mm. Otherwise, the RFS cannot be accommodated. Since the floor to ceiling height in most of the current buildings is over 2550mm, the input of RFS without UAD is feasible.

Table 5.3 Minimum Slab to Slab Distance for RFS Applications

<table>
<thead>
<tr>
<th>Minimum slab to slab distance (mm)</th>
<th>With UAD</th>
<th>Without UAD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With ceiling renovation</td>
<td>Without ceiling renovation</td>
</tr>
<tr>
<td>Reduced ceiling</td>
<td>3550</td>
<td>3900</td>
</tr>
<tr>
<td>Removal of ceiling</td>
<td>3320</td>
<td></td>
</tr>
</tbody>
</table>

In summary, based on a perceived structural beam of 500mm in height, the minimum slab to slab distance for RFS application in retrofit projects is summarized in Table 5.3. For RFS uses in new buildings, the minimum slab to slab distance can refer to these values; however, the actual value may be smaller if a flat beam is used in the structure. For example, if a flat beam of 200mm is considered, UAD used and ceiling removed, the minimum slab to slab distance for RFS application is 3020mm.
In particularly, many interviewees are concerned with the potential increase of slab-to-slab distance. According to the above analysis, the use of underfloor air distribution can lead to a reduced ceiling plenum or totally removal of the ceiling, and reduce the overall height of service plenums, which finally decrease the slab-to-slab distance potentially. For both new-built and retrofit buildings, a smaller ceiling plenum (100-150mm) for return air combined with a lower height underfloor plenum (200-400mm) for unducted air flow and other building services can replace a single large overhead plenum (600-1000mm typically in the current Australian practice) to accommodate large supply ducts and other ceiling services. Under this circumstance, this offers a net saving in the order of 300-450mm in slab to slab distance for new construction. This means that the use of RFS including underfloor HVAC system can contribute to one additional floor per construction of ten floors under the traditional fitout method, as shown in Figure 5.5. The construction height in many cases can be reduced by 10-15% with major savings in construction materials, curtain walling, structural frame, lift shafts, service risers and stairwells.

As to Issue A3, 10 people regarded it as an issue influencing RFS application, representing a response rate of 50%. They argued that the transition issues are the key limitation for RFS use in retrofit projects, although they admitted that ramps and steps can be used to mitigate the difficulty, as one put forward that:

“I cannot give you any good ways to solve these transition issues. Although ramps and steps can be used in the lift lobby to make the floor level adapt to the lift system, it is not aesthetic and wastes floor areas.”
At the same time, 25% of interviewees thought that most of the issues relating to transitions are not unsolvable problems but big challenges to architects and consultants. For example, RFS can be used in the lift lobby if the operating program of the lift systems can be adjusted to match the RFS level. However, they acknowledged that most architects and consultants are more likely to make no changes to the lift lobby and design RFS only for the general office spaces, using ramps and steps to connect the two zones. As for existing doors, most respondents argued that replacing the old doors with new ones is more reasonable than cutting the old doors to adapt to the new RFS level, because the latter is more time and cost consuming. The arrangements of toilets and stair landings present the same dilemma as that of lift lobby. As such, RFS is not recommended for the building core area. Nevertheless, RFS can be used in the core area in new buildings provided that the building structure design has already taken account of the RFS features in advance.

Although the questionnaire survey highlighted Issue A4, most interviewees did not think that the inappropriate height to existing windows, cabinets and ablution blocks is a problem. A general perceived problem relating to windows is that a lower window sill may result in safety problems. However, most respondents argued that:

“In modern multi level or high rise buildings, windows are normally locked as the HVAC system is very popular and windows are designed for day lighting rather than for ventilation. So, there is not such a risk of falling down through windows.”

As far as cabinets and ablution blocks are concerned, if they are located in the core and RFS is not recommended there, this is not an issue. If cabinets and ablutions are located in resource rooms in the office areas rather than in the building core, they need to be raised up to an appropriate height to adapt to RFS. Again, it becomes the architects’ job. So, Issue A4 will not influence RFS fitout significantly.

With respect to the impact of the existing ceiling-based air conditioning system on RFS applications, 9 out of 20 interviewees believed that the influences depend on many factors, such as the building space volume, the ceiling configuration, the disposal of the ceiling air system and the designed FFH. As Issue A2 stated, the space volume is normally limited in a retrofit project. If clients want to keep the ceiling air system while using RFS, the building may not allow substantial space to
accommodate the UAD. However, if the space volume is big enough or the clients are willing to remove the ceiling air system, the discussed issue is not a barrier at all. Unfortunately, many clients intend to keep the ceiling system while using RFS in case of any failure of UAD and also for future changes. Meanwhile, 6 interviewees presumed that the ceiling air system won’t affect RFS application; rather, it is just a design issue. They admitted that architects and consultants can seek appropriate solutions to coordinate the two air systems.

Similarly, a concern about the impact of the traditional cable and wire distribution upon RFS application was discussed. The interview feedback shows that 16 interviewees out of 20 did not agree with it, representing a response rate of 80%. Even though there are 15% of interviewees regarding it as an issue, they could not comment exactly what the influences are except that the limited space in the building core and limited underfloor plenum cannot contain the bulky cables and wires in a high-rise building. However, it might also be an important issue for the traditional ceiling cable and wire distribution systems if it is deemed as a problem for RFS, so the underfloor void can possibly allow more space for wiring. Therefore, the traditional cable distribution does not impede RFS application in retrofit projects.

As outlined in Issue A2, the existing structural beams normally occupy half of the section space of the ceiling plenum. Nine respondents out of 20 agreed that the existing beams influence the RFS application on condition that a major ceiling reconfiguration takes place. A typical contradiction is that an insufficient occupied space requires the shrinkage of the ceiling plenum to allow space for RFS; however, large structural beams may block the rise of the ceiling panels. Likewise, if an interior design tries to remove the ceiling air system and keep a small ceiling for the return air and the ambient lighting, large beams may impede the saving of ceiling space as well. However, some respondents argued that existing structural beams do not necessarily hinder RFS application. One of them specifies that:-

“Neither the return air nor the ambient lighting necessarily needs a ceiling. There are many ways to cope with them. The return air path can be in the wall or besides window frames, and the ambient lighting can be attached to the wall or around desks. Many successful cases with exposed upper slab are available in the globe. The ceiling services can be exposed as well if they are well decorated.”
Although the above statement strengthens the flexibility of the ceiling configuration, it also indicates that a good plan for the decoration of structural beams and ceiling configuration in the interior design is absolutely necessary. From this viewpoint, a holistic design incorporating ceiling and RFS features is decisive to the RFS application in retrofit projects. The same rationale also applies to the initial structure design for a new building using RFS fitout.

Based on the above analysis, the initial building structural irregularity is widely recognized as a potential restriction for RFS application. The space and the beam configuration can influence the decision on RFS application. RFS is not recommended for the building core area; otherwise, architects should pay attention to the transition issues among RFS, general offices and building core areas. The inappropriate height to windows, cabinets and ablution blocks, is generally assumed to have little influence and can be easily accommodated by a good interior retrofit design. As to existing ceiling air system and cable and wire distribution system, the former can exert an influence on the RFS application whereas the latter cannot and can be addressed by an appropriate interior plan and design. As a result, Issue A1-A3, A5 and A7 are justified as SIFs whereas Issue A4 and A6 are non-SIFs.

It should be noted that the judgement of SIFs from non-SIFs based on the statistic results of the interviewees’ selection on the three choices, i.e. “Agree”, “Disagree” and “It Depends”. A response rate of 50% is used to judge SIFs. The specific criteria are presented as follows.

• Factors with no less than 50% of agreement are regarded as SIFs;
• Factors with a combined percentage of not less than 50% of selection on “Agree” and “It depends” will be regarded as SIFs as well.

The first criterion is straightforward. A typical example is the judgement of Issue A1 and Issue A3 as SIFs. As shown in Table 5.2, more than 50% of respondents agreed with these two issues, and hence they are regarded as SIFs.

The second criterion is reasonable as the choices on “It depends” should be attended to as well. As issues of “It depends” may lead to problems under certain conditions, which also result in problems in RFS fitout implementation. Hence, they should be
counted. An example of such a case is the judgement of Issue A2 as a SIF. Besides 15% of interviewees agreed with it, a total of 80% of interviewees argued that Issue A2 may lead to problems under some pre-requisites. They include the use of UAD, determination of finished floor height, the renovation of ceiling plenum, building structure design, new-built or retrofit projects, etc.

The same rationale applies to the judgement of SIFs in RFS service integration, industry practitioners’ knowledge and cost concerns in the following sections.

5.4.3 RFS Service Integration

Advantages of RFS fitout are demonstrated through its cutting-edge underfloor services which mainly include underfloor HVAC system, PVD system and fire safety system. As mentioned in Chapter 2, underfloor HVAC system can give occupants a more responsive control of their personal workplace climate; underfloor PVD system can support flexible relocations with “plug and play” characters; underfloor fire safety system is installed to prevent fire emergencies occurring in the airtight plenum. A total of 7 issues associated with the RFS service integration were identified and the interviewees’ general opinions on these issues are summarized in Table 5.4.

Table 5.4 Feedback on RFS Service Integration

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Regarding the two key techniques of delivering quality air to office buildings, the hot air delivery and air dehumidification were both perceived as difficult tasks in the UAD as per the questionnaire survey; however, most interviewees did not think the two issues were hard nuts to crack, with response rates of 60% and 50% pertaining to Issue B1 and B2 respectively.
In general offices, most consultants argued that there is not much difference in the delivery of hot air either in the ceiling or in the floor plenum. They further presented several applicable hot air delivery methods. For example, hot air can be generated by primary units in the plant room, then mixed with recirculated room air and finally delivered to each workstation through the underfloor plenum; hot air can also be generated on sites using fan coil units attached to the panel soffit in the floor plenum. The primary unit method is very economical while the fan coil units method can give occupants more control of individual climate. Accordingly, the method applied in all possibility depends on the architects and consultants’ design and cost concerns.

Likewise, half of the interviewees argued that the UAD makes it easy to perform the air dehumidification. Although most of them thought that there is not much difference in the air dehumidification mechanism between the two air systems, one issue is believed to be worthy of attention all the same. That is:-

“The supply air temperature in the UAD is around 18°C that is much higher than the 10-12°C supply air in most ceiling air system. The hotter supply air in the UAD needs to be dehumidified before it goes to the floor plenum.”

“As per the psychrometric chart, one way of the dehumidification is to cool the air down to a low temperature and then re-heat the air, which is viable but energy-inefficient. The ameliorated method is to cool primary fresh air to 12°C and mix it with the recirculated air, and then the supply air to the workplace is dry enough to allow a proper environment.”

Water distribution is put into the floor plenum for three possible uses, i.e. the hot or chilled water piping to fan coil units in a UAD (e.g. for heating or cooling in perimeter zones), the water piping for fire protection if sprinklers are used, and the water piping for logistic water usage outside building cores. As per the interview feedback, there is a broad agreement that transferring the water piping from the ceiling to the floor plenum does not necessarily cause any major problems except that if too much piping were laid it might block the air path and influence the even air distribution in a limited FFH. Therefore, the water distribution will not influence RFS application. Nevertheless, a holistic coordination of the services underneath cannot be overemphasized to find a proper underfloor water distribution and FFH.
Over half of the interviewees agreed with Issues B4, with a response rate of 55%. They stated that the Early Fire Hazard Indices of the floor system should comply with Clause C1.10 of BCA when tested in accordance with AS 1530.3. Particularly, the manufacturer further specified that the panels, without floor coverings, shall provide zero fire hazard indices under Australian Standard AS 1530 for Ignitability, Spread of Flame, Heat Evolved, and Smoke Developed. As to the principle of underfloor fire protection, one manufacturer quoted Rospond’s (2003) study and argued that the research in this area is just initiated in the world such as the research in the Centre of the Built Environment at the University of California at Berkeley, USA. He also said that there is not a standard in this regard in Australia and the practices normally abide by the following rules:-

“In a floor cavity with height less than 200mm, the fire protection service is not necessary because fire cannot be developed in such small space lacking oxygen; however, it is wise to use a VESDA system (an early smoke detector). If the cavity height is less than 400mm but over 200mm, it is necessary to partition the whole floor space using dividers, which can effectively prevent the spread of a potential fire. Each enclosed floor space is around 400sqm and the VESDA system is required in all the voids. If the cavity height is more than 400mm, fire sprinklers are mandatory.”

“Some details in this regard were established in Germany. According to the Sample Guideline for Fireproofing-Related Requirements on Cavity-type Flooring and Raised Flooring published in 1998, the design of the fire safety of RFS should consider protection of adjacent emergency rescue routes, protection of other neighbouring units used, maintaining the stability of partition walls put on the floor, fire-resistance period of the design, combustibility and building-materials rating, protection against a fire in the floor cavity, and protection against a fire in the room.”

The manufacturer gave an example to explain the mechanism, as shown in Figure 5.6. The plasterboard partition wall between the general office space and the corridor should have high level fire resistance, and the wall should extend to the subfloor in order to reduce fire and smoke transmission between different zones.

Many consultants and contractors acknowledged that the fire safety system needs additional work on the service design and integration, puts an extra burden on the capital cost, and extends the project time. So, most clients try to keep the FFH as low
as possible in case of using fire sprinklers. As such, the fire safety system can influence RFS application.

![Diagram of protection against fire transmission between office and corridor]

Figure 5.6 Protection against Fire Transmission between Office and Corridor

With regard to the recycling of cables and wires in retrofit projects, a popular concern is that the old cables and wires are not compatible with the new PVD system. The interview feedback shows that most people cannot comment on this issue due to a lack of knowledge. Meanwhile, 35% of interviewees agreed that the incompatibility will influence RFS application. And some interviewees stated that the compatibility depends on the extent of the retrofit, as one consultant argued that:

“For a minor retrofit which does not include major technology upgrade, the old cables and wires can be recycled. However, for a major retrofit project, the old cables and wires cannot meet the new requirements in all possibility. Therefore, removing the old cables and wires and replacing them with new compatible ones are necessary.”

However, they admitted that the recycling of old cables and wires can minimize the capital cost of the retrofit, which is the reason why most clients tend to reuse them if possible. If clients plan to recycle old cables and wires, the compatibility of these old cables and wires should be deliberated in the design of the PVD system.

The questionnaire feedback revealed that it is hard to locate ambient lighting if the ceiling is removed. It infers that there is no place to fix the lighting equipment and the power cables have to be exposed to public and are unsightly. Nevertheless, these worries did not concern most interviewees, with a response rate of 55%, arguing that even without a ceiling, the ambient lighting equipment can be attached to the upper slab and cables and trays concealed with proper decoration. Many good examples of
exposed ceilings are available around the world. Some consultants and contractors put forth that the non-task lighting does not have to be located in the ceiling.

“The upper lighting equipment can be locked on or put besides a desk with power supplied from the floor plenum. Also, it can be attached to the upper wall with power supplied in the wall. Particularly, reverberatory lighting, an innovative approach, is getting more popular for interior decoration today. Therefore, the ambient lighting will not influence RFS application.”

In particular, a few interviewees presented that the acceptance or rejection of the suspended ceiling is based on the designers’ holistic consideration of building systems and environments. For new-built projects, ceiling can be reduced or totally removed. A reduced ceiling space can be used to run the fire protection system and cables and wires for the ceiling lighting. If the ceiling is totally removed, the exposed slab soffit can be decorated to improve the inner office aesthetics. For retrofit projects, the ceiling can be kept without any changes provided that the floor-to-ceiling space is big enough to accommodate the RFS. Otherwise, the ceiling needs to be reduced or removed to allow enough space for the RFS and the minimum floor-to-ceiling space (not less than 2400mm) according to the BCA. On the other hand, some interviewees pointed out that the configuration of ceiling depends on many individual preferences on environment, social and company culture, and project budget, which however are not considered in this research.

Underfloor PVD system organizes the cable and wire distribution by putting different cables in adjacent conduits in the same tray and integrating different cable outlets in the same floor-based distribution box. As a result, a mutual harassment among power, data and other signal cables was perceived. However, the interview feedback shows that 50% of interviewees did not regard it as an issue. They said that they have not met any harassment in the practical use of the PVD boxes and the potential signal harassment should have been considered and solved during the product design and manufacturing. No interviewee agreed with Issue B7, which further justifies that the perceived harassment among power, data and other signal cables is not a real issue.

As a summary of the previous analysis on the 7 issues pertaining to the RFS service integration, a conclusion is reached that the delivery of hot air for the UAD, the air
dehumidification for the UAD, the water distribution in the floor plenum, the supply of ambient lighting without ceiling, and the perceived mutual harassment among the power, data and other signal distribution, etc. are not SIFs. They can be easily accommodated with proper design. On the other hand, the fire safety system for RFS fitout and the compatibility of wires and cables are SIFs. These issues may result in additional cost and extend the project time and therefore need to be carefully addressed in the initial planning and design of the underfloor services.

5.4.4 Industry Practitioners’ Knowledge

Industry practitioners’ knowledge is always the first momentum driving the construction industry ahead. Particularly, their learning, acceptance and promotion are essential for the implementation of innovative building technologies. As per the questionnaire survey, 6 issues with respect to the industry practitioners’ knowledge of RFS were identified and the interviewee’s general opinions on these issues are summarized in Table 5.5.

Table 5.5 Feedback on Industry Practitioners’ Knowledge

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The architects and engineers’ consideration for the integration of RFS with the building structures and services is highlighted. A total of 13 respondents agreed that most architects and engineers do not have knowledge of combining RFS features with the building structures in new-built or retrofit projects and do not understand the integration of underfloor services and RFS. Three clients revealed that:-

“Architects and engineers do not fully understand what is involved in the installation of RFS. Most of them simply recommend putting RFS in but do not have a clear idea as to the amount of cables and wires underneath against the given FFH. They always wake up to mistakes in their design only after the suppliers send the RFS products to the construction sites.”
Two contractors said that the location of pedestals always conflicts with the path of cable trays and water piping. They agreed that the achievement of RFS functions, to a large extent, depends on the quality of the architects’ design work. Most interviewees strongly advised to educate architects and consulting engineers to enhance their knowledge of RFS and underfloor services. Alternatively, to make a flexible design rather than force clients and buildings to accept RFS passively, a knowledgeable consulting team needs to be established.

Issue C2 explored the causality between poor RFS fitout design and low construction productivity. More than half of the respondents agreed with this statement and complained that they had many awful experiences in this regard although this problem is not just applicable to the RFS fitout projects. Due to poor design, many conflicts, revisions and even the re-construction of building and RFS components have taken place, which wastes time and money and hence decreases the construction productivity. They further pointed out that:-

“Most architects are incompetent in dealing with a proper design due to unfamiliarity with the diverse RFS services. The early involvement of RFS subcontractors or manufacturers in the project team can help to coordinate these possible issues comprehensively and make a consummate interior design. The coordination and planning of the initial design is never overloaded.”

Many consultants and contractors argued that the lack of coordination of the fitout design and construction is also an important reason for the low construction productivity. Choosing a proper fitout project delivery method such as D&B and CM/GC, can make for construction progress. Moreover, 20% of respondents argued that the low construction productivity is also due to the poor coordination of subcontracts and installation procedures. They reached it by reasoning that:-

“The subsystems in the underfloor plenum are designed by consultants and could be planned very well. However, interferences between different trades often take place on site and decrease construction productivity, which get nothing to do with the individual service design but the coordination of them.”

In all, the above viewpoints highlight that both poor design and coordination and improper contracting strategy can possibly decrease the construction productivity.
A total of 60% of interviewees agreed that there is no evidence or cases to show the linkage between UAD and workplace productivity. The interviewees, particularly the consultants and manufacturers, also proposed some possible reasons for Issue C3. The reasons include the following aspects. Firstly, insufficient researches have been undertaken in this area in the world and inadequate practices of UAD are available in Australia construction industry. Secondly, there is not a mature feedback mechanism to examine the UAD operation in the industry although few buildings did use RFS. Thirdly, even though some feedbacks are raised from occupants, the industry and research body do not put effort into it to examine the linkage between UAD and workplace productivity. As a result, it seems that there is no relative evidence or recorded cases reflecting the relationship between UAD and workplace productivity.

Three interviewees contended that although some researches have been attempted in this field, they are too disperse and weak to persuade people to believe the advantages brought by the UAD. Two consultants proposed to explore the UAD’s contribution to the workplace productivity through the following shortcut:-

“The improved workplace productivity may result from good workplace, but it has no causality with UAD. So, in order to justify the linkage between the UAD and the workplace productivity, a shortcut might be to prove the UAD’s contribution to workplace environment at first.”

Hence, the UAD’s contribution to workplace productivity has not proved yet. The justification of this causality determines the successful integration of UAD into RFS.

As far as Issue C4 is concerned, there is a general agreement that most clients do not understand UAD although they know about raised floors, with a response rate of 65%. Most respondents indicated that RFS is noted for the flexible cable and wire distribution rather than for the air delivery in the mind of the industry practitioners. A typical answer indicates the poor knowledge of the UAD in the industry, that is:-

“The general problems in the ceiling air system cannot be addressed by the UAD either. Furthermore, if the air conditioning is fixed overhead, you get nothing to block the air flow; however with the UAD, you get chairs, desks and equipment on the way of air flow. So, the UAD is not going to work.”
The scarcity of the UAD cases also underm ines people’s confidence in adopting it. Several consultants pointed out that even though a few developers and clients have heard of the UAD, they refuse to use it for the following reasons:-

“RFS and UAD are perceived to contribute to high capital cost. Developers and clients will not pay extra money for the UAD if they cannot see the benefits, such as higher rentals and incentives to the market. Similarly, the occupants do not want to pay more for the UAD if they cannot acquire a low running cost, better office environment and higher workplace productivity.”

“Owners, consultants, project managers and contractors feel more comfortable to design and construct a ceiling-based air system as they have seen and done lots of it. Comparatively, they have not got enough live UAD projects for their references. Even though they have it, they still do not want to bear a risk to do it differently. So, the low awareness of the UAD in the industry obstructs its application.”

Consequently, Issue C4 can influence RFS and UAD applications. Interviewees also advised that carrying out a strategic research to justify the UAD advantages and presenting live UAD cases to show its real merits are crucial in enhancing the public knowledge and improving the market.

Contractors’ knowledge and skill have a significant effect upon the delivery of RFS. Most interviewees agreed that contractors are generally unfamiliar with RFS products and installation. However, they admitted that RFS subcontractors are more competent than most general contractors in this regard. Since raised floors and underfloor services are not standard applications in Australia, most general contractors lack basic experience and knowledge, and may have not structured a professional consulting and management team for knowledge inputs; on the other hand, they are normally reluctant to bow to other people’s advice that might really do good to the project. In an aim to enhance contractors’ knowledge in the RFS fitout, many consultants advised that:-

“Normally, consultants’ knowledge and information is newer than most contractors’. So, consultants can give general contractors much advice on the coordination of different work procedures and further help them supervise the RFS construction.”

Subcontractors are normally professional in their areas, e.g. raised floor installation, cable and wires distribution, UAD layout, etc. However, they sometimes do their job
without conforming to specifications. Typical examples include that dust is not cleaned out at the end of their work; cable trays block the air path to panel diffusers; and air leakage and balance are not tested although required by the specifications, etc. Therefore, the education of general contractors, effective supervision of subcontractors, and proper coordination and supervision from project managers is all indispensable to assure the quality of all RFS trades.

Quantity surveyors (QSs) present cost information to a project team and hence have the ability to influence the decision-making on RFS application. A total of 65% of respondents agreed with Issue C6. Most QSs never commit themselves on research to justify the rationality of the products appointed by the designers and consultants. As a result, the project team cannot make economical decisions. On the other hand, most QSs do not endeavour to upgrade their knowledge and are always reluctant to do anything unfamiliar. In consequence, many new technologies are possibly killed in the QSs’ hands before they can actually be reviewed by the project team.

Besides the above given 6 issues, another two issues were proposed by a big proportion of interviewees. The first issue is that the industry practitioners without RFS experience have a relatively low awareness of RFS and its associated advantages, which is consistent with the questionnaire findings. Some consultants and developers emphasized that the low awareness of RFS and its associated advantages will hinder its acceptance by the industry. Based on their hands-on experience, the two manufactures argued that:

“When we try to introduce our products to a project, most clients and consultants always refuse to use RFS in the first instance just for one reason – ‘why I am supposed to build RFS with extra money while the current practice works very well’.”

Some consultants and contractors also raised that the industry practitioners generally lack knowledge to facilitate RFS implementation. Since RFS fitout is different from the traditional fitout methods, special steps should be taken into consideration during the project design and construction processes so that the integration of RFS with building service systems can be ensured. They further argued that solid constructability review programs may help to enhance RFS implementation, particularly for those practitioners without on-site RFS experience.
In summary, all issues pertaining to the industry practitioners’ knowledge of RFS are believed to influence the RFS implementation. Incompetent architects and consultants will produce poor design causing low construction productivity and cost overruns. Low awareness of UAD benefits will hinder the integration of the state-of-the-art technology with RFS. What’s more, a lack of LCC concerns among QSs may kill the RFS in the cost-driven Australian industry. The general industry practitioners’ low awareness of RFS and its endowed benefits, and lack of RFS fitout knowledge mentioned by the interviewees will hinder RFS implementation. In addition, the low awareness of RFS and lack of knowledge in RFS implementations were discussed and named with Issues C7 and C8 to help the following analysis.

5.4.5 Cost Concerns

Cost is always the orientation of activities in market economics. As such, cost is regarded as one of the most important factors influencing the RFS implementation in the Australian construction industry. Based on the questionnaire survey, a total of 6 cost issues with respect to the RFS fitout were identified and the interviewee’s general opinions on these issues are summarized in Table 5.6.

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A total of 13 interviewees agreed that the capital cost of RFS is assumed as the most significant obstacle for the RFS implementation. However, they admitted that this conclusion is based on their experience rather than any real research; and currently, no research from an unbiased standpoint has been conducted on the cost comparison between the RFS and the traditional fitout approach. Meanwhile, RFS may cost more because it can offer many more benefits. Two popular ideas from the clients and developers are highlighted as follows:-
“It is a matter of deciding what you want to do, and then saying this is the cost to do it. You got to pay what you want to enjoy.”

“As to the initial capital cost, RFS is higher than the traditional fitout method. However, there is a capital cost for putting RFS in and there is also an ongoing cost for operation, maintenance and churn. We choose RFS because it is worthwhile.”

On the contrary, four interviewees argued against Issue D1. They agreed that the capital cost of RFS is a big issue but not the most significant obstacle. Two of them assumed the existing building structure as the biggest influence factor. The reason has been discussed previously. Another two stated that the most critical impediment is the developers and the clients’ acceptance. Standing on his decade’s RFS experience, one consultant revealed that:-

“The market acceptability of RFS is the biggest problem. People do not like things that are different. You got to sell the idea of RFS by making it cheaper or the performance better rather than just saying it is different and then wanting the industry to accept it.”

Therefore, cost is definitely one of the most significant influence factors in the way of RFS implementation; meanwhile, the restrictions due to the existing building structure and the market acceptability of RFS also deserve industry’s attention.

With respect to the owners’ underestimation towards LCC, 40% of respondents agreed that owners normally stress the capital cost rather than the LCC. The value of life cycle costing has not taken root in most owners’ mind. They can see the capital cost and hence grasp it tightly, whereas they do not believe that the future can be accurately forecast and mastered due to the ever-changing business, environment, technology, society as well as market trends. In a word, they are not willing to bear the risks of using new technologies. Furthermore, the running cost has nothing to do with building owners if they are not the real occupants. A typical voice is that:-

“Owners pay the bills for the RFS fitout, while occupants enjoy the lower running cost brought by the cutting edge facilities. However, most occupants are only willing to accept the normal market rental. So, what is the benefit for extra capital investment?”

On the other hand, 35% of interviewees revealed that the owners’ attitude towards LCC depends on many factors. Firstly, if the owners occupy the buildings themselves or rent out part of the buildings, they normally care about the building
Chapter 5: Interview Data Analysis and Findings

LCC. Secondly, government building owners always stress the LCC more than the speculative building owners do. Thirdly, the owners’ attitude towards the LCC is greatly influenced by the project team. For example, the owners may be persuaded that the RFS fitout results in high capital cost but can potentially contribute to low running costs and high rental, attract more tenants and retain quality tenants. From this viewpoint, owners should be educated about LCC; otherwise, their lack of understanding cannot but retard RFS implementation.

The impact of design upon the construction productivity was discussed previously in Issue C2 and its influence upon cost is now explored. A majority of interviewees agreed that poor design is one of the main reasons for cost overrun. They disclosed that RFS is still unpopular in the market and most architects and consulting engineers lack experience of it. Under this scenario, the inexperienced attempts at RFS cannot avoid mistakes in the initial interior design and hence bring about conflicts in the construction works, which unavoidably lead to many revisions, delay of project progress and finally cost overrun. Meanwhile, a couple of respondents argued that unrealistic costing also contributes to cost overrun to a large extent. And further argument about cost overrun lies with the contractors, installers and builders’ lack of skill in RFS construction. One comment outlines the problem:

“Most installers, contractors and builders lack experience on RFS construction; however, they won’t follow the specification. They always try to lay the floor pedestals and panels before all the underfloor services. They never know that their activities will waste time and cost.”

To minimize cost overrun, the following advice is gained from the interviewees. Firstly, do a realistic cost planning in the feasibility analysis of the fitout project; secondly, educate architects and consulting engineers with RFS knowledge to minimize mistakes in designs; thirdly, construction personnel may be called to join the project team for technological support; fourthly, select an appropriate project delivery method to keep continuity between design and construction.

In terms of the maintenance costs, 60% of interviewees thought that the maintenance cost associated with RFS was lower than that associated with the traditional fitout method. Owing to its flexibility, RFS can offer easy underfloor service access and
technology upgrades, encourage flexible relocation, and minimize the interruption of normal office activities, all of which accrue to the cost reduction of maintenance.

Meanwhile, 25% of interviewees cannot comment in this regard due to lack of experience and knowledge on the RFS maintenance costs. The manufacturers emphasized that a maintenance contract is worthwhile with a view to cut maintenance costs. In comparison, only one person argued that the maintenance cost is not always as low as expected, and nor is the maintenance cost with RFS fitout. Consequently, the maintenance cost of the RFS will not hinder RFS application.

Considering the risks inherent in new technologies, the industry is generally suspicious about the payback period of the higher capital cost with the RFS. The interviewees’ feedback confirms the existence of such concerns in the industry. More than half of the respondents thought that the cost incurred by RFS is significantly higher than that of the traditional fitout method and is not paid back soon enough. A typical concern voiced that:-

“There is no proof that RFS can be paid back soon for people who afford it. The industry needs to find a way for RFS to be paid back in 5 years; otherwise, there is no way for its entry to this cost-driven market.”

However, 20% of interviewees argued that RFS does not necessarily cost significantly more although its cost is higher than the traditional fitout method based on their experience. Concerning the payback period, another 20% of interviewees do not agree with the statement of Issue D5 either. One of them put forward that:-

“The payback period depends on how much churn a client gets. If the churn is very high, the higher capital cost of RFS can be reimbursed quickly, even possibly within three to four years. So, in a sense, RFS is quite suitable for the modern changing business operation.”

One consultant acknowledged that the capital cost could be too high to be paid back soon enough if RFS is constructed just for cable and wire distribution. He further advised that the integration of UAD can greatly reduce the payback time, because the UAD, without too much additional investment, can support flexible relocation, reduce energy consumption and improve the workplace environment.
The questionnaire feedbacks revealed a valid argument that buildings are usually owned by owners/developers while fitout with RFS is the occupants’ responsibility. An office building can be leased out on condition that it is fully ducted, power in and ceiling ready rather than just providing a shell and core as in the UK. Bearing this idea in mind, most occupants argued that RFS is part of the interior fitout and should be carried by developers. A popular viewpoint of this issue is made obvious by the following statement:-

“The RFS involves the cable and wire distribution and underfloor air conditioning, both of which are the basic prerequisites for the lease of an office space. Just like the ceiling configuration, RFS is part of the basic structure rather than part of the interior fitout, and therefore should be constructed at the owners/developers’ expenses.”

However, most owners and developers held an opposite idea that RFS is not part of the building structure but a piece of fitout furniture. So, they pushed the burden onto their occupants if they intend to use it.

As per the interview, there is not a dominant proposition on this, and who should pay for RFS fitout creates debate between developers, owners and occupants. Most interviewees considered it as an issue to balance risk and benefits. One consultant specifies the dilemma:-

“There is a discontinuity between initial capital costs and ongoing operational costs, and different parties have different cost drivers throughout the building life cycle. If no benefits are associated with providing or using RFS, why do they have to consider RFS in their properties?”

Consultants addressed at length that developers need to be aware of the current and future market demands. If the RFS is popular or is going to become accepted in the office lease market, it is wise to provide a building with RFS or at least with the capability to accommodate RFS in the future. Developers also need to consider the benefits of presenting RFS with their own costs, such as a potentially higher rental and an incentive to attract more tenants and retain quality tenants. Without clear benefits, developers are not motivated to provide RFS services because they, especially speculative developers, are chasing minimum investment and maximum
return all the time. On the contrary, occupants need to comprehend that they should pay extra money for the enjoyment of the RFS benefits, which can be either a higher rental or an extra investment for a RFS fitout.

The procurement of the RFS is actually a negotiation process. Occupants can be involved in the early project plan, in which negotiation on the RFS fitout cost, property rental and lease term is levelled between occupants and developers. In particular, most consultants acknowledged that it is more realistic to expand RFS market through a mechanism in which developers build RFS and then surcharge it back through a rental premium. Otherwise, the occupants are likely to lose their mobility if they pay for the RFS themselves. Whatever happens, both developers and occupants need to make decisions rationally. Developers should not provide RFS just for a particular tenant rather than for a prospective market, while occupants should not pay to put RFS in unless they are sure of a long tenancy in a particular building.

In conclusion, except for the maintenance cost, all issues pertaining to the RFS costs exert significant influence on the RFS implementation. As the interview analysis concluded, the Australian office building market is totally a cost-driven. Owners and developers pursue low capital costs, high rentals, short payback time, while occupants chase low rentals and low running costs. This reality highlights the importance of dealing with the RFS cost issues appropriately. Any ill-considered cost issues will result in cost overrun, high running costs, project quarrels, market failure, etc. Therefore, most of the issues except the maintenance cost are SIFs which deserve a comprehensive plan in advance in the RFS fitout project.

5.4.6 Post-Construction Issues

As highlighted in the previous sections, many SIFs influence the RFS design and construction, which further determine the RFS service operation and maintenance. Identifying the real problems in the post-construction stage can help to foresee the potential problems in the design and construction and seek appropriate solutions. Based on the questionnaire results, a total of 18 perceived issues in RFS operation and maintenance were identified and the interviewee’s general opinions on these post-construction issues are summarized in Table 5.7.
### Table 5.7 Feedback on Post-Construction Issues

<table>
<thead>
<tr>
<th>Code</th>
<th>Agree</th>
<th>Disagree</th>
<th>It depends</th>
<th>No comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Percentage</td>
<td>No.</td>
<td>Percentage</td>
</tr>
<tr>
<td>E1</td>
<td>5</td>
<td>25</td>
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<tr>
<td>E2</td>
<td>10</td>
<td>50</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>E3</td>
<td>10</td>
<td>50</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>E4</td>
<td>12</td>
<td>60</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>E5</td>
<td>8</td>
<td>40</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>E6</td>
<td>8</td>
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<td>25</td>
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<tr>
<td>E7</td>
<td>9</td>
<td>45</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>E8</td>
<td>7</td>
<td>35</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>E9</td>
<td>1</td>
<td>5</td>
<td>17</td>
<td>85</td>
</tr>
<tr>
<td>E10</td>
<td>10</td>
<td>50</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>E11</td>
<td>6</td>
<td>30</td>
<td>8</td>
<td>40</td>
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<tr>
<td>E12</td>
<td>5</td>
<td>25</td>
<td>9</td>
<td>45</td>
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<tr>
<td>E13</td>
<td>6</td>
<td>30</td>
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<td>20</td>
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<tr>
<td>E14</td>
<td>3</td>
<td>15</td>
<td>6</td>
<td>30</td>
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<tr>
<td>E15</td>
<td>12</td>
<td>60</td>
<td>4</td>
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<td>E16</td>
<td>1</td>
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<td>14</td>
<td>70</td>
</tr>
<tr>
<td>E17</td>
<td>8</td>
<td>40</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>E18</td>
<td>2</td>
<td>10</td>
<td>13</td>
<td>65</td>
</tr>
</tbody>
</table>

Issue E1 suggests that excessive cables and wires block the even spread of underfloor cool air. Out of 20 interviewees, 11 of them mentioned whether cables and wires block the air distribution depends on many factors, such as the FFH of RFS, the underfloor air pressure and the rationality of the cable and wire distribution layout. Many respondents pointed out that:-

"The underfloor air distribution can be hindered by the cables and wires in the floor plenum. Electrical subcontractors do not care about the air distribution when they are doing their work."

They further commented that:-

"The way to solve this problem is to re-lay the cables and wires evenly if the FFH of RFS is adequate, say not less than 300mm. This method is supposed to clear the obstruction on the way of air flow. If it cannot solve the problem, adding FFH of RFS or the air pressure needs to be considered."

Instead of putting RFS in without deliberation, one client emphasized that developers should fully understand their clients’ needs, based on which they encourage consultants to think about the services in the underfloor space. He specified that:-
“What will be fitted in the RFS to make it work properly? What level of data cabling is put in the plenum? How cool air is distributed underneath? How to mix the return air with the primary air? How about air temperature, pressure and volume? And are they enough?”

Essentially, all these factors are closely pertaining to the quality of the interior design and construction of RFS and UAD. Finding appropriate ways to integrate the above factors is critical to minimize uneven air distribution.

Issue E2 is also pertinent to the UAD but is particularly associated with its use in computer and equipment rooms where hot spots often appear because the limited cooling capacity cannot cope with the large amount of heat generated by mainframes. The interview responses indicate that most people regarded it as a problem. However, they argued that the particular hot spots can be eliminated simply by increasing the amount of cool air from the underfloor plenum to the potential hot spots. Using perforated panels and grills, and adding outlets can all help to raise the flux of cool air to the particular area and hence enhance the cooling capacity.

Meanwhile, those people disagreeing with Issue E2 argued that maintenance people such as electricians, plumbers and cleaners always put things in the way of air flow thus wrecking the air balance. This kind of wrong activity will inevitably result in hot spots even around small equipment. This problem is also applicable to the initial installation of RFS and UAD even though a good design has been provided. Consequently, a good design, proper installation and coordination, as well as correct maintenance are all indispensable to the elimination of hot spots in computer rooms.

The interview feedback indicates that there is approximately the same proportion of respondents arguing for and against Issue E3. In support of this issue, interviewees pointed out that cool air is always felt around the joints of floor panels and the junctions between walls and panels. As to the causes for air leaking, the manufacturers and contractors specified that:

“Incorrect design of underfloor air mechanism (e.g. exorbitant underfloor air pressure and supply air volume), inaccurate location of floor panels and pedestals, poor layout of carpet tiles, no air balance and leak testing during the installation of UAD, and
improper lift up of panels (without using special tools) during maintenances, etc. can all bring about air leakage.”

Objecting to this idea, some interviewees reasoned that the leakage of cool air can only appear in computer and equipment rooms where the vinyl edge trim for high pressure laminate floor coverings rather than carpet tiles are used. In general offices, cool air cannot come out through the panel joints as they are covered with carpet tiles and the air pressure is too low to push the air out.

From the energy saving point of view, a majority of respondents thought that there was no energy waste in spite of the air leakage. They specified the reason that:–

“Although the air may come out of the plenum through the interstices between panels, it still goes to the occupied space and removes the heat generated by equipment, human body and activities. So, there is no energy waste.”

However, most respondents admitted that the air infiltration should be minimized because too much air leakage will destroy the whole air balance in the floor plenum and wreck personal control ability of individual workplace environments.

Issue E4 highlights the draught issues associated with the UAD. Twelve interviewees out of 20 thought that draught arises due to the UAD method. Since grills or swirl diffusers are usually positioned besides desks and chairs, people can easily feel a strong draught from the underfloor plenum, making the female staff feel uncomfortable, complaining of cold feet and skirts blowing up. On the other hand, three interviewees argued that draught is not a negative feature pertaining to the UAD whereas the ceiling-based air system has even stronger draughts.

On exploration of the reasons for draughts, unreasonable air velocity and pressure, poor airproof measurement of air ducts and improper maintenance are highlighted as the most possible causes. Failures to abide by the UAD operation guidelines can lead to draughts as well, even though the above three factors have been strictly followed. A typical mistake is to put luggage, bags or other items on the top of a diffuser, which unavoidably increases the air volume coming from the uncovered part of this
diffuser and other diffusers. In the respondents’ opinion, reasonable design, correct operation and proper maintenance are all necessary to minimize draughts.

With respect to Issue E5, most interviewees specified a range of reasons that may result in an uneven raised floor surface, e.g. unprepared subfloors not being free from dust, wet and dangerous materials, laying floor panels without the assistance of laser planometers, failure to replace panels accurately after maintenance, using low grade raised floor products in a heavy load environment, etc. Except for the panel distortion, the raised floor surface can be levelled by adjusting the height of the pedestals for particular panels. Manufacturers and a few consultants advised that concrete floors must be primed with an approved primer before installation.

In terms of Issue E6, most respondents believed that the connectivity between panels and walls is always a big trap due to the irregular building shape design. Today’s architects prefer to design a curved building façade to exhibit company spirit and culture, which makes the design and installation of raised floors difficult. On the other hand, both unskilful panel cutting and inaccurate installation of pedestals along the junctions can result in a poor connectivity between panels and walls as well. As far as the solution is concerned, most respondents thought that there is no better way to solve this problem than using regular building facades or spending money in reshaping the panels to match the irregular walls.

Issue E7 presents another RFS connectivity issue that is pertaining to different floor levels. Half of the respondents believed that a poor configuration of floor levels, unmatchable design and adoption of ramps and steps, lack of regular maintenance of floor panels, etc. can all give rise to a poor connectivity between floor levels. In terms of the potential solutions, most respondents thought that integrating RFS features into the initial building structure design and interior fitout design and implementing regular maintenance is the answer.

Seven interviewees out of 20 agreed with Issues E8. They reasoned that floor panels might retard underfloor accessibility for a variety of reasons, e.g. inappropriate panel and pedestal locking methods, lack of floor panel maintenance, panel distortion, inaccurate forecast of the underfloor access frequency, incompatible selection of
panels and carpet tiles to particular fitout environments, etc. As to the solutions, most interviewees advised that selecting appropriate panel products, installing panels and pedestals accurately, and using and maintaining RFS according to specifications can help to minimize the problem.

As far as Issue E9 is concerned, a total of 85% of interviewees did not think that it was hard to relocate cables, wires and outlets. They indicated that flexibility is the most recognized advantages associated with RFS fitout, particularly for the relocation and upgrade of PVD components. They specified that:

“The underfloor cable and wire goes from the building core to the workstations with clip-connector character which supports easy upgrade to meet changing technologies of peripherals, networks and servers. Open cable trays in the floor plenum divides power and data grid of service, nodes on 5 meter tether, which can give a changeable density of outlet types without waste. Furthermore, the floor outlets are relocatable boxes with ‘plug-and-play’ feature.”

Accordingly, it is beyond all doubt that Issue E9 is an imagined problem. Undoubtedly, proper design and installation is the pre-requisite to achieve flexibility in the underfloor PVD system.

Most respondents admitted that extra holes might be needed in the panels for additional PVD boxes and air diffusers after the buildings are put into use, which costs extra money and causes mess. As to the possible reasons, they thought that a failure to predict the accurate number of holes, inaccurate cooling capacity calculation, unskilful cutting of panels, etc. can all lead to additional hole drilling in the post-construction stage. A few consultants pointed out the dilemma:-

“It is very difficult to predict the location and size of holes actually during the initial orders of the products. Of course, you can purchase them from the suppliers again once you need extra. However, it is very expensive. As such, most clients and developers prefer to cut holes by their staffs. As you know, these staffs are not professional in this regard. Mess is unavoidable.”

Consequently, Issue E10 is recognized as a real major problem deserving comprehensive design and installation in advance to minimize extra cost and mess.
As to Issue E11, 40% of interviewees disagreed with the existence of too much travel of sound associated with RFS. There are two subjects concerning the travel of sound as per the interview feedback, i.e. noise generated by the air conditioning system and voice transferring from one room to adjacent rooms. For the first instance, most interviewees argued that the noise made by the UAD is much lower than that of the ceiling-based air system, as they specified that:-

“High air velocity and pressure and irregular shape of air ducts can all possibly result in travel noise. Compared with the ceiling air system, the UAD has a lower air velocity and pressure and has no air ducts potentially. So, there is no reason for a louder and unbearable noise generated by the UAD.”

For the second instance, most interviewees agreed with the possibility of sound transmission from one room to adjacent rooms through the floor plenum. They recommended that a proper selection of floor panels and carpet tiles can reduce this problem. For example, the high grade fibreboard core has excellent sound attenuation, and stringer or pedestal gaskets can further dampen sound. On the other hand, a good combination of the acoustic baffle against sound transmission with the construction of underfloor smoke and fire dividers can help to retain sound within the original space. In particular, soundmasking speakers installed in the floor plenum can reduce the sound transmission effectively.

The questionnaire survey indicated that holes in panels induce stress concentrations leading to further cracks. Although most interviewees did not acknowledge this problem, most of them admitted that cracks in panels may appear as a result of stress concentrations if the holes are not drilled strictly in conformity with the specifications. In order to minimize the problem, the manufacturers revealed several factors deserving attention. Firstly, panels need to meet needs of the particular environment. Secondly, holes need to be drilled with appropriative tools, such as chain, band and circular saws. Thirdly, the location and size of holes needs to be studied to prevent a too great a reduction in the panel carrying capacity. Fourthly, additional pedestals need to be added if holes are located near the edge of the panels. The manufacturers also pointed out that:-
“When you drill a hole in a panel, you reduce its capacity to carry load. Provided that the dimension of the hole is reasonable, the worst thing that you can do is to reduce the panel carrying capacity by 40-45%. Otherwise, it may produce cracks.”

Unfortunately, most facility managers and contractors are not aware of these important factors and their arbitrary drilling without a view to the panel strengths and applications will inevitably lead to stress concentrations and eventual cracks.

With regard to the panel movement during operation, most respondents thought that this depends on the construction and maintenance activities. For example, no amendment to the subfloor surface before the pedestal installation, unreliable fixing of pedestals on the subfloors, faulty vertical measurement of pedestals, unreliable anchor of panels upon pedestals, improper lift of panels for underfloor access, etc. can all lead to the panel movement. As per their suggestion, comprehensive selection of products, proper fixing of pedestals and regular maintenance are all indispensable to eliminate the panel movement.

Likewise, the flexibility of panel relocation is suspected due to the possible panel distortion. Generally floor panels are manufactured in standard sizes, normally 600mm by 600mm or 750mm by 750mm, and hence they are essentially changeable and relocatable. As to Issue E14, most interviewees argued that there is little chance for its occurrence except where panels are installed without following the specifications or are used in a very harsh environment outweighing the panel maximum endurance. Once again, it comes to the selection of appropriate raised floor products to meet the specific application environments.

On the other hand, the manufactures argued that floor panels cannot assure absolutely quality. In the case of inferior products, the panel quality is normally guaranteed for 5-7 years. Moreover, many panels are recycled by manufacturers after 10 years of use, which can further reduce the possibility of panel distortion.

As far as Issue E15 is concerned, a majority of interviewees agreed that dust is often built up during the RFS construction and operation. However, most of them believed
that dust is mainly generated during the construction process rather than during the operation and maintenance process. They put forward that:

“Raised floor subcontractors normally forget to clean dust although it is a must as per the specifications; on the other hand, other trades for power and data, air conditioning and piping may also generate a great deal of dust and do not remove them at their work completion. Therefore, the project manager’s supervision of subcontractors to clean underfloor dust associated with all individual jobs is necessary to reduce dust generating from construction.”

They further refuted the possibility of generating dust during the operation process. They believed that:

“There is little chance to get dust into the plenum from occupied areas above because, if UAD is used, the floor void is air-pressured and dust can be possibly blown out rather than attracted in.”

However, they admitted that the delivery of underfloor air may bring dust in if the air filters do not work properly, and the maintenance of underfloor services can possibly induce dust into the floor void as well. To minimize the above issues, regular maintenance to air filters and proper performance of all underfloor service maintenances are significant. Particularly, one consultant revealed that dust can also be produced due to the split of the subfloor concrete surface after many years’ services. A pre-seal with special glue to the subfloor concrete surface prior to laying raised floors and other services can make for the minimization of this phenomenon.

Issue E16 concerns water leakage problem which, once occurred, might cause deterioration in the underfloor environment and influence the underfloor service operation. Based on the interview feedback, a total of 70% of interviewees argued that there is little chance for water leaking into the floor outlets and underneath space. Even though water may sink down into the floor boxes, it cannot overflow into the floor plenum. The floor air diffusers are usually designed with a capacity to hold at least one cup of water. Meanwhile, most respondents advised that regular maintenance is conducive to removing dust and water insides the outlet boxes. Therefore, water leakage is not a real problem.
Both related to trip hazards, Issue E17 and E18 present that people walking on floor panels are likely to encounter trip hazards if the panel surfaces are not free from irregularities, roughness and projections. Although 8 interviewees disagreed with this problem, another 8 persons explained that the floor coverings using 500mm by 500mm sized carpet tiles, tend to shrink or curl after years of use without regular maintenance. They also stated that the inclinations of floor panels or outlet boxes during installation can also lead to potential accidents. As to solutions, a majority of interviewees believed that accurate fixing of floor panels and outlet boxes as well as regular maintenance of panels and floor coverings can minimize trip hazards.

As to Issue E18, it is conceivable that the panels with cable passes or outlets expose the holes to pedestrian traffic when the fitout changes. However, a majority of interviewees argued that this issue is just a perceived problem because the panels with holes are normally replaced with new and complete panels once holes are not needed there. The replaced panels with holes will be used in other areas where holes are anticipated. Accordingly, Issue E18 is not a real problem.

In conclusion, among the 18 issues pertaining to the RFS service operation and maintenance raised from the questionnaire survey, Issue E9, E16 and E18 are seen as false problems while the rest issues as real ones. In detail, the false problems are perceived issues that actually do not exist. Issue E5-E8, E11-E14 and E17 are minor problems which occur infrequently and can be solved easily. However, these issues are still worthy of attention because they, once occurring, hinder the achievement of RFS functions. Meanwhile, Issue E1-E4, E10 and E15 are recognized as major problems which emerge frequently if one or more sectors during the RFS design, construction, operation and maintenance are not executed strictly in compliance with the specifications. Both the major and minor problems and their conceptual solutions need to be further investigated in order to improve RFS project implementation.

5.5 Findings of Interview Data Analysis

Based on the above interview data analysis, the SIFs and real problems were justified and their conceptual solutions were recognized as well. To give a succinct and clear
overview of the data analysis findings, these SIFs, real problems and their conceptual solutions are summarized in five tables, which are put in Appendix. Particularly, Appendix 5 summarizes the results of the interview feedback analysis for structural constraints, Appendix 6 for RFS service integration, Appendix 7 for industry practitioners’ knowledge, Appendix 8 for cost concerns, and Appendix 9 for post-construction issues. A total of 20 SIFs and 15 real problems are pinpointed and their conceptual solutions are listed as well. In particular, through the semi-structured interview, two SIFs that had not been listed in the prepared interview questions were suggested by the interviewees. For the real problems, 6 are major problems while the rest 9 are minor ones.

Most of the contents in Appendix 5-9 have already been presented in the earlier interview data analysis. However, it should be noted that some of the solutions in the tables derives from the interview data directly and have not been mentioned in the previous section for the purpose of minimizing lengthy analysis. In order to facilitate the presentation and discussion in the following chapters, each of the SIFs and real problems is abridged to simple terms, as illustrated in Table 5.8 and 5.9.

5.6 Summary

This chapter presented an in-depth interview data analysis, which is based on the feedbacks obtained from the 20 semi-structured interviews. The feedbacks to the 26 potential influence factors were presented and analysed, based on which the SIFs were told from the non-SIFs. As a result, 20 SIFs pertaining to structural constraints, RFS service integration, industry practitioners’ knowledge and cost concerns were reached and their conceptual solutions were identified as well. Similarly, feedback to the 18 potential problems was presented and studied, based on which 15 real problems were exposed and their solutions were highlighted.

The next chapter will present the site observation and focus group data analysis and findings.
### Table 5.8 Summary and Abridged Names for SIFs

<table>
<thead>
<tr>
<th>SIFs concluded by the interview survey</th>
<th>Abridged names</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural constraints</strong></td>
<td></td>
</tr>
<tr>
<td>• The initial building structural regularity restricts building retrofit with RFS;</td>
<td>Structural irregularity</td>
</tr>
<tr>
<td>• The space volume (distance between slab and slab) is a problem;</td>
<td>Space volume limitation</td>
</tr>
<tr>
<td>• Transitions to lift system, existing doors, stair landings and toilets are problems;</td>
<td>Transition difficulties</td>
</tr>
<tr>
<td>• The existing overhead HVAC system configuration influences RFS application;</td>
<td>Overhead HVAC influence</td>
</tr>
<tr>
<td>• The existing structural beams influence RFS application;</td>
<td>Structural beam restriction</td>
</tr>
<tr>
<td><strong>RFS service integration</strong></td>
<td></td>
</tr>
<tr>
<td>• The fire safety system is hard to be accommodated in the RFS fitout;</td>
<td>Fire safety system accommodation</td>
</tr>
<tr>
<td>• Existing cables and wires are not compatible with new PVD systems;</td>
<td>Cables and wires incompatibility</td>
</tr>
<tr>
<td><strong>Industry practitioners’ knowledge</strong></td>
<td></td>
</tr>
<tr>
<td>• The integration of RFS with building structure and services has not been fully considered</td>
<td>Architects &amp; engineers’ incompetency</td>
</tr>
<tr>
<td>by most architects and engineers;</td>
<td></td>
</tr>
<tr>
<td>• Poor design is one of the main factors resulting in low construction productivity;</td>
<td>Poor design influence on construction</td>
</tr>
<tr>
<td>• No evidence and cases show the links between UAD and productivity;</td>
<td>UAD influence on productivity</td>
</tr>
<tr>
<td>• Most clients do not understand what UAD is although they know raised floors;</td>
<td>Clients’ low familiarity with UAD</td>
</tr>
<tr>
<td>• Contractors have a low familiarity with RFS products and installation;</td>
<td>Contractors’ incompetency</td>
</tr>
<tr>
<td>• Most QSs do not care LCC and are not interested in new systems;</td>
<td>QS’ incompetency</td>
</tr>
<tr>
<td>• The industry practitioners without RFS experience have a relatively low awareness of RFS and its</td>
<td>Low awareness of RFS</td>
</tr>
<tr>
<td>advantages;</td>
<td></td>
</tr>
<tr>
<td>• The industry practitioners lack knowledge to facilitate RFS implementation.</td>
<td>Ignorance of RFS implementation</td>
</tr>
<tr>
<td><strong>Cost concerns</strong></td>
<td></td>
</tr>
<tr>
<td>• The most significant obstacle is the capital cost of RFS;</td>
<td>Capital cost obstacle</td>
</tr>
<tr>
<td>• Owners only stress capital cost rather than LCC;</td>
<td>Underestimate of LCC</td>
</tr>
<tr>
<td>• Poor design is one of the main reasons resulting in cost overrun;</td>
<td>Poor design influence on cost</td>
</tr>
<tr>
<td>• RFS cost significantly more compared with traditional fitout approach and for most clients,</td>
<td>Suspcion of RFS payback ability</td>
</tr>
<tr>
<td>it is not paid back nearly soon enough;</td>
<td></td>
</tr>
<tr>
<td>• Building is owned by the developers while fitout is occupants’ responsibility.</td>
<td>Ambiguiy of fitout responsibility</td>
</tr>
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</table>
Table 5.9 Summary and Abridged Names for Real Problems

<table>
<thead>
<tr>
<th>Post-construction issues</th>
<th>Real problems concluded by the interview survey</th>
<th>Abridged names</th>
<th>Major/Minor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Excessive cable and wire distribution prevents even spread of underfloor cool air;</td>
<td>Uneven air distribution</td>
<td>Major</td>
</tr>
<tr>
<td></td>
<td>UAD does not allow an easy solution to deal with hot spots in computer rooms;</td>
<td>Hot spots</td>
<td>Major</td>
</tr>
<tr>
<td></td>
<td>Cool air in the UAD is often leaking from the interstice between panels;</td>
<td>Cool air leaking</td>
<td>Major</td>
</tr>
<tr>
<td></td>
<td>Draught arises due to the UAD method;</td>
<td>Draught</td>
<td>Major</td>
</tr>
<tr>
<td></td>
<td>The floor surface composed of panels is uneven;</td>
<td>Uneven raised floor surface</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>The connectivity between panels and walls is poor;</td>
<td>Poor panel &amp; wall connectivity</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>The connectivity between different floor levels is not aesthetic;</td>
<td>Poor floor connectivity</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>Panels do not present well and limit the underfloor ongoing accessibility;</td>
<td>Inconvenient underfloor access</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>Additional hole drilling results in costs and mess;</td>
<td>Additional hole drilling</td>
<td>Major</td>
</tr>
<tr>
<td></td>
<td>Much travel of sound appears;</td>
<td>Noise</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>Holes in panels induce stress concentrations leading to further cracks;</td>
<td>Breakdown due to holes</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>Panels tend to be moving due to poor installation;</td>
<td>Panel moving</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>Panels are hard to relocate for its distortion.</td>
<td>Panel distortion</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>Dust is often built up during RFS construction and operation;</td>
<td>Dust</td>
<td>Major</td>
</tr>
<tr>
<td></td>
<td>Lifting of facial components on panel creates trip hazards;</td>
<td>Trip hazards</td>
<td>Minor</td>
</tr>
</tbody>
</table>
CHAPTER 6
SITE OBSERVATION AND FOCUS GROUP DATA ANALYSIS AND FINDINGS

6.1 Introduction

Through the questionnaire survey, the general recognition level of RFS applications for office building fitout in the Australian construction industry was studied, which highlighted a range of issues pertaining to RFS implementation, e.g. low awareness of RFS advantages except flexibility, unfamiliarity with RFS specifications, low awareness of RFS integration and constructability, etc. Then, site observations and focus groups were conducted to further investigate these pending issues.

The questionnaire survey also identified 44 potential issues hindering the RFS implementation which was further explored through semi-structured interviews. After in-depth interview data analysis, 20 SIFs and 15 real problems (major and minor) were recognized and their appropriate conceptual solutions were gained as well. Following the above steps, site observations and focus groups were carried out to further explore and validate these recognized SIFs and real problems in the office building sites with RFS fitouts.

This chapter presents the data analysis and findings of the site observations and focus groups. It first introduces the basic information of the sites and the data collection methods and then presents the RFS specifications, good practices and problems explored on existing office building and construction sites. After that, it validates the real problems and justifies RFS fitout advantages based on focus group feedbacks. Finally, the research comes up with four findings.
6.2 Purposes of Site Observations and Focus Groups

With the consciousness of the many pending issues derived from the questionnaire and interview survey, the site observations and focus groups were conducted with the aim of achieving the following purposes:

- To develop RFS specifications and explore RFS integration and constructability;
- To further explore problems associated with RFS fitout implementations;
- To further study the RFS advantages for office building fitout; and
- To validate the results of the previous interview survey.

6.3 Information of the Sites

Seven site observations were conducted between August and December in 2003. The seven sites included one Australian raised floor manufacturer and six office building sites. The six office building sites involved four exiting office buildings with RFS fitout and two office building construction sites with RFS fitout. The seven observation sites were not selected randomly. Rather, these sites were recommended during the interview survey by the clients, consultants and manufacturers who have robust knowledge and extensive experience of RFS fitout. These sites involved both good and bad practice of RFS fitout, and demonstrated typical problems associated with RFS design, construction and performance. Therefore, the seven sites are representative and the findings of the observations can be extrapolated to general practice. The details are summarized in Table 6.1.

The company specializing in manufacturing raised floors was visited for the purpose of collecting data of RFS specifications. The four existing office building sites cover RFS projects with different gross floor areas (GFA), from 18,325sqm to 110sqm. Two of the four existing sites are located in Brisbane while the rest are located in Sydney and Newcastle. These projects were built for different purposes, e.g. government office building, energy company computer centre, commercial bank offices, and research institute offices. Particularly, underfloor HVAC system was applied in all these buildings; however, the government office and the energy company only adopted it in computer rooms.
Two office building construction sites were observed to study the RFS installation process. Located in Brisbane, the two projects included an education training space and a government office building, neither of which had UAD. Although the researcher tried to find construction projects with UAD, there were none available either in Brisbane or Sydney when the site observations were conducted. This further proves that the UAD is not popular in the Australian office building market.

### 6.4 Data Collection Methods

The researcher took advantage of digital cameras to photograph the items of interest on the sites during the observations. Specifically, the items of interest included:

- Typical RFS products and applications;
- Good practices associated with RFS fitout implementation; and
- Problems associated with RFS fitout Implementations

The periods of site observations varied a lot since different purposes were applicable to different sites. For the raised floor company, three days were spent there for gathering firsthand data of RFS products and applications. For the 4 existing office building sites, the periods varied from one to three days; for the 2 construction sites, the time lasted approximate three months. RFS specification data, good practices and problems associated with RFS implementation were obtained on these sites. Data collected was analyzed to reach the first two purposes. On the other hand, three focus groups were organized in the research institute offices, commercial bank headquarter

---

**Table 6.1 Information of the Six Office Building Sites**

<table>
<thead>
<tr>
<th>Type of sites</th>
<th>Project information</th>
<th>Location</th>
<th>GFA with RFS (sqm)</th>
<th>With UAD area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exiting office building sites</td>
<td>Government office building</td>
<td>Brisbane</td>
<td>18,325</td>
<td>Computer rooms</td>
</tr>
<tr>
<td></td>
<td>Energy company</td>
<td>Brisbane</td>
<td>110</td>
<td>Computer rooms</td>
</tr>
<tr>
<td></td>
<td>Commercial bank headquarters</td>
<td>Sydney</td>
<td>16,000</td>
<td>Dealing rooms and computer rooms</td>
</tr>
<tr>
<td></td>
<td>Research institute offices</td>
<td>Newcastle</td>
<td>2,400</td>
<td>All spaces</td>
</tr>
<tr>
<td>Office building construction sites</td>
<td>Education training space</td>
<td>Brisbane</td>
<td>331</td>
<td>No UAD</td>
</tr>
<tr>
<td></td>
<td>Government office building</td>
<td>Brisbane</td>
<td>Around 1,000</td>
<td>No UAD</td>
</tr>
</tbody>
</table>
and government office building. Engaging a few general employees, the focus groups aimed to obtain the occupants’ general opinions on the advantages and problems associated with RFS operation and maintenance. With hands-on RFS experience, the occupants could present reliable feedbacks that can be used to further study the RFS advantages and to validate the real problems concluded by the interview survey.

6.5 Site Observations Data Analysis

Different from the previous survey research, the data collected from site observations mainly encompassed a diversity of first hand RFS products data and pictures collected from the raised floor company and the six office building sites. The data is presented along with the discussion of the proposed items of interest.

6.5.1 RFS Specifications

RFS specifications include product specifications and application specifications. Product specifications describe the classification and features of different RFS components, while application specifications define the performance standards in different fitout environments in office buildings. With the visit to the raised floor company, a wide range of firsthand RFS product data was gained. On the other hand, much information about RFS specifications was gained through the observations on the 6 office building sites. Although most projects used the local raised floor products, some of them chose products imported from the USA, Germany and South Africa. With a comprehensive comparison and unification, succinct but comprehensive specifications for RFS products and applications were developed.

6.5.1.1 Specifications of RFS Products

As mentioned in Chapter 2, RFS consists of 3 parts: structural units, accessories and service units, involving a wide range of components. Some are indispensable, whilst others are optional. To give a strong focus to the specifications developed here, the range of components to be studied is narrowed down to the essential ones, such as panels, understructures, floor coverings, underfloor HVAC system and PVD system.
Panels

Panels are a standard RFS component manufactured in the factory and installed on project sites. A variety of panels are produced to accommodate different fitout purposes. Basically, in view of loading capacity, panels are designed from medium grade to extra heavy grade. Considering materials, panels can have concrete or fibre cores. Besides individual characteristics, panels share the following features as per the analysis of the prevalent RFS in Australia.

Table 6.2 Characteristics of Raised Floor Panels

<table>
<thead>
<tr>
<th></th>
<th>Medium grade</th>
<th>Heavy grade</th>
<th>Extra Heavy grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>Mostly 600mm×600mm</td>
<td>750mm×750mm available for special fitout purpose</td>
<td></td>
</tr>
<tr>
<td>Load bearing</td>
<td>Referring to Table 6.3-6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>Around 30mm</td>
<td>Around 35mm</td>
<td>Around 40mm</td>
</tr>
<tr>
<td>Weight</td>
<td>Around 12kg</td>
<td>Around 14kg</td>
<td>Around 15kg</td>
</tr>
<tr>
<td>Surface</td>
<td>Bare top ready for carpet tiles or durable anti-static high pressure laminate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire proofing</td>
<td>All the materials are non-combustible and in conformity with the early fire hazard indices under the Australian Standard AS 1530 Part 3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soundproofing</td>
<td>Airborne and footfall sound reduction of approximately 50-70 dB.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrostatic resistance</td>
<td>$5 \times 10^7$ Ohms - $2 \times 10^{10}$ Ohms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As per fabric structures, panels include solid and ventilation panels, as shown in Figure 6.1. Solid panels are the most frequently used in office buildings, computer/equipment rooms, lift lobby and dealing rooms, and are fabricated to exacting tolerances from steel or aluminum, welded to form a unitized shell, and then filled with a highly controlled mixture of cement.

![This figure is not available online. Please consult the hardcopy thesis available from the QUT Library](Figure 6.1 Typical Solid Panels and Ventilation Panels)

Source: Tate Access Floors Pty Ltd website: [www.tateaccessfloors.com](http://www.tateaccessfloors.com)
panels provide optimum laminar airflow without turbulence, and the advanced model, the chamfered perforated panels provide superior particulate control with up to 20% increase in airflow. Grate panels are designed to provide superior airflow, even better than perforated panels. Ventilation panels are fully interchangeable with solid panels.

**Understructures**

Understructures include pedestals and stringers. Pedestals are indispensable in all fitout spaces while stringers are only used in heavily loaded environments such as computer and equipment rooms. Pedestals are engineered to provide strength and stability and create an interstitial space under the floor for the service distribution. Pedestal assemblies include base and head. The base consists of a base plate and base tube. The head involves a head plate and head tube. The base and the head together pre-determine the finished floor height (FFH), and the head mates with the base tube to provide adjustment. Pedestal products should abide by the following requirements:

- Pedestals provide enough axial load capacity, usually no less than 22kN, to withstand the loads without permanent deformation.
- Pedestals are made of galvanized steel, and for special use non-metal pedestals are available. The pedestal base plate shall be no less than 100mm×100mm square area.
- Pedestals provide a means of leveling and locking the assembly at a selected height, requiring deliberate actions to adjust the height and prevent vibration displacement.
- Pedestals vary from 60mm to 1200mm for different floor height. For a FFH of 150mm and over, pedestals should provide a range of not less than ±25mm vertical adjustment. For FFH less than 150mm, pedestals should provide a minimum of ±10mm adjustment.

The pedestal plates are normally attached to the subfloor using an appropriate adhesive but in special cases mechanical fixings may be specified for greater stability. The pedestal heads are normally joined with the panels by three methods, i.e. cornerlock, freelay and stringerlock, as shown in Figure 6.2.

Source: Tasman Access Floors Pty Ltd website: www.tasmanaccessfloors.com.au

Figure 6.2 Typical Locking Methods between Panels and Pedestals
For the purpose of providing greater strength, excellent lateral stability and easy access for RFS, stringers are used to secure panels when demanding load capacity or a floor height more than 600mm are needed. The main specifications pertaining to stringers include:

- Stringers shall be zinc coated to achieve lifetime protection against corrosion, and be bolted to the pedestal head or be the snap-on type and capable of being removed individually and easily.
- Stringers shall be capable of supporting a 90kg concentrated load at mid-span with less than 2mm permanent set.
- Stringers shall be provided in a standard length (usually 600mm). 1200mm stringers are also available to add the whole structural stability.

Floor Coverings

Floor coverings are designed to protect the panel surface from corrosion, and reduce the vibration and noise produced by dynamic loads exerted on the floor panels. In office building scenarios, acoustic absorption, appearance with reconfigurations, reduced static electricity, low outgassing, maintainability, durability and recyclability are the most important factors to be reckoned with. Currently, carpet tiles and laminates are two of the most popular floor coverings available for RFS panels, as illustrated in Figure 6.3.

Carpet tiles are widely used in office buildings, particularly in general office spaces, lift lobbies and lounges. The normal carpet tiles can potentially lead to carpet running and time-consuming for getting underfloor access. PosiTile carpet tiles are design to minimize the problems. The product specifications mainly include:

- Carpet tiles are accurately cut 600mm×600mm to allow simple one-to-one match with panels; however, 500mm×500mm are also popularly adopted.
• PosiTile Carpet Modules are locked against lateral movement by positioning buttons precision matched with perforations in the panel surface, supporting easy replacement and access to the underfloor plenum.

A robust range of laminates is available from conductive and nonconductive static dissipative rubber and vinyl flooring to designed laminates, which creates unique and individual designs such as mosaics, inlaid company logos and more to make the workplace functional, comfortable and attractive. High pressure laminate (HPL) is mainly used in computer and equipment rooms.

**Underfloor HVAC System**

Underfloor HVAC system is designed to deliver task/ambient air, create an ideal environment and cope with the high churns in modern office buildings. The underfloor HVAC system should meet the following requirements:

- It shall provide flexible control on air volume and direction in individual workstations.
- It shall be easily and quickly reconfigured or relocated by non-professionals, and the reconfiguration can occur during regular working hours with minimum interruption to the affected department.
- The underfloor system should be dust-protected and maintained easily.
- The configurations have three basic approaches: pressurized plenum, zero-pressure plenum and ducted air supply. They may be combined in a particular project.

![Twist diffuser](Image)
![Adjustable diffuser](Image)
![Displacement diffuser](Image)
![Rotary twist diffuser](Image)

Source: Krantz Komponenten Company, Germany. Website: [www.krantz.de](http://www.krantz.de)

**Figure 6.4 Typical Floor-Based Air Outlets**

At present, a few floor mounted air outlets are available. Figure 6.4 presents the floor air outlets manufactured by the Krantz Komponenten Company, Germany. Figure 6.5 shows the typical models in the Australian practices. Swirl diffusers are used in
general offices for personal control of individual climate. Grilles are designed for computer and equipment rooms to allow higher cooling capacity. Fan air terminals, like swirl diffusers, are mainly adopted in general offices; however they are powered to draw conditioned air to the office space. For perimeter zones or printing rooms, fan coil units are also available to provide additional heating or cooling by treating a mixture of conditioned air from the floor plenum and air from the office spaces.

Underfloor PVD System

The underfloor PVD system is designed as a state-of-the-art solution to plug or unplug any of the components in the entire cable system from the panel board to the receptacle, and is also deemed as the most modular subsystem in RFS.

- The entire PVD system is prefabricated, delivered to the site and distributed on a floor-by-floor basis for easy installation. The PVD system shall house the type, quantity, and variety of circuits and receptacles needed for any conceivable engineering layout.
- The PVD system shall be easily and quickly reconfigured or relocated by non-professionals, and the reconfiguration can occur during regular working hours with minimum interruption to the affected department.

Different underfloor PVD practices are available in the world. The typical underfloor PVD module in the USA is the Tate PVD Module, which usually includes the main distribution box, zone distribution box, secondary distribution box, power extender cable, telecom extender cable as well as PVD servicenter (Tate, 2001), as shown in Figure 6.6. This system does not use cable trays and can easily support “plug and play”; however, the associated capital cost is relatively high.
The Australian practice is significantly different from the USA practice. The PVD system in the market involves 4 main parts: cables, conduits, cable trays and PVD servicenters, as shown in Figure 6.7.

Figure 6.7 Typical Underfloor PVD Components in the Australian Practices

The Australian practice is significantly different from the USA practice. The PVD system in the market involves 4 main parts: cables, conduits, cable trays and PVD servicenters, as shown in Figure 6.7.

Figure 6.6 Typical Underfloor PVD Components Used in USA

Source: Tate Access Floors Company, USA. Website: www.tateaccessfloors.com
6.5.1.2 Specifications of RFS Applications

The typical fitout environments in office buildings include general office spaces, computer/equipment rooms, lift lobby and dealing rooms, in which varying equipment loads, human density and foot traffic exist. The human-related working conditions such as air quality and temperature are also dissimilar in these environments. In particular, the lift lobby and dealing rooms have many characters in common. The specifications of RFS applications in office building scenarios are developed with three versions in conformity with the three particular environments.

**General Office Spaces**

For general office spaces, medium and heavy load performances are applicable. A medium load environment is a *general* office environment where people, workstations and normal office equipment occupy the space. The space is likely to be subject to *light* equipment loads, *normal levels* of foot traffic and *infrequent* rolling loads in the office corridors and aisleways. In comparison, heavy load performances may take place under special circumstances. A *heavy-duty* environment often experiences *high densities* of people and/or equipment occupying the space. The space is likely to be subject to *extreme levels* of foot traffic, *heavy* equipment loads and *frequent* rolling loads in the corridors and aisleways. By consolidation of the Australian local products and other similar products seen during the site observations, the load performance standards in general office spaces are summarized in Table 6.3.

<table>
<thead>
<tr>
<th>Load Level</th>
<th>Static Loads</th>
<th>Rolling Loads</th>
<th>Impact Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concentrated Load</td>
<td>Uniformly Distributed Load</td>
<td>Ultimate Load</td>
</tr>
<tr>
<td>Medium load</td>
<td>2.5~4.5kN</td>
<td>10~12kN/m²</td>
<td>9.0~15kN</td>
</tr>
<tr>
<td>Heavy load</td>
<td>4.5~6.0kN</td>
<td>12~15kN/m²</td>
<td>15~18kN</td>
</tr>
</tbody>
</table>

*Note:* Concentrated, ultimate and impact loads are applied on a 25mm×25mm point load. The same applies in the following two tables.

Some basic considerations for the main RFS components are provided as follows.

- **Panels.** Solid panels are generally used. Medium grade panels are used for the medium load office environments while heavy or extra heavy grade panels are used for the heavy load office environment.
• **Pedestals.** All pedestals can accept 22.5kN axial load without failure. Cornerlock method is normally used whereas freelay method is applied when requiring frequent and easy underfloor access.

• **Stringers.** Stringers are not necessary for the medium load office space but may be applied in the heavy load offices to add loading capacity and lateral stability.

• **Floor coverings.** PosiTile carpets are recommended for easy underfloor access.

• **Underfloor HVAC system.** Swirl diffusers and fan air terminals are recommended. Fan coil units may be needed in perimeter zones to cope with the external climate influences.

• **Underfloor PVD system.** The current under floor cable and wire distribution method in Australian construction industry is recommended. However, Tate PVD Modular system is preferred if budget permits.

### Computer and Equipment Rooms

For computer and equipment rooms, medium, heavy and extra heavy load performances may apply. Medium load performances are applicable in a small anti-static computer/equipment room where standard computer equipment occupies. The space is likely to be subject to medium-duty equipment loads, normal levels of foot traffic, and medium-duty infrequent rolling loads in the aisleways. Heavy load performances normally appear in an anti-static computer/equipment room where all types of computer equipment occupy. The space is likely to be subject to heavy equipment loads, normal levels of foot traffic and heavy infrequent rolling loads in the aisleways. Comparatively, extra heavy load performances take place in an extra heavy-duty anti-static computer/equipment room where all types of computer equipment occupy. The space is likely to be subject to severe equipment loads - static and dynamic, plus high levels of foot traffic and heavy frequent random path rolling loads in the aisleways. By consolidation of the data collected, the load performance standards in computer and equipment rooms are summarized in Table 6.4.

### Table 6.4 Load Performance Standards in Computer and Equipment Rooms

<table>
<thead>
<tr>
<th>Load Level</th>
<th>Static Loads</th>
<th>Rolling Loads</th>
<th>Impact Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concentrated Load</td>
<td>Uniformly Distributed Load</td>
<td>Ultimate Load</td>
</tr>
<tr>
<td>Medium load</td>
<td>3.0~4.0kN</td>
<td>8~12kN/m²</td>
<td>12~13.5kN</td>
</tr>
<tr>
<td>Heavy load</td>
<td>4.0~5.0kN</td>
<td>12~15kN/m²</td>
<td>13.5~16kN</td>
</tr>
<tr>
<td>Extra heavy load</td>
<td>5.0~7.0kN</td>
<td>15~18kN/m²</td>
<td>16~18kN</td>
</tr>
</tbody>
</table>
Some basic considerations for the main RFS components are provided as follows.

- **Panels.** Solid panels and ventilation panels are both generally used. Medium, heavy and extra heavy grade panels are used for the medium, heavy and extra heavy load computer and equipment rooms respectively.

- **Pedestals.** All pedestals can accept 22.5kN axial loads without failure.

- **Stringers.** Stringers are generally required to add loading capacity and lateral stability.

- **Floor coverings.** High pressure laminates or factory laminated carpet tiles are necessary.

- **Underfloor HVAC system.** Perforated or grate panels and grilles are recommended. Dampers may be applied to adjust air volumes.

- **Underfloor PVD system.** The Australian current cable and wire distribution method is recommended.

### Lift Lobby and Dealing Rooms

For the lift lobby and dealing rooms, medium and heavy load performances may apply. Medium load performances are applicable in a *heavy-duty* environment where a *high density* of people and/or equipment occupies. The space is likely to be subject to *extreme levels* of foot traffic, *heavy* equipment loads and *frequent* rolling loads in the corridors and aisleways. In comparison, heavy load performances take place in an *extra heavy-duty* environment where a *high density* of people and/or *heavy* equipment occupies. The space is likely to be subject to *severe levels* of foot traffic and *heavy* equipment loads, plus *frequent* rolling loads in the corridors and aisleways. By consolidation of the data collected, the load performance standards for lift lobby and dealing rooms are summarized in Table 6.5.

<table>
<thead>
<tr>
<th>Load Level</th>
<th>Static Loads</th>
<th>Rolling Loads</th>
<th>Impact Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concentrated Load</td>
<td>Uniformly Distributed Load</td>
<td>Ultimate Load</td>
</tr>
<tr>
<td>Medium load</td>
<td>4.5~5.5kN</td>
<td>12~15kN/m²</td>
<td>13~16kN</td>
</tr>
<tr>
<td>Heavy load</td>
<td>5.5~6.5kN</td>
<td>15~18kN/m²</td>
<td>16~18kN</td>
</tr>
</tbody>
</table>

Some basic considerations for the main RFS components are provided as follows.

- **Panels.** Solid panels are generally used. Medium and heavy grade panels are used for the medium and heavy load life lobby and dealing environments respectively.
• **Pedestals.** All pedestals can accept 22.5kN axial loads without failure. Cornerlock method is normally used whereas freelay method is applied when requiring frequent and easy underfloor access.

• **Stringers.** Stringers are not necessary for the medium load environment but may be applied in the heavy load environment to add loading capacity and lateral stability.

• **Floor coverings.** PosiTile carpets are recommended for easy underfloor access. High pressure laminates are also available for lift lobby areas.

• **Underfloor HVAC system.** Swirl diffusers and fan air terminals are recommended. Fan coil units may be needed in perimeter zones to cope with the external climate influence.

• **Underfloor PVD system.** The Australian current cable and wire distribution method is recommended. However, Tate PVD Modular system is preferred if budget permits.

### 6.5.2 Good Practices Associated with RFS Fitout Implementation

Many good practices of RFS fitout were discovered in the site observations, which covered the whole process of RFS implementation. To make this section succinct, typical good cases are illustrated with pictures. Some explanatory drawings and explanation to the pictures comprise the main contents of this section.

**Integrating RFS Features in the Building Structure Design**

Representing a good constructability practice, the integration of RFS features with the initial building structure design was explored in the new-built projects. One of the typical cases showed an innovative structure design to achieve smooth transition between general office spaces and lift lobby. In this project, a 300mm FFH RFS was used in the general office space while the lift lobby is kept as original concrete floor with marble facing. Figure 6.8 presents 3 views of the connection configuration.
The picture on the left shows the section view taken from the underfloor plenum, in which the RFS matched the level difference between the lift lobby slab and the general office space slab. The picture in the middle shows the smooth connection between the RFS surface in the general offices and the concrete floor with marble facing in the lift lobby. The last picture shows the structural configuration of the connection taken from the lift lobby on the next lower floor. Structurally, a further explanation is illustrated in Figure 6.9.

Recessing the general office space slab allows installation of a raised floor at the same level as surrounding floors, eliminating the need for ramps and steps. While this innovation is acknowledged by most industry practitioners, some researchers do not agree with it totally. They are concerned with the possible outdated building structural slab if RFS is not used in the future. Another case is shown in Figure 6.10, in which a similar structure consideration was implemented between the computer rooms and the adjacent areas.

**Transition Issues in Retrofit Projects**

Without embedding RFS features in the initial structure design, retrofit projects should encompass special arrangements to deal with the transition issues. In current
Australian practice, ramps and steps are commonly used to accommodate the transition requirements between different floor levels. Figure 6.11 shows three examples for the applications of steps and ramps. With a proper decoration of steps and ramps, occupants alike may not even recognize the transition among different floor levels in the building precincts.

Appropriate Design and Layout of Floor-Based Outlets

The design and layout of the floor-based outlet boxes significantly influence the achievement of RFS advantages. Two examples were identified for scrutinization. The first case is about the location of the floor-based air diffusers. With cool air coming out of them, the layout of air diffusers should be studied to avoid being located exactly under desks or close to the workers’ feet to prevent potential draughts or cold feet. Figure 6.12 illustrated both proper and improper diffuser locations in general office spaces. The two pictures on the left show the proper locations in which the diffusers are fixed around the desks to allow easy air adjustment. On the contrary, the right hand picture shows the improper location, in which the diffuser is put under the desk and close to workers’ feet. Bearing this consideration in mind in the initial design and layout of air diffusers, the office ergonomics can be enhanced.
Another example relates to the appropriate location of the floor-based outlets in the panels, as shown in Figure 6.13. The left picture shows that the PVD servicenter is located in the top left corner of the panel. Taken from the floor plenum, the right picture displays that the air diffuser is fixed along the left hand edge of the panel.

![Location of PVD Servicenter](image1) ![Location of Air Diffuser](image2)

**Figure 6.13 Appropriate Locations of Floor-Based Outlets in Panels**

The reason for fixing the outlets in this way is substantiated in Figure 6.14. Raised floors provide flexibility in changing the locations of the outlets. By installing the outlet in one of the four corners of the square panel, the panel can be rotated to provide four different locations of the box without additional costs. Specifically, for PVD supply, this arrangement of the outlets can support a flexible layout of the office equipment and furniture. For UAD, this kind of design can avoid putting the air diffusers directly under the desk or close to people’s feet.

![Location of PVD Servicenter](image3) ![Location of Air Diffuser](image4)

**Figure 6.14 Appropriate Locations of Floor-Based Outlets in Panels**

The current Australian practices normally use rectangular PVD boxes; however, it was reported by some contractors that round PVD boxes can allow easy-cutting and reduce installation costs. On the other hand, some consultants revealed that the floor outlets should be located in the middle of the panel which can reduce the panel loading capacity minimally.
Using Special Tools

Special tools are needed to support RFS installation and maintenance. Two examples are presented here. The first case is about the adoption of special tools for the installation of RFS. As per the construction specifications, the finished floor surface shall be level, not varying more than 1.6mm in 3 meter length or 3.2mm overall. With the naked eye, it is hard to achieve the required accuracy. Consequently, special tools are necessary to facilitate the installation.

Figure 6.15 presents the generally tools, laser planometer and aluminum level. The picture at the top left is the laser planometer, consisting of a Laserplane and a Level-eye. Located on a horizontal datum mark, the Laserplane sends laser signals out for reference. Mounted on a pedestal rod, the Level-eye is put on the panel’s top surface to receive the signals. The large picture on the right shows the mechanism of the laser planometer. The Level-eye has an indictor in the embedded LCD screen assessing the horizontal status of the panel. The picture in the bottom left is an aluminum level which is used in small areas to align a panel with its adjacent panels.

Figure 6.15 Special Tools for Installation of Raised Floor Panels

Figure 6.16 shows two pictures for a double cup suction panel lifter. When underfloor access is required, the panel lifter should be applied to uncover the panels.

Figure 6.16 Panel Lifter for Underfloor Access and Maintenance
**Good Design of Ambient and Task Lighting**

Task lighting is applied for desk work while ambient lighting is for traffic and communication. Separated from the task lighting, the innovative ambient lighting, without having to be fixed in the ceiling, can reduce or remove the ceiling space to allow room for UAD. Task lighting can be easily delivered by many desk-based lights. Ambient lighting can be provided with floor or wall-based lighting fixtures. Figure 6.17 demonstrates several typical task lighting and ambient lighting methods.

![Figure 6.17 Typical Task and Ambient Lighting Methods](image)

**Good Organization of RFS Construction Sites**

Good organization of construction sites is indispensable to achieve the quality of RFS fitout. Two reviews of site organizations were conducted; however, totally different site conditions were identified, as shown in Figure 6.18. The site in the right two pictures is better organized than that in the left picture. The well organized site shows a tidy construction scene. In conformity with the specifications, no heavy items were put on the top of finished raised floors. A large plastic film was used to cover the surface of finished areas to avoid unforeseen scratches on the panels.

![Figure 6.18 Comparison of RFS Construction Site Management](image)
It is almost unbelievable that the subcontractors for the two projects were the same raised floor installer. However, the sites were organized poles apart. This interesting story highlights the significance of project management to the RFS implementation.

As a conclusion, the above six examples describe the main findings relating to good practices of RFS fitout identified on the six sites observed. These good practices indicate that holistic integration of RFS design and construction, strict conformity with RFS specifications, as well as effective project management are essential for the success of RFS fitout projects.

### 6.5.3 Problems Associated with RFS Fitout Implementations

During the site observations, the researcher always kept an eye on the real problems and SIFs that had been identified from the previous interview survey. However, since the researcher was not involved in the initial planning of those projects being visited, only part of the recognized issues pertaining to RFS implementation could be explored. Since most of the issues have been discussed in the survey analysis, the overwhelming majority of the content in this section are pictures plus some subsidiary explanation.

**Excessive Cables and Wires**

Excessive cables and wires distributed in the limited underfloor space are one of the main causes for the problems associated with underfloor HVAC system. As shown in Figure 6.19, the bulky cables and wires were popularly identified in the computer and equipment rooms during the site visits, in which the cables and wires occupied nearly the whole section of the underfloor plenum.

![Figure 6.19 Excessive Cables and Wires in Underfloor Plenum](image)
**Ignorance of RFS Service Integration**

Two examples about the ignorance of RFS service integration are identified. The first case relates to the integration of RFS with the building structure while the second one pertains to the integration of RFS subsystems.

![Figure 6.20 Revision of Blowholes in the Wall Considering RFS Features](image)

Figure 6.20 outlines the revision of a blowhole design in the western wall of a RFS construction site. For the purpose of cooling the bulky cables and wires in the underfloor plenum through natural ventilation, consultants designed a big blowhole with 1000mm in length and 280mm in height in the external wall. However, during the installation, the duct connected to the blowhole was found to be too big to locate between two pedestals. As a result, the consultants had to change the big blowhole into two small blowholes, allowing appropriate space for the pedestals and also enough ventilation capacity for cooling purposes. Due to the revision and reconstruction of the blowholes, time and money were wasted, which proved that a poor design can lead to low construction productivity and cost overrun. For more information, the pictures of the revised blowholes are shown in Figure 6.21.

![Figure 6.21 Revised Blowholes in the Wall Considering Pedestal Locations](image)

Figure 6.21 Revised Blowholes in the Wall Considering Pedestal Locations

Figure 6.22 shows an apparent contradiction of locations among cable trays, underfloor fire safety pipes and pedestals. Due to a poor design or installation, the cable tray had to be cut to allow space for the pedestals, and the fire safety pipe was
Chapter 6: Site Observation and Focus Group Data Analysis and Findings

laid upon the cable trays. As a result, it is difficult to relocate the cable tray, cables and wires, and fire safety pipe in the future, which reduces the flexibility of RFS.

![Contradictions due to Poor Coordination among RFS Services](image)

**Figure 6.22 Contradictions due to Poor Coordination among RFS Services**

**Poor Installations of Panels and Pedestals**

As shown in Figure 6.23, the poor fixed panels normally result in uneven floor surface and poor connections with walls, which further generates squeaky noises and a feeling of instability when people are walking on panels. Without timely maintenance, panels may tend to be moving and showing deflection or distortion after a period of operation. In addition, if UAD is applied, an air leaking problem will arise. A picture showing a deflective pedestal is presented in the figure as well.

![Uneven floor surface due to poor installation](image)
![Poor connectivity between panels and walls](image)
![Deflective pedestal](image)

**Figure 6.23 Poor Installations of Raised Floor Panels and Pedestals**

**Additional Holes Drilling**

Additional holes were normally cut by occupants without the aid of special tools, creating mess. Moreover, owing to a lack of RFS knowledge, the locations and sizes of the holes were normally decided without considering the possible damage to the panel loading capacity. For all these reasons, stress concentration and distortion in
panels may appear, and underfloor air pressure may be unbalanced. Figure 6.24 presents three improper examples of the additional holes in computer rooms.

![Figure 6.24 Additional Holes Drilled Improperly Due to Poor Estimation](image)

**Dust and Debris**

Dust and debris were identified on the six sites, particularly on the two construction sites. As analyzed in Chapter 5, dust and debris are often produced in the construction process and remain in the floor plenum. The top three pictures in Figure 6.25 demonstrate dust and debris with the progress of different trades. Meanwhile, spots of dust and debris were identified in the plenum in some existing office building sites, as shown in the bottom three pictures.

![Dust and debris in the RFS installation](image)

![Dust and debris in the underfloor plenum during operation](image)

**Figure 6.25 Dust and Debris Identified from Site Observations**

**Construction without Conforming to Specifications**

Many cases without conforming to specifications are discovered on the construction sites, which might be due to contractors’ ignorance or lack of responsibility. Take dust and debris as an example. The general contractor managed the site poorly and
subcontractors might not remove it at the completion of their jobs. Two more cases are presented in Figure 6.26 to reveal the subcontractors’ unfamiliarity or lack of responsibility. The left picture shows that a worker was using a hammer to adjust the corner of a panel as it could not be locked on the pedestals properly. Panels are produced to specifications, so the above problem is the most possibly due to the inaccurate installation of the pedestal rather than poor panel quality. The adjusting of the panel corner is an improper solution under this scenario.

![Figure 6.26 Subcontractors’ Lack of Knowledge or Responsibility](image)

The second and third pictures show another improper arrangement when the installer met problems with the corner locking. The worker used a hammer to knock off the location lug in the pedestal head in order to avoid the match of the location lug and the hole in the panel corner. Without doubt, crushing floor panels into an improper space will result in problems in the later operation.

**Poor Subfloor Preparation before Construction**

As per the specifications, the subfloor must be rigid, dry, smooth, flat, level, sound, clean and free from harmful material. However, these regulations were not generally followed in those projects being observed. Figure 6.27 presents two epitomes of the unprepared subfloors. In the left picture, the subfloor was rough and full of concrete dust and debris. In the right picture, the subfloor is wet and dirty. The basic requirements of subfloor conditions were not followed generally, let alone other complicated installation specifications, such as temperature and lighting conditions.

![Figure 6.27 Messy Subfloor Condition before RFS Installation](image)
Failure of Panel Sealing
The panel sealing in general offices is very important because the personal control of workstation climate might be less efficient due to the air leaking everywhere. Some potential air leaking areas were identified, as shown in Figure 6.28. The left picture points to the interstices along the edges of panels in computer and equipment rooms, while the right one highlights the holes in the panels for the cable and wire distribution in general offices.

Problems with Carpet Tiles
Nonstandard layout of carpet tiles was generally found in office spaces and lounges, as presented in Figure 6.29. The top two pictures demonstrate a bad layout of carpet tiles along the boundary of panels and wall. The carpet in the top left picture was arched and the other one in the top right picture did not cover the boundary very well, both of which can cause trips or air leakage. The bottom left picture shows a big gap due to the poor inosculation between two carpet tiles, which can also put people in traffic danger. The bottom right picture was taken on a maintenance site. A lot of dust lies on the panel, which tends to result in carpet movement in the future.
In brief, many problems were identified through the investigations on the six office building sites. However, the problems are not limited to the aforementioned issues; many others are not presented here due to the thesis space limitation. These findings substantiate many of the real problems associated with the RFS implementation recognized in the interview survey.

6.6 Results of Focus Groups

Three focus groups were conducted in three of the four existing office building sites, i.e. the research institute office building, the commercial bank headquarters and the government office building. These sessions aimed to obtain respondents’ opinions on the problems associated with the RFS operations in their workplaces and at the same time, explore their impressions regarding RFS advantages.

Different numbers of members were involved in the focus groups. For the first session, 10 respondents were chosen from the employees for second level of the research institute office building. For the second session, 9 respondents were nominated from the general employees in the dealing rooms. For the third session, 7 respondents were engaged, including one facility manager and six general employees who were responsible for the operation of the computer and equipment rooms or who needed to visit this area frequently in their work. Each focus session lasted approximate 2 hours.

6.6.1 Problems in RFS Service Operation and Maintenance

Initially, the researcher planned to discuss the whole 15 recognized real problems and 20 SIFs factors with the focus group members. However, since the respondents were general employees, all the SIFs were not appropriate for them to answer. Therefore, only the 15 real problems were raised for discussion without informing the group members of the “major” or “minor” difference among these problems. The 15 issues are presented in Table 6.6 again in order to facilitate the interpretation.
During the three sessions, the group members were asked to select *agree* or *disagree* with the above recognized issues based on their experiences in their workstations and office buildings. Due to the limited time, the respondents were asked to choose the main problems they had encountered, and possibly gave succinct explanations to their decisions. The feedbacks from the 3 groups are summarized in Table 6.7, in which the response rate means the percentage of the respondents in each group agreeing with the particular problems. For example, the percentages of people in Group 1, 2 and 3 agreeing with Issue E1 are 50, 56 and 71 respectively.

### Table 6.7 Response Rates to Real Problems from Focus Groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>E6</th>
<th>E7</th>
<th>E8</th>
<th>E10</th>
<th>E11</th>
<th>E12</th>
<th>E13</th>
<th>E14</th>
<th>E15</th>
<th>E17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>50</td>
<td>50</td>
<td>40</td>
<td>80</td>
<td>10</td>
<td>30</td>
<td>10</td>
<td>20</td>
<td>40</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>Group 2</td>
<td>56</td>
<td>44</td>
<td>44</td>
<td>78</td>
<td>33</td>
<td>56</td>
<td>33</td>
<td>22</td>
<td>67</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>56</td>
<td>22</td>
</tr>
<tr>
<td>Group 3</td>
<td>71</td>
<td>86</td>
<td>86</td>
<td>71</td>
<td>0</td>
<td>14</td>
<td>43</td>
<td>0</td>
<td>100</td>
<td>57</td>
<td>29</td>
<td>7</td>
<td>29</td>
<td>43</td>
<td>0</td>
</tr>
</tbody>
</table>

In order to highlight the generally recognized problems, it is necessary to arrange the above statistic data in descending order as per their percentage values. Table 6.8 shows the re-arranged result. The issues with yellow background represent those problems with a response rate not less than 60% from the three groups individually. The issues with grey background indicate those problems with a response rate between 60% and 40%. The issues with cyan background outline those problems with a response rate less than 40%.
As per Table 6.8, 9 issues were highly recognized as problems among these groups with not less than 60% agreement. The 9 issues consist of 6 unrepeated issues, i.e. Issue E1-E4, E10 and E15. In comparison, a total of 24 issues were hardly perceived as problems with less than 40% agreement, and consist of 9 unrepeated issues, i.e. E5 - E8, E11-E14 and E17. In addition, 12 issues were moderate with agreement levels varying between 40% and 60%, and involved 8 unrepeated issues, i.e. E1-E3, E6, E7, E10, E11 and E15.

The above statistic results present a perfect coincidence that the 6 most highly recognized issues from the focus groups are exactly the 6 real major problems derived from the earlier interview, while the 9 lesser recognized issues are exactly the 9 real minor problems (referring to Table 5.14). This unbelievable match indicates that the interview findings on the 6 real major problems and 9 real minor problems are valid.

As far as the 8 moderately recognized issues are concerned, it might be worrying to find that 5 of them belong to the highly recognized group while the rest 3 issues fall into the less recognized group, which seems to be inconsistent with the findings in the above paragraph. However, this result is rational. In accordance with the respondents’ succinct explanations for their choices, the reason for this inconsistency is owing to the different experiences on different RFS applications in different office building environments. Combining the explanations and the RFS applications on the sites, a rationalization for the above perplex are interpreted as below.

- Issue E1 and E2 were not highly important in Group 1 and Group 2, because the respondents were general personnel lacking experience of the UAD problems and understanding of the possible causes.
• Issue E3 was not highly recognized in Group 1 and Group 2 mainly in respect that the respondents considered the UAD in the general office and dealing rooms rather than in the computer rooms. The air leaking mostly exists in the computer and equipment rooms where carpet tiles are not used and the airproof arrangement is not that effective.

• Issue E6 and E7 were well recognized in Group 2 and Group 3 respectively for the reasons that the considerations of connectivity were not integrated in the RFS fitout design although the connectivity is very important in these scenarios for business operations and computer room activities.

• Issue E10 was not highly identified in Group 1 because the research institute office building was designed with accurate estimations of the holes, perforated panels, grilles, etc.

• Issue E11 was well recognized in Group 3 due to the “bare” panels without carpet tiles. The panels in the computer rooms normally use high pressure laminate coverings, which are more inclined to generate noise when people are walking on them. However, most respondents in this group acknowledged that the walking noise in the general office spaces was not a big issue, neither was the noise associated with the underfloor HVAC in computer rooms.

• Issue E15 was not highly acknowledged in Group 2 and Group 3, probably because an annual cleaning of the underfloor plenum has been executed in the two buildings or the construction dust and debris was removed totally and the panel surface has been sealed tightly without any residue dust or debris.

6.6.2 RFS Fitout Advantages

The perceived RFS merits may include flexibility, ergonomics, fitout cost-saving, workplace productivity, time-saving, etc. However, only RFS enabled flexibility was highly acknowledged as per the questionnaire and interview feedback. Taking advantage of the focus groups, the researcher asked the participants to evaluate the advantages of RFS based on their daily occupancy in the RFS facilities.

Owing to the respondents’ characters as general employees rather than project managers or facility managers, it is impossible to get reliable answers with respect to
some of the perceived RFS advantages, such as fitout cost-saving and time-saving for construction. As occupants, the respondents are apt to evaluate those RFS advantages which can be experienced through a period using of these RFS facilities. As such, flexibility, ergonomics, time-saving for maintenance, and workplace productivity attributed to the RFS applications were explored.

**Flexibility**

Since the focus group members were the occupants of the RFS facilities, their opinions on flexibility mainly related to RFS operation and maintenance rather than construction. The feedbacks collected are analyzed and presented below.

- **Easy reconfiguration to accommodate task and ambient office space requirements.** The focus group in the government office building presented a compartment of two small meeting rooms from a large open-plan office space as an example. The compartmentation was completed quickly in a week. Owing to RFS flexibility, all they needed to do once the two spaces had been separated with plasterboards was adding PVD boxes and air diffusers in the floor panels.

- **Easy relocation of PVD outlets and air diffusers for minor reorganization in individual workstations.** This small relocation happened every two months in the three office buildings, which might take a long time and interrupt the normal office work in the traditional fitout method, however could be done in a few hours without the aid of professional workers in the RFS fitout environment.

- **Enough space to accommodate bulky cables and wires, particularly for dealing rooms and computer and equipment rooms.** This acknowledgement was proposed by most group members. With the appropriate height of the floor plenum, the cables and wires can be distributed easily.

- **Cost-saving and speedy retrofit for the whole space to meet market demands.** This idea was proposed by the employees in Group 2. Every 6 to 12 months, the bank needed to retrofit most of the facilities in the dealing rooms to create a fresh and friendly environment for their business purposes, attracting customers and upgrading technologies. With the RFS fitout, the whole space retrofit could be completed quickly and economically.

- **Easy access for the maintenance of underfloor services.** This is also acknowledged by most respondents in the three groups. Both the mechanical
services and the electrical services were mainly distributed in the floor plenum using RFS fitout, so the access to these services for maintenance is much more convenient than that to the overhead HVAC and power-pole methods.

Ergonomics
Office ergonomics study how to work in an office at ease and efficiently (Kroemer and Kroemer, 2001). According to this conception, respondents were advocated to recall the ergonomics in their workplaces owing to the use of RFS facilities. The focus groups’ feedbacks are presented below.

- **Better air quality.** A majority of respondents in Group 1 and Group 2 put forward that the air quality with UAD was better than that with the ceiling air system. The underfloor air seems to be fresher and healthier although there was not a scientific test to prove this impression. However, the lower illness and absenteeism can justify the improved air quality to some extent. They also mentioned that the floor diffusers need to be properly located to avoid draughts.

- **Enhanced thermal comfort to satisfy individual preferences.** A majority of respondents in Group 1 and Group 2 argued that what is of importance to the individual employee was not the whole office climate but the workstation climatic conditions within which one interacted directly. They all desired an individual microclimate that felt comfortable under given conditions of adaptation, clothing, work and individual preference. They agreed that the underfloor HVAC method largely improved personal control of individual workplace environment.

- **Orderliness and cleanliness in workplace.** Most respondents in all groups proposed that the RFS fitout delivered power and data through the PVD servicenters directly under the desks and hence reduced the exposition of cables and wires in the office spaces, which made the workplace more tidy and pleasing-to-eye. Furthermore, the danger of falls was minimized.

- **Comfortable ambient lighting minimizing glare.** Most respondents in Group 1 and Group 2 thought that the separation of task lighting from ambient lighting allowed individual adjustment of task lighting. Compared with the traditional ceiling lighting methods, the new lighting system could minimize glare and at the
same time reduce energy consumption since the task lighting for unattended
desks could be turned off.

• Accommodation of personal layout preference. A proportion of respondents both
in Group 1 and Group 3 stated that the RFS fitout supports a personal layout
preference of individual workstations. Due to the limitations of power points and
ceiling-based air diffusers, it was awkward to move computers, desks and other
furniture to meet personal preference. However, the RFS could satisfy these
requirements by simply relocating the floor-based PVD outlets and air diffusers.

The researcher also tried to explore the respondents’ opinions on the RFS
contribution to open communications. Most respondents proposed that this concept
was misunderstood indeed. They explained that it was the open-plan office style that
facilitated open communication in the general office space. In the traditional cellular
offices, communication between employees could only be reached through telephone
services or a long walk. In comparison, the open-plan office organization could
support mutual communications easily, even by gestures without actual
conversations. However, since most RFS applications took place in the open-plan
office environment, people took it for granted that RFS could contribute to open
communications.

**Time-saving**

Time-saving is demonstrated in the RFS construction and maintenance. The potential
time-saving in RFS construction was popularly recognized during the visit to the two
office building construction sites. With the benefit of a floor plenum for service
distribution, the installations of HVAC and PVD systems are conducted at the floor
level rather than at the ceiling level, avoiding the time for climbing ladders.
Furthermore, the concrete floor surface does not have to be screeded strictly in
conformity with the BCA requirements, because the pedestals can allow a degree of
adjustment to trade off the imperfect base surface. The time-saving for maintenance
was discussed in the groups. They generally argued that owing to the RFS endowed
flexibility, the maintenance activities such as workplace relocation, malfunction
servicing and technology upgrade, became much easier and took less time.

• Less time for workplace relocation and reconfiguration. Respondents in Group 1
and Group 2 agreed that the PVD servicenters and floor air diffusers could be
relocated easily to meet workplace changes. To add workstations in an open-plan space, the facility manager only needed to add a set of desks and chair and insert a couple of PVD servicenters and air diffusers in the floor panels. Compared with the traditional methods, it took less time to meet all these diverse requirements.

- **Less time for malfunction servicing.** All respondents agreed that raised floors allowed easy access to the underfloor services for breakdown or malfunction servicing. In comparison, the maintenance to the traditional ceiling-based services took longer time.

- **Less time for technology upgrades.** Most members argued that as what happened to the malfunction servicing, the same rationale was applied to technology upgrades that always involve more work than the malfunction servicing. For example, the upgrade of Lan cables was much easier to do in the floor plenum; however, the traditional fitout needed to take time to consider appropriate space and aesthetic issues for the new cable distribution in the workplace.

### Workplace Productivity

The RFS contribution to workplace productivity was explored in the focus groups even though the researcher understood the low possibility of acquiring a specific value to quantify the improvement rate. The respondents provided the following evidence to show the enhancement of workplace productivity owing to the deployment of RFS.

- **Less absenteeism.** Most respondents said that they were more unlikely to fall sick in the new workplace, in which a healthier environment could be achieved with fresh supply air, better thermal comfort, less lighting glare, etc. As a result, the absenteeism due to illness was reduced.

- **Less interruption from maintenance or relocation.** Most respondents agreed that they had less interruption from the normal office maintenance or minor relocation in the new office. They pointed out that the RFS endowed flexibility could facilitate the maintenance and relocation speedy and reduce major interruption.

- **Longer time concentration on works.** Most respondents revealed that they could concentrate on their works for a longer time probably owing to the better office environment and less interruption.
• **Good feeling during work.** Some respondents stated that they felt good during their work because they believed that RFS enabled environment was healthy and reliable. The good feeling could enhance their work productivity.

### 6.7 Findings of Site Observations and Focus Groups

Through the site observations and focus groups, much first hand data such as pictures, documents and feedbacks were studied, which lead to the following findings in conformity with the purposes of the site observations and focus groups.

**Finding 1: RFS products and application specifications were developed**

The questionnaire outlines that most industry practitioners were not familiar with RFS and its components, as well as RFS specifications. Through the visit to the Australian raised floor company and investigations of the four existing office building sites and two office building construction sites, much data regarding RFS product classifications and features and RFS application performance standards was gained. With a holistic comparison and consolidation, the specifications of RFS products and applications in office building environments were developed. Particularly, the product specifications for panels, understructures, floor coverings, underfloor HVAC system and PVD system were formulated. Meanwhile, the application specifications for the typical office building environments, i.e. general office spaces, computer and equipment rooms, as well as lift-lobby and dealing rooms, were generalized.

**Finding 2: Many good practices pertaining to RFS integration and constructability can facilitate RFS implementation**

Since many problems arose in the RFS implementation, the exploration of good practices pertaining to RFS integration and constructability is significant. The site observations highlighted many typical cases for improving RFS integration and constructability, which largely improved RFS implementation in these projects. For example, the integration of RFS features in the structure design in a new office building can help to facilitate a smooth connection between the general office spaces and lift lobby. The above presented cases are just part of the good practices identified
on sites. Recording and introducing these good practices to the industry and encouraging the practitioners to apply them in real projects is important for RFS implementation in Australia.

Finding 3: Many problems pertaining to RFS implementation were identified, which substantiate the SIFs and real problems

The site observations identified a range of problems pertaining to RFS implementation, i.e. excessive cables and wires, ignorance of RFS service integration, poor installation of panels and pedestals, additional holes drilling, dust and debris, construction without conforming to specifications, poor subfloor preparation before installation, failure of panel sealing, as well as problems with carpet tiles. These problems together with many unidentified problems will reduce the RFS construction quality and retard the utilization of RFS advantages in the post-construction stage. In view of the interview findings, these problems are actually due to improper arrangements of particular SIFs and may result in real problems in the RFS service operation and maintenance, as shown in Table 6.9.

For example, excessive cables and wires might be due to three reasons. Architects and engineers’ incompetency in the design of underfloor PVD system can result in irrational cable and wire distribution; space volume limitation may not allow a enough FFH to accommodate the cables and wires; contractors may distribute the cables and wires in breach of the design and specification. As a result, the excessive cables and wires may lead to uneven air distribution, hot spots, draughts, etc.

Due to the limited number of site observations, only the above 9 major problems were identified and many other problems exist but are not recognized. Accordingly, the listed SIFs and real problems in Table 6.9 are just part of the 20 SIFs and 15 real problems concluded in the interview. However, the above alignment, to a large extent, substantiates the validity of the SIFs and real problems.
Problems observed | SIFs | Real problems
--- | --- | ---
Excessive cables and wires | Architects & engineers’ incompetency; Space volume limitation; Contractors’ incompetency. | Uneven air distribution,; Hot spots; Draught.
Ignorance of RFS service integration | Architects & engineers’ incompetency; Poor design influence on construction. | Inconvenient underfloor access; Uneven air distribution.
Poor installation of raised floor panels and pedestals | Contractors’ incompetency; Poor design influence on construction. | Uneven raised floor surface; Poor floor connectivity; Panel moving.
Additional holes drilling | Architects & engineers’ incompetency; Ignorance of RFS implementation. | Breakdown due to holes; Air leaking; Dust.
Dust and debris | Contractors incompetency; Ignorance of RFS implementation. | Dust.
Construction without conforming to specifications | Contractors incompetency; Structural irregularity. | Panel moving; Poor panel & wall connectivity; Panel distortion.
Poor subfloor preparation before installation | Contractors’ incompetency. | Panel moving; Uneven raised floor surface; Poor panel & wall connectivity.
Failure of panel sealing | Architects & engineers’ incompetency; Contractors’ incompetency. | Air leaking; Trip hazard.
Problems in carpet tiles | Architects & engineers’ incompetency; Transition difficulties. | Trip hazard; Air leaking.

Finding 4: RFS can improve workplace flexibility, ergonomics and productivity, and reduce time for construction and maintenance

Through the focus groups with the occupants, many RFS advantages were confirmed by their daily RFS practice. Flexibility was demonstrated by easy reconfiguration to accommodate task and ambient office space requirements, easy relocation of PVD outlets and air diffusers for minor reorganizations, enough space to accommodate bulky cables and wires, cost-saving and speedy retrofit for the whole space to meet market demands, and easy access for the maintenance of underfloor services, etc. Office ergonomics was illustrated by better air quality, enhanced thermal comfort to satisfy individual preferences, orderliness and cleanliness in the workplace, comfortable ambient lighting minimizing glare, personal layout preference, etc. Workplace productivity was indicated by less absenteeism, less interruption due to
maintenance or relocation, ability to improve long time concentration and a good
feeling during work, etc. Time-saving for construction was demonstrated by many
cases in the two office building construction sits while time-saving for maintenance
was justified by less time for workplace relocation/reconfiguration, malfunction
servicing and technology upgrades. Since the focus group members were occupants,
the perceived RFS advantages in terms of cost could not be explored, which will be
discussed in the next chapter.

Finding 5: The interview survey findings are reliable and valid
Validation of the interview survey findings is one of the main purposes of site
observations and focus groups. The previous research highlighted 20 significant
influence factors pertaining to RFS fitout planning and 15 real problems associated
with RFS service operation and maintenance, through a series of comprehensive
interviews.

The site observations identified 9 problems associated with the RFS applications on
the existing office buildings and construction sites, which resulted from the 20 SIFs
and would result in problems in RFS service performance. On the other hand, the
focus groups, through discussion with RFS occupants, identified 6 highly recognized
problems and 9 lesser recognized problems in the RFS post construction stages. This
result is in a high coincidence with the 6 major problems and 9 minor problems
concluded by the interview survey.

The data obtained through observations of events as they normally occur are
generally more reliable and free from respondent bias; the opinions from focus group
members who are occupants of RFS facilities are reliable. Based on the above
justifications, a conclusion can be reached that the interview findings with respect to
the 20 SIFs and 15 real problems are reliable and valid.

6.8 Summary

Following the interview survey, site observations were conducted at the raised floor
company, 4 existing office building sites and 2 office building construction sites.
Through the site observations, the RFS product specifications and application specifications were developed; the good practice about RFS integration and constructability were explored; many problems associated with RFS implementation were identified on sites. In addition, three focus groups were undertaken to substantiate the real problems recognized by the interview survey and justify the RFS advantages for office building fitout. Based on the above findings, a conclusion as to the reliability and validity of interview survey results can be reached.

The next chapter will discuss the LCC comparison between RFS and traditional fitout method.
CHAPTER 7
LIFE CYCLE COST COMPARISON

7.1 Introduction

Most benefits enabled by RFS fitout such as flexibility, ergonomics, time-saving and improved workplace productivity have been explored in the survey and justified in the site observations and focus groups. The cost benefit of RFS fitout was also explored in the survey but a consensus was not reached. While Chapter 3 highlighted the importance and mechanism for probing into the cost respects of RFS, this chapter provides detailed comparison between RFS fitout and the traditional fitout method.

As indicated by the survey, cost was one of the most significant issues hindering the RFS implementation in the Australian construction industry. The initial capital cost of RFS is the first concern perceived by most owners and developers. Due to a general scarcity of knowledge and experience in RFS and its applications, most industry practitioners assume that RFS have a remarkably higher capital cost than the traditional office fitout methods. On the other hand, even though they can accept a higher capital cost, they are still suspicious of the possible running cost benefits brought by the new facilities. In addition, there is considerable evidence to indicate that many organizations, both in the private and public sectors, make acquisitions of building assets simply on the basis of initial capital cost (Woodward, 1997; Green and Moss, 1998; Clift and Bourke, 1999). The low recognition of building whole-life costs stop owners and developers considering the user of RFS fitout in their projects.

As many interviewees revealed, the Australian construction industry is a totally cost driven market. Without evident cost benefits, owners, developer and occupants are
unlikely to take the plunge and use RFS to substitute the traditional fitout method that they are more familiar with. Based on this understanding, a LCC comparison between the RFS fitout and the traditional fitout method is necessary in order to explore the reality of RFS cost pros and cons. This chapter first introduces the main differences between RFS and traditional fitout method, then puts forward the construction process of the LCC comparison model, and finally presents a case study to compare the cost issues between the two fitout methods.

### 7.2 Main Differences between RFS and Traditional Fitout Method

Generally speaking, the services in modern office buildings include HVAC system, PVD distribution system, lighting system, fire protection system, vertical transport system, water supply system, etc. (Parlour, 1997). The fitout work in an office building environment involves most of these services. However, in comparison with the traditional fitout method, RFS fitout mainly distinguishes itself in the design and distribution of the PVD system and the HVAC system.

#### 7.2.1 PVD Services

As described in Chapter 2, the traditional practice uses power-pole or poke-through methods for the cable and wire distribution horizontally and vertically. The power-pole method uses conduits to run cable and wire to each workstation with sockets embedded in walls, partitions or furniture, while the poke-through method normally takes advantage of furniture to supply the power and data or embeds receptacles in the concrete floor slab. Both methods can use ducted skirting for cable and wire distribution. The traditional cabling and wiring method can meet basic office PVD requirements but cannot provide the office space with flexibility to accommodate the PVD relocation and future technology upgrades economically and speedy.

In comparison, the RFS fitout creates an underfloor plenum for cable and wire distribution. Rather than being embedded in the concrete slab, the RFS run cables and wires directly from the building core area through the floor plenum to the PVD servicenters fixed in the raised floor panels in each workstation. This method
distinguishes itself from the traditional method in the following two aspects. Firstly, cables and wires are neither fixed in the concrete slab nor attached to the soffit of the upper slab and hence can be moved or re-laid easily. Secondly, the PVD boxes fixed in the panels can be unplugged easily for relocation, which is demonstrated in Chapter 6. In addition, since the installation of cabling and wiring is conducted at the floor level rather than in the ceiling and at high wall level, the labour cost can be reduced significantly. Last but not least, the material cost might be reduced since power poles are eliminated and fewer cables and wires are required in the rooms.

7.2.2 HVAC Services

The overhead air conditioning system is popularly used in the traditional fitout environment. Depending on the air conditioning systems, cool air or chilled water is supplied from the plant rooms in the building core through ductworks or piping in the ceiling to the diffusers or fan coils units fixed in the overhead place of each office. Reversely, the size of the air conditioned space, ceiling space and plant rooms also influence the selection of the mechanism of the air conditioning system, which can be single-duct or dual-duct, variable air temperature or variable air volume, or a combination. The single-duct variable air volume system (SDVAV) has become the standard for office buildings because of its economy and controllability when applied to rooms of similar use for comfortable air conditioning purposes (Chadderton, 1997).

In the RFS environment, both underfloor HVAC system and ceiling-based HVAC system are used. In the interests of improving workplace comfort and economy, the underfloor air system is recommended for its potential merits as mentioned in Chapter 2. The underfloor HVAC system is similar to the conventional overhead system in the types of equipment used at the cooling and heating plants as well as primary air handling units. Key differences arise with the underfloor HVAC system in the use of an underfloor air supply plenum, localized air distribution and the resulting floor-to-ceiling air flow pattern and the solutions used for perimeter zones (Webster et al., 2002). As a result, the ductwork for air delivery can be minimized with the employment of the floor plenum; the supply air temperature can be higher contributing to a reduced capacity of the primary AHU, a smaller size of fan, etc. In consequence, the capital cost for underfloor HVAC system can be reduced. Again,
since the installations of the equipment pertaining to the two different HVAC systems are performed at different space levels, different installation costs may apply.

7.3 Assumptions for the LCC Comparison Model

Life cycle costing techniques depend heavily on forecasts about the future. Some of the forecasts will be no more than expert judgement, best guesses or hunches (Flanagan et al., 1989). With this understanding, a few factors need to be addressed before conducting the LCC comparison between RFS and traditional fitout method.

7.3.1 RFS Fitout Scenario and Areas

RFS can be used in new buildings where RFS features can be integrated with the design and construction of the initial building structures or in retrofit buildings where RFS is needed to adapt the existing building structures, as described in Chapter 5 and 6. In this model, an existing floor plate without any services is the RFS fitout scenario, which is neutralization between new buildings and retrofit buildings. This assumption is made for the following two reasons. Firstly, RFS fitout has a big potential market in both new and retrofit office buildings. Secondly, as per the interview feedback, most owners and developers may be persuaded to try RFS, but they are unwilling to build structure incorporating RFS features, such as lower floor-to-floor heights and higher window frames. Although some researchers have claimed the structure reduction up to 10% in floor-to-floor height owing to the employment of RFS and UAD (Ellison and Ramsey, 1989; Bauman, 1999; Reitz, 2002), most owners and developers alike are not willing to bear the risk of their building structures being outmoded in the future due to the “fool” incorporation of RFS features in the initial structure design.

7.3.2 Owner Occupied Office Building Space

Office buildings are generally developed for two purposes, i.e. speculative developments and owner self occupancy. From a speculative developer’s point of view, making money fast, selling the building profitably and attracting potential
tenants are goals. Accordingly, Internal Rate of Return, Return on Investment, Net Operating Income, Cash Flow and Market Value of the Property are important figures to consider when making decisions to invest in equipment in the building. For owner occupied buildings, low running cost, high retained value of building, better work environment, and improved workplace productivity are targeted. Therefore, IRR, Net Present Value (NPV) or the payback period will be figures used to justify an investment.

Considering that this research aims to explore the RFS advantages such as cost benefits and improved workplace productivity rather than higher rentals and profits, the LCC comparison model will be focused on owner occupied office buildings.

7.3.3 Appointment of Traditional Fitout Method

As aforementioned, the main differences between RFS and traditional fitout method lie on the HVAC and PVD distributions. The traditional fitout approach uses a variety of methods to accommodate the two services. To facilitate the LCC comparison, specific HVAC and PVD systems need to be defined in advance. In the case study presented later in this chapter, the ceiling-based single duct VAV air conditioning system and the power-pole cable and wire distribution are perceived as representative of the traditional fitout method.

7.3.4 Selection of LCC Comparison Model

A variety of LCC models are available for different purposes (Dhillon, 1989; Griffin, 1993). In this research, two methods are applicable to build the cost comparison model. The first method is a complicated one. After calculating the capital cost of each element in the fitout, the model sums up the total capital costs and the running costs in a given life cycle pertaining to both fitout methods, then reaches two NPV values after considering time value of money, and finally compares the two values to judge the cost benefits of RFS fitout. The second method is more focused on the differences between the two fitout methods. It first identifies the main differences in the initial capital cost elements and running cost elements pertaining to the two fitout
methods, then calculates the cost differences, and finally considers time value of money to reach the total NPV of cost differences.

The first model is complete but too complicated, and does not expose the main elements with different capital costs and the running costs between the two fitout methods. The second model is simple but robust, so it is chosen as the prototype of the LCC comparison model.

### 7.3.5 Discount Rate, Taxation and Life Term

Discounting and inflation are both used to recognize the time value of money. For a given period, the interest rate and inflation rate are supposed to be constant. Then, a modified factor known as nominal discount rate (ndr) is gained, as shown in the Equation (7-1).

\[
 r = \left[ \frac{1+r_1}{1+r_2} \right] - 1 
\]  

(7-1)

Where,  
- \( r \) = nominal discount rate;  
- \( r_1 \) = interest rate;  
- \( r_2 \) = inflation rate.

The time value of money is considered during the calculation of NPV in the case study presented later in this chapter; however, it is embedded in the NPV of each cost element in the subsequent LCC comparison model.

Through consulting manufacturers and consultants, the typical functional life of raised floors is 25 years and that of the floor swirl diffusers is more than 10 years. Based on this understanding, a 10-year life term is considered for calculation purposes although the RFS products still work after this time. As to taxation, accelerated depreciation is not considered for RFS products in Australia. Accordingly, the taxation benefit is not considered in the LCC comparison model.
### 7.4 Elements of Life Cycle Costing

Following the structural work, the office fitout starts and employs a variety of trades, such as HVAC installation, PVD distribution, ceiling finish, wall partition, lighting, fire protection, etc. For owner occupied buildings, the fitout work is all the owners’ responsibility, which avoids the quarrels or negotiations usually happening between developers and tenants.

A life cycle costing must, by definition, consider all aspects of project work from cradle to grave (Griffin, 1993). Particularly, three major costs elements are generally considered, i.e. capital costs, running costs and disposal costs. However, since the LCC comparison model described here mainly aims to study the cost differences between the RFS and the traditional fitout method in a given period which is much less than the project life cycle, the disposal cost is not considered.

The complexity of the LCC model largely depends on the amount of information. The more details of the design and operation are available, the more specific the life cycle costing can be made (Cole and Sterner, 2000). On the other hand, the real elements adopted in a model must service the comparison purpose. There is little point to build a complex model taking into account of all the cost details in a building life cycle. Only the elements among the feasible options which may lead to different costs are worth being reckoned in the LCC comparison model.

#### 7.4.1 Initial Capital Cost Differences

The initial capital costs for office fitout include raised floor, HVAC, PVD, floor covering, ceiling finish, lighting, furniture and equipment costs, etc. However, it makes sense that only those items that change along with the fitout methods are considered and other items that remain the same are not taken into account in the cost model. Under this prerequisite, the possible fitout cost difference relates to the raised floor, HVAC, PVD, floor covering, underfloor fire safety and acoustic baffle, and ceiling finish. On the other hand, since the RFS fitout may reduce the fitout time and allow earlier occupancy, the resultant rental saving are counted as well.
Raised Floor Related Cost Difference
Raised floors consist of floor panels, understructures and accessories. Compared with the traditional fitout method, the investment on raised floors is apparently an additional cost, which may apply in the following areas:

- Additional raised floor material cost;
- Additional raised floor installation cost;
- Cost saving due to being exempt from the concrete subfloor screeding.

HVAC Related Cost Difference
The difference between underfloor and overhead HVAC systems has been explored previously. Due to these dissimilarities in equipment distribution and system configuration, the capital cost saving of RFS fitout may apply in the following areas:

- Cost saving in the purchase of HVAC equipment (e.g. chiller, AHU, fans, etc.);
- Cost saving due to easy and safe HVAC installation.

PVD Related Cost Difference
The underfloor PVD distribution is different to the traditional power-pole or poke-through method in many aspects. The outlets, cables and wires fixed in the walls and/or the unsightly power poles can be completely eliminated with the application of the underfloor PVD system using the current Australian practice. Accordingly, the capital cost differences may apply in the following areas:

- Cost difference in the purchase of the PVD material – distribution horizontally (e.g. cables and wires, conduits, trays, etc.);
- Cost difference in the purchase of the PVD material – distribution in workstations (e.g. cables and wires, PVD servicenters, outlets, etc.);
- Cost saving due to easy and safe installation work.

Floor Covering Related Cost Difference
Floor coverings for the general office areas in both RFS fitout and traditional fitout environments are carpet tiles. However, due to different size and model, the capital cost difference may apply in the following areas:

- Cost difference in the purchase of carpet tile material;
- Cost difference due to different installation work.
Chapter 7: Life Cycle Cost Comparison

**Underfloor Fire Safety Related Cost Difference**
As analyzed in Chapter 5, if the floor plenum height is more than 200mm, smoker detectors and smoke dividers are recommended; if the height is more than 400mm, fire sprinklers are mandatory. These will lead to additional cost for RFS applications.

**Underfloor Acoustic Baffle Related Cost Difference**
Although the possibility of voice transmission through the floor plenum is very low (Sodec and Craig, 1991), consultants advised to use acoustic baffles in order to minimize sound and noise transmission between adjacent office rooms. This will lead to additional cost.

**Ceiling Finish Related Cost Saving**
With the integration of underfloor HVAC system in the RFS fitout, some researches indicate that the ceiling space can be reduced, partly removed or totally removed (Tate, 2003; AET, 2004). Accordingly, the false ceiling can be partly or totally remove in the RFS fitout environment, which may reduce ceiling finishing cost. The soffit of the upper slab can be decorated with cheap plaster or paint. Similarly, the installation cost for the ceiling finish can be reduced.

**Earlier Owner Occupancy Saving**
Unlike the delivery of traditional HVAC system and PVD system in the ceiling space, most of the fitout activities in the RFS environment are carried out at the floor level. As such, the fitout time can largely be shortened. As per Tate (2001), the fitout time for RFS project can be at least 15% less than that for the traditional fitout approach. This early completion can allow earlier owner occupancy, which contributes to a rental saving or a rental income.

**7.4.2 Running Cost Differences**
As per Griffin (1993) and AET (2004), the running cost will account for up to 80% of the total LCC of a project, which indicates the importance at the initial concept, design and authorization stage of a project in considering the resources needed for its life long operation. However, all too often, a building authorization has been largely...
based on the first cost, and owners or developers pay scant attention to their own or their successor’s future cash flow. In this regard, the importance of running cost comparison between RFS fitout method and the conventional fitout method is projected. Again, only the possible running cost differences are considered in the construction of the LCC comparison model. As per York (1992), Tasman (1996), Reitz (2002) and Partridge (2003), the possible running cost differences between RFS and traditional fitout method can be originated from the following aspects.

**Churn Related Cost Saving**
With the reference to the literature review, office churns result in a high running cost. The office churns cover a range of occasions from individual staff relocations to whole organizations move-in and -out. This study focuses on secondary and tertiary churn in terms of internal moves and reconfigurations (Ballesty, 2002); rather than primary churn which includes organizational relocation and new facilities construction. In addition, since the model studies owner occupied buildings, it is confirmed that only the workplace reorganization churn is studied, which further direct to the PVD and HVAC relocations. In consequence, the office churn related cost saving may include the following two items:
- PVD churn related cost saving;
- HVAC churn related cost saving.

**Reduced Energy Consumption Benefit**
Due to the merits of underfloor HVAC system, the RFS fitout method is believed to be more economic in energy consumption than the conventional fitout method. According to Wright (1996), Bauman and Webster (2001) and Terranova (2001), the underfloor HVAC system can deliver supply air with a higher temperature, decreased central fan size, as well as unused space not being air-conditioned. Furthermore, some systems allow overnight thermal mass pre-cooling, in which both the panels and the concrete subfloor slab regulate the supply air temperature and as a result, the peak cooling requirements are reduced.

According to Bauman and Arens (1996), the cooling energy saving brought by the UAD can be 15% owing to the reduction in the chiller energy consumption. The supply fan energy use in pressurized UAD operating at an average of 70% of
capacity will have a reduction of energy of 45%. As to the thermal mass, depending on the external climate, the pre-cooling can lower peak summer demand up to 40%.

**Reduced Absenteeism Benefit**

As analyzed in Chapter 2, the UAD allows individual control of the workstation climate and improves air quality, which can accommodate different preferences of thermal comfort at large and supply fresh air to the occupied zone directly. Owing to these benefits, the indoor air quality can be largely improved and the sick building syndrome (SBS) be reduced significantly. Tate (2001) indicates that the enhanced air quality can reduce the employee absenteeism by up to 30%.

**Improved Workplace Productivity Benefit**

As the workplace environment is improved due to the use of RFS services, Kroner *et al.* (1992) and Wyon (1996) reveal that the improved workplace productivity rate owing to the enhanced workplace environment can be 3-7%. Since 90% of a company’s annual costs are attributed to salary costs, increasing employee’s productivity by as little as 3% can have a cumulative value over the life time of the building (Bauman, 1999)

**Cleaning Cost Difference**

To ensure the supply air quality, the underfloor plenum, the floor-based swirl diffusers, fan powered diffusers, fan coil units, etc. need to be cleaned regularly. According to the interview survey, most of the RFS occupants with underfloor HVAC application did a whole cleaning of the floor plenum and diffusers annually although a standard regulation in this regard has not been established in the Australian industry yet. Compared with the overhead HVAC system, the cleaning work for the underfloor air system might be more onerous without the application of ducting work for air distribution, which will lead to additional maintenance costs.

**7.5 Life Cycle Cost Comparison Model**

RFS and traditional method are studied individually for the fitout of a presumed existing floor plate. Based on the cost elements analyzed above, a LCC comparison
model is set up by comparing the running cost differences to the capital cost differences. Then, the payback time and NPV of cost differences over a given life cycle are studied to reveal the LCC benefit of RFS fitout.

### 7.5.1 Initial Capital Cost Differences

The above discussions outlined 8 main elements for the capital cost difference comparisons. An estimation of the cost difference in each element is worked out based on the data obtained from real project and reasonable assumptions. The total initial capital cost difference is found by summing up all the cost differences of all elements. Then, the total initial capital cost difference is calculated by Equation (7-2).

\[
NPV_{\text{diff-cap}} = \sum_{i=1}^{8} NPV_{\text{cap-i}} = NPV_{\text{diff-rf}} + NPV_{\text{diff-hvac}} + NPV_{\text{diff-pvd}} + NPV_{\text{diff-fc}} + NPV_{\text{diff-fs}} + NPV_{\text{diff-ab}} + NPV_{\text{diff-cf}} + NPV_{\text{diff-oc}}
\]

Where,  
\( NPV_{\text{diff-cap}} = NPV \) of the initial capital cost difference;  
\( NPV_{\text{cap-i}} = NPV \) of the element \( i \) capital cost difference;  
\( NPV_{\text{diff-rf}} = NPV \) of the raised floor related cost difference;  
\( NPV_{\text{diff-hvac}} = NPV \) of the HVAC related cost difference;  
\( NPV_{\text{diff-pvd}} = NPV \) of the PVD related cost difference;  
\( NPV_{\text{diff-fs}} = NPV \) of the underfloor fire safety related cost difference;  
\( NPV_{\text{diff-cf}} = NPV \) of the floor covering related cost difference;  
\( NPV_{\text{diff-oc}} = NPV \) of the underfloor acoustic baffle related cost difference;  
\( NPV_{\text{diff-cf}} = NPV \) of the ceiling finish cost difference;  
\( NPV_{\text{diff-oc}} = NPV \) of the early occupancy cost difference.

If the fitout work can be finished in a short term and the start point for considering the time value of money starts from the completion of fitout, the NPV consideration will not be applicable to the initial capital cost difference.
7.5.2 Running Cost Differences

The competitive benefits of RFS on the running cost are essential for its potential substitution for the traditional fitout method. The above discussions highlighted 6 main elements for the running cost difference comparisons between the two fitout methods. Based on reasonable assumptions, the running cost differences for each of the 6 elements are estimated and then added up to reach the total running cost differences. Then, the total running cost difference is calculated by Equation (7-3).

\[ NPV_{\text{diff-run}} = \sum_{j=1}^{6} NPV_{\text{run-j}} \]

\[ = NPV_{\text{diff-pvd}} + NPV_{\text{diff-hvac}} + NPV_{\text{diff-ene}} + NPV_{\text{diff-abs}} + NPV_{\text{diff-pro}} + NPV_{\text{diff-cle}} \]  

(7-3)

Where, \( NPV_{\text{diff-run}} \) = NPV of the running cost difference;
\( NPV_{\text{run-j}} \) = NPV of the element \( j \) running cost difference;
\( NPV_{\text{diff-pvd}} \) = NPV of the PVD churn related cost difference;
\( NPV_{\text{diff-hvac}} \) = NPV of the HVAC churn related cost difference;
\( NPV_{\text{diff-ene}} \) = NPV of the reduced energy consumption benefit;
\( NPV_{\text{diff-abs}} \) = NPV of the reduced absenteeism benefit;
\( NPV_{\text{diff-pro}} \) = NPV of the workplace productivity benefit;
\( NPV_{\text{diff-cle}} \) = NPV of the cleaning cost difference.

An alternative way to calculate the total running cost difference is based on the annual running cost difference that can be calculated separately. The total running cost difference in the given life cycle is reached by adding the annual running cost difference together, which is indicated by Equation (7-4).

\[ NPV_{\text{diff-run}} = \sum_{k=1}^{n} NPV_{\text{run-k}} \]  

(7-4)

Where, \( n \) = the counted life term of the project;
\( NPV_{\text{run-k}} \) = NPV of the running cost difference in year \( k \).
7.5.3 LCC Comparison Model

With the support of the above discussed calculations of the initial capital cost difference and the running cost difference, the total LCC differences can be worked out by adding them together, as shown in the following Equation (7-5).

\[
NPV_{\text{diff}} = NPV_{\text{diff-cap}} + NPV_{\text{diff-run}}
\]

\[
= \sum_{i=1}^{8} NPV_{\text{cap}-i} + \sum_{j=1}^{6} NPV_{\text{run}-j}
\]

or

\[
NPV_{\text{diff}} = NPV_{\text{diff-cap}} + NPV_{\text{diff-run}}
\]

\[
= \sum_{i=1}^{8} NPV_{\text{cap}-i} + \sum_{k=1}^{n} NPV_{\text{run}-k}
\]

(7-6)

Where, \( NPV_{\text{diff}} \) = NPV of the total LCC differences between the two fitout methods.

As far as the payback time is concerned, there are two methods to calculate the return period of the additional investment, i.e. static payback time and a dynamic one. In this research, the dynamic payback method is chosen. When the NPV of the LCC comes to zero, the corresponding time will be assumed as the payback time. Given a life term, the corresponding NPV of LCC difference can be reached as per Equation (7-5) or (7-6), which is the cost benefit brought by the RFS fitout.

7.6 A Case Study of LCC Comparison

An office retrofit project was envisioned in the School of Construction Management and Property, QUT, Australia. The project was proposed for two purposes, i.e. improving workplace environment for the school administration staff and acting as a research case study for the RFS implementation in office buildings. Based on Equation (7-1) – (7-5), the LCC comparison between RFS and traditional fitout method was conducted to reveal the LCC benefits associated with RFS fitout. The drawings of the fitout plan and service distribution are presented in Appendix 11 and 7, and the application of the model is attached in Appendix 13.
7.6.1 Project Background

The retrofit office space is located at the western corner on the fourth level in a campus building. The given office space was initially divided with fixed plasterboard wall and used to accommodate the school administrative workplaces and a staff resource room. Due to the frequent staff changes, the workstations need to be reorganized or relocated to satisfy new office organizational requirements every two to three years. In addition, most of the office furniture and equipment was obsolete and needed to be upgraded to meet the changing technologies. Under these scenarios, the School decided to reconfigure this office area to meet these changes. However, when it came to the selection of fitout method, the project manager from the facility management department and the School were both swaying between the traditional method and the RFS method, both of which had pros and cons. In this context, a project team was established to make a rational decision between the two methods.

Based on the industry practice and the school research, the project team knew that RFS could enhance the workplace environment to some extent but considered three possible constraints simultaneously. Firstly, the limited underfloor plenum height might influence the air distribution and further introduce hot spots in the workplace areas. Secondly, the limited floor to ceiling height might be insufficient to allow air stratification. Thirdly, the RFS cost might be more than the budget that the School anticipated. A rough fitout plan drawing of the proposed fitout project is presented in Figure 7.1, and more details can be referred to Appendix 11.
For the first issue, a consensus was reached by the project team that ductworks needed to be deployed to carry sufficient cool air to the far front sides of the underfloor plenum and high loading areas while part of the air was delivered into the floor plenum directly from the vertical fan coil unit installed in the adjacent plant room, as shown Appendix 12. For the second issue, since the project manager wanted to keep the ceiling without any changes, the limited floor to ceiling space after allowing a RFS with 190mm FFH could only leave 2400mm for the room space, which is the bottom line according to the BCA. A world renowned building consulting company was employed to analyze the possible office thermal environment in the limited 2400mm room space using the UAD method. Different computational fluid dynamics (CFD) techniques were used to study and determine the thermal and comfort performance parameters, which reached a decision on a few parameters. Specifically, with 18°C supply air, the thermal comfort in most of the offices can be met with a 5 litre supply air per second per square metre except that the Resource Room and Office need to be provided with 7 litre supply air per second per square metre, as shown in Appendix 11. Hence, more diffusers needed to be put in the Resource Room and Office to ensure that sufficient cool air could be supplied. A CFD analysis result with respect to the plant size is summarized in Table 7.1.

Table 7.1 Estimation of Supply Air and Plant Size

<table>
<thead>
<tr>
<th>Room units</th>
<th>Design supply air rate (l/s_m²)</th>
<th>Air flow in total (l/s)</th>
<th>Plant load in total (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office 404</td>
<td>5</td>
<td>87.02</td>
<td>1.36</td>
</tr>
<tr>
<td>Office 403</td>
<td>5</td>
<td>134</td>
<td>2.10</td>
</tr>
<tr>
<td>Staff Room</td>
<td>3</td>
<td>81</td>
<td>1.27</td>
</tr>
<tr>
<td>Office</td>
<td>7</td>
<td>88.74</td>
<td>1.39</td>
</tr>
<tr>
<td>Administration</td>
<td>5</td>
<td>193.75</td>
<td>3.04</td>
</tr>
<tr>
<td>Corridor</td>
<td>3</td>
<td>45.78</td>
<td>0.72</td>
</tr>
<tr>
<td>Kitchen-Resource Room</td>
<td>7</td>
<td>169.61</td>
<td>2.66</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>900</td>
<td>12.53</td>
</tr>
</tbody>
</table>

With respect to the cost concern, both the RFS fitout and the traditional fitout have taken into consideration the initial capital cost difference and the running cost difference separately. Then, LCC techniques are used to do a cost comparison with the aim to explore the perceived benefits of RFS fitout. As indicated in the above...
comparison model, the two fitout methods have a lot of items in common and only those items with different costs will be considered in the comparisons.

7.6.2 Project Details and Cost Analysis Assumptions

The net floor area of the planned office space is 183sqm and the floor plate was reconfigured into different function areas: three personal offices, one open-plan office with three workstations, a staff room, a resource room and a small kitchen. For the traditional fitout method, the total fitout areas are 183sqm and covered with resilient carpets. For the RFS fitout, a total of 170sqm of raised floor panels are used, two ramps are designed for the transition to the outside office areas and corridors, and one step is designed for the transition between the plant room and the RFS areas.

Some of the data in the feasibility report prepared by the project manager is used to calculate the relevant cost for RFS fitout. Meanwhile, some reasonable assumptions to support a focused cost estimation and comparison are made as follows.

- The LCC comparison model only considers items with different cost occurrences associated with initial capital costs and running costs;
- A floor plate without services is conceived as the basis of the fitout work for a fair cost comparison between the two fitout methods;
- The traditional fitout method is assumed to be characterized by overhead HVAC system and power-pole PVD distribution;
- Underfloor fire safety equipment is not used in this project due to the low-profile floor cavity in which there is not enough Oxygen to support fire occurrence.
- Underfloor acoustic baffle is not considered due to the low-profile floor cavity.
- Accelerated depreciation is not considered for the RFS facilities as per the consultations to RFS manufacturers, consulting engineers and accountants;
- The Rawlinsons Australian Construction Handbook (Edition 21) and Cordell Commercial & Industrial Building Cost Guide (2004) are generally referred for cost information; some RFS cost data unavailable in the two books is acquired from the manufacturers directly; and GST is not included in the cost calculation;
- Some reasonable estimation is made for the capital cost and running cost calculation pertaining to both fitout methods;
Chapter 7: Life Cycle Cost Comparison

- A life term of 10 years is assumed for the LCC comparison, with the understanding that the life of RFS products is not less than 10 years.

7.6.3 Initial Capital Cost and Running Cost Differences

The cost estimation is based on the data in the feasibility report and references to the existing research findings in this field. The calculation is carried out with the aid of Microsoft Excel 2003 and the details of the cost calculation processes are presented in Appendix 13. Particularly, for the running cost difference estimation, a cooling energy reduction is considered for the potential energy saving, and an average 2% improvement of workplace productivity and an average reduced absenteeism of 2 days are assumed as benefits brought by the enhanced workplace environment. A simple summary of the capital cost difference and annual running cost difference pertaining to the RFS and the traditional method for the fitout of the given administrative office space is presented in Table 7.2.

Table 7.2 Initial Capital Cost Difference and Annual Running Cost Difference

<table>
<thead>
<tr>
<th>Items</th>
<th>RFS Fitout</th>
<th>Traditional Fitout</th>
<th>Cost Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Capital Cost Difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RFS related cost</td>
<td>$23,548</td>
<td>$0</td>
<td>$23,548</td>
</tr>
<tr>
<td>HVAC related cost</td>
<td>$36,238</td>
<td>$42,090</td>
<td>-$5,852</td>
</tr>
<tr>
<td>PVD related cost</td>
<td>$13,005</td>
<td>$17,385</td>
<td>-$4,380</td>
</tr>
<tr>
<td>Floor covering cost</td>
<td>$13,725</td>
<td>$8,601</td>
<td>$5,124</td>
</tr>
<tr>
<td>Early occupancy benefit</td>
<td>$0</td>
<td>$1,500</td>
<td>-$1,500</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>$16,940</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Running Cost Difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVAC churn cost</td>
<td>$60</td>
<td>$583</td>
<td>-$523</td>
</tr>
<tr>
<td>PVD churn cost</td>
<td>$553</td>
<td>$968</td>
<td>-$415</td>
</tr>
<tr>
<td>Energy reduction cost</td>
<td>$4,511</td>
<td>$5,600</td>
<td>-$1,089</td>
</tr>
<tr>
<td>Productivity benefit</td>
<td>$0</td>
<td>$4,800</td>
<td>-$4,800</td>
</tr>
<tr>
<td>Absenteeism benefit</td>
<td>$0</td>
<td>$1,600</td>
<td>-$1,600</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>$384</td>
<td>$168</td>
<td>$216</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td>-$8,212</td>
</tr>
</tbody>
</table>

The initial capital cost of RFS fitout is $16,940 higher than that of the traditional fitout method. The higher capital cost arises from the RFS related cost and floor covering cost although the RFS fitout can bring some cost benefit in the HVAC
configuration, PVD distribution and early occupancy. Meanwhile, the annual running cost in the RFS fitout is $8,212 lower than that in the traditional fitout. The main running cost saving is attributed to the improved workplace productivity and reduced absenteeism. The reduced energy consumption, HVAC churn cost and PVD churn cost can all contribute to the lower running cost in the RFS fitout environment.

### 7.6.4 LCC Comparison Analysis

Since the fitout project is pertaining to an owner occupied office space, the NPV and payback time are used for the LCC comparisons. Furthermore, sensitivity analysis is conducted to analyze the associated risks.

#### NPV and Payback Time

Table 7.2 reveals that the additional investment on the RFS fitout can contribute to a reduced annual running cost. In view of the time value of money and as per Equation (7-6), the discounted payback curve of the RFS fitout compared with the conventional fitout approach is demonstrated in Figure 7.2.

![Discounted Payback of RFS Fitout](image)

The figure illustrates that with an additional capital cost investment of $16,940, a resultant annual running cost saving of $8,212, a discount rate of 7% and a given life term of 10 years, the payback time for the extra capital investment is 2.31 years and
the NPV of the LCC saving brought by RFS fitout is $40,734, compared with the traditional fitout. The intersection of the accumulated NPV curve and the abscissa axis points to the payback time.

**Single Parameter Sensitivity Analysis**

Employing the comparison model to justify the LCC benefits of RFS fitout provides an auditable result; however, the uncertainty surrounding the variables in the model throws a question over the validity of the solution. Therefore, key factors that may vary a lot need to be identified and reconsidered to reduce possible distortions or misleading information that may have been introduced (Sadi *et al.*, 2002). According to Flanagan *et al.* (1989), where there is a wide disparity in both running costs and initial capital costs across the options being compared, both the period of analysis and discount rate need to be considered in the sensitivity analysis. However, since the payback time is very short (around 2.31 years) under the assumptions in this research, the period of analysis will not be studied in the sensitivity analysis.

Most cost elements in the initial capital cost lists are unlikely to change tremendously because the cost data is based on a detailed feasibility study to the given floor plate, and hence they will not be taken into account in the sensitivity analysis. In comparison, many cost elements in the running cost list have a large uncertainty in their estimations. Particularly, the productivity and absenteeism rates are both referenced to the available researches, and they are more likely to change in different workplace environments. In addition, the calculation of the reduced energy consumption is based on assumptions and they are likely to vary as well. Under these circumstances, sensitivity studies need to take account of the potential influences of the reduced absenteeism, improved workplace productivity as well as reduced energy consumption in the final judgement of RFS fitout cost benefits.

Figure 7.3 shows the single parameter sensitivity analyses pertaining to the discount rate (ndr), reduced absenteeism (RA), improved productivity (IP) and reduced energy consumption (REC). Nine NPV curves are illustrated. The red one in the middle of the groups is the nominal curve based on the input of the initial data and assumptions (ndr = 7%, RA = 2 days and IP = 2%). The other four pairs are the outcomes of the positive and negative sensitivity analyses of the four parameters being tested.
To facilitate the recognition of the variations relating to the payback time and NPV of cost differences between RFS and traditional fitout method, the results illustrated in Figure 7.3 are presented in Table 7.3 as well.

**Table 7.3 Results of Single Parameter Sensitivity Analyses**

<table>
<thead>
<tr>
<th></th>
<th>ndr 5%</th>
<th>ndr 10%</th>
<th>RA (days)</th>
<th>IP 0%</th>
<th>IP 4%</th>
<th>REC +10%</th>
<th>REC -10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payback time (years)</td>
<td>2.24</td>
<td>2.44</td>
<td>2.92</td>
<td>1.91</td>
<td>6.32</td>
<td>1.42</td>
<td>2.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV (over 10 years)</td>
<td>$46,467</td>
<td>$33,516</td>
<td>$29,497</td>
<td>$51,972</td>
<td>$7,021</td>
<td>$74,448</td>
<td>$41,499</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since the discount rate, reduced absenteeism, improved productivity and reduced energy consumption are obviously different types of parameters, their variations are
determined as per the actual possibility rather than strictly abiding by the established normal sensitivity analysis rules, such as changing by ±5% or ±10%. Specifically, when the discount rates of 5% and 10% are tested, the payback times are 2.24 years and 2.44 years and the NPVs of the cost differences over 10 years life term are $46,467 and $33,546 respectively, indicating that a higher discounted rate may weaken the cost benefits of RFS fitout by extending the payback time and reducing the cost savings whereas a low discount rate can strengthen the cost benefits.

As far as the reduced absenteeism is concerned, a conservative estimation with no reduced absenteeism brought by the RFS lead to a payback time of 2.92 years and a NPV of cost benefits of $29,497 over 10 years. In comparison, if the RFS fitout environment can contribute to a reduced absenteeism of 4 days per employee, the payback time is shortened to 1.91 years and the NPV of cost benefits is enhanced to $51,972. These results reveal that the more reduced absenteeism that the RFS fitout can contribute to, the more cost benefits in RFS fitout can be achieved.

The contribution of the improved workplace productivity occupies the largest proportion in the nominal cost benefit assumption (ndr = 7%, RA = 2 days and IP = 2%). However, when a conservative estimation advises no improvement at all, the payback time is largely extended to 6.32 years and the NPV of cost benefits is just $7,021 over 10 years. On the contrary, an optimistic forecast of 4% improvement of productivity will curtail the payback time to 1.42 years and raise the cost benefits to $74,448. These results reveal two important issues. Firstly, improved workplace productivity can lead to robust cost benefits in the RFS fitout; secondly, a reasonable estimation of the RFS contribution to the workplace productivity is significant for the decision-making of RFS applications.

Comparing with the above three parameters, the influence of the reduced energy consumption on the RFS cost benefits is insignificant. With a ±10% changing of the assumed energy reduction, the variation of the payback time and the NPV are negligible, which indicates that the reduced energy consumption is not a sensitive parameter in this case.
Multiple Parameters Sensitivity Analysis – Extreme Conditions

While single parameters can individually influence the output of the cost model, they do not necessarily take place individually. Multiple parameters sensitivity analysis can access the co-effects of a range of variables at the same time. However, the analysis here only estimates the extremely optimistic and pessimistic conditions of key parameters which tend to vary. Meanwhile, since the low running cost in the RFS fitout is mainly attributed to the reduced absenteeism and the improved workplace productivity, the two variables are considered to act abreast at the extreme conditions. In reality, this assumption for the multiple parameters sensitivity analysis is logical because enhanced workplace environment normally reduces absenteeism and improves productivity at the same time.

Figure 7.4 shows the multiple parameters sensitivity analyses pertaining to the reduced absenteeism (RA) and improved productivity (IP) under different discount rates.

Figure 7.4 Multiple Parameters Sensitivity Analyses

Figure 7.4 shows the multiple parameters sensitivity analyses pertaining to the reduced absenteeism (RA) and improved productivity (IP) under different discount
rates. Again, to highlight their cooperative influences on the outcomes of the LCC comparison model, the results in Figure 7.4 are reflected in Table 7.4.

### Table 7.4 Results of Multiple Parameters Sensitivity Analyses

<table>
<thead>
<tr>
<th>ndr =</th>
<th>RA = 0 day and IP = 0 %</th>
<th>RA = 4 days and IP = 4 %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>Payback time (years)</td>
<td>12.92</td>
<td>15.71</td>
</tr>
<tr>
<td>NPV (over 10 years)</td>
<td>-$2,952</td>
<td>-$4,216</td>
</tr>
</tbody>
</table>

In view that the absenteeism and workplace productivity have interrelation and are independent of the discount rate, their combinations involve two major groups consisting of six extreme conditions, as shown in Figure 7.3 and Table 7.4. In a conservative estimation involving no reduced absenteeism and no improved workplace productivity and assuming that no major renovations are conducted in the whole life cycle, the discount rates of 5%, 7% and 10% will lead to the payback times of 12.92 years, 15.71 years and 28.67 years, and the 10-year RFS cost benefits of -$2,952, -$4,216 and -$5,809 respectively. The results indicate that the cost benefits of the RFS fitout against the traditional fitout are not that persuasive and convincing, particularly a payback time of 28.67 years under a discount rate of 10% which is not acceptable by most owners.

In comparison, an optimistic estimation involving a reduced absenteeism of 4 days and an improved workplace productivity of 4% per employee will lead to totally different outcomes. The payback times are all less than 1.5 years and the NPVs of the RFS cost benefits are all more than $70,000 over 10 years life term. This positive cost benefit might attract most owners to choose the RFS fitout method.

Comparing the above two groups, it is evident that the reduced absenteeism and the improved workplace productivity are the most significant parameters determining the cost benefits of the RFS fitout. Although the discount rates are changing, their influence on the NPV and payback time is insignificant.
7.7 Findings of LCC Comparisons

Based on reasonable assumptions, available research outcomes and a comprehensive comparison between RFS and traditional fitout methods, a total of 14 major elements with possible cost differences are identified. These elements consist of 8 issues pertaining to the initial capital cost and another 6 pertaining to the running cost, as summarized in Table 7.5.

Table 7.5 Summary of Elements with Possible Cost Differences

<table>
<thead>
<tr>
<th>Elements with Possible Cost Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial capital cost</strong></td>
</tr>
<tr>
<td>• Raised floor related cost difference;</td>
</tr>
<tr>
<td>• HVAC related cost difference;</td>
</tr>
<tr>
<td>• PVD related cost difference;</td>
</tr>
<tr>
<td>• Floor covering related cost difference;</td>
</tr>
<tr>
<td>• Underfloor fire safety related cost difference;</td>
</tr>
<tr>
<td>• Underfloor acoustic baffle related cost difference;</td>
</tr>
<tr>
<td>• Ceiling finish related cost difference; and</td>
</tr>
<tr>
<td>• Earlier owner occupancy savings.</td>
</tr>
<tr>
<td><strong>Running cost</strong></td>
</tr>
<tr>
<td>• PVD related churn cost saving;</td>
</tr>
<tr>
<td>• HVAC related churn cost saving;</td>
</tr>
<tr>
<td>• Reduced energy consumption benefit;</td>
</tr>
<tr>
<td>• Reduced absenteeism benefit;</td>
</tr>
<tr>
<td>• Improved workplace productivity benefit; and</td>
</tr>
<tr>
<td>• Cleaning cost difference.</td>
</tr>
</tbody>
</table>

In view of the time value of money, a range of equations are established to calculate the LCC differences between the innovative and traditional fitout approaches. Since the LCC comparison model is set up for owner occupied office buildings, the payback time and NPV methods are presented for the LCC comparison analysis.

A case study is presented based on a proposed fitout project at QUT. Under some reasonable assumptions, the established LCC comparison model is used to study the potential cost benefits of RFS fitout compared with the traditional method. Within presumed data, the payback time of the extra RFS capital investment is 2.31 years and the NPV of the cost benefits over 10 years is $40,734. As per the interview feedback, a rational payback time for additional capital investment that developers can accept is up to 5 years and for owner occupied buildings, a longer time might be acceptable. From this perspective, the proposed project with RFS fitout is positive.
Sensitivity analysis techniques are employed to overcome the risks presented by the many uncertainties upon some key parameters in the element cost estimations. Single parameter sensitivity analyses highlight that the workplace productivity has the most significant influence upon the achievement of the cost benefits perceived for the RFS fitout, followed by the reduced absenteeism. Particularly, if the improved workplace productivity is not considered, the payback time of additional RFS investment is 6.32 years. The discount rate and the reduced energy consumption have only a small effect in this regard.

In addition, multiple parameters sensitivity analyses are undertaken to explore the co-effects of the reduced absenteeism, improved workplace productivity and discount rate upon the outcomes of the LCC comparison model in extremely optimistic and pessimistic conditions. The results show that the RFS fitout is not desirable if reduced absenteeism and improved productivity are not counted. On the other hand, if an optimistic estimation is assumed, the payback time is less than 2 years no matter what kind of discount rate is used.

### 7.8 Summary

Justifying the cost benefits associated with RFS fitout is a big challenge to encourage RFS implementation in the Australian construction industry. RFS and traditional fitout methods were compared and their major differences in service distribution were identified. Then, the elements with potential cost differences pertaining to the initial capital costs and running costs were analyzed, based on which a LCC comparison model was set up. The NPV and payback time techniques were recommended for the LCC comparison analysis. A case study was presented to demonstrate the implementation of the LCC comparison analysis. A case study was presented to demonstrate the implementation of the LCC comparison model and justify the cost benefits and risks associated with RFS fitout with the aid of sensitivity analysis techniques.

The next chapter will present discussion of results obtained from the previous chapters.
CHAPTER 8
DISCUSSION AND FINDINGS

8.1 Introduction

The previous research instruments identified many pros and cons of RFS fitout in office buildings, compared with the traditional fitout approach. The recognized RFS advantages such as flexibility, ergonomics, improved workplace productivity, time-saving and lower LCC, are catalysts to stimulate owners, developers and tenants alike to use RFS fitout to supersede traditional methods in the future. The general awareness of RFS among industry practitioners with RFS experience and the improved RFS adaptability are also impetuses for RFS implementation in Australia. On the other hand, 20 SIFs influencing RFS fitout implementation and 15 real problems in RFS service operation and maintenance were recognized and justified. In this context, analyzing the relationships of these SIFs and real problems with the project delivery process (PDP) and seeking appropriate approaches to accommodate them are significant and constructive in order to achieve a successful RFS fitout implementation.

This chapter first reviews the catalysts for RFS fitout implementation, aiming at highlighting potential opportunities for the widespread of RFS application in Australia. Then, the SIFs and real problems are analyzed in depth and their relationships with the PDP are explored, which highlights a range of critical factors in RFS fitout design, construction, operation and maintenance (DCOM). After that, a constructability study is undertaken to examine how these barriers and their solutions can be integrated with the RFS fitout PDP. Through the constructability study, five key issues are highlighted for further investigation in order to achieve an integrated
RFS fitout project delivery. Based on the above findings, guidelines for the RFS fitout implementation are formulated for the reference of industry practitioners. At the end of this chapter, the research outcomes are validated through a questionnaire survey to acquire comments from the previously engaged interview respondents.

8.2 Catalysts Stimulating the RFS Implementation in Australia

People with site experience might have certainly heard the words “why I am supposed to build RFS in an office building while the current practice works very well.” Even though many pros and cons presented by RFS fitout were argued by some researchers as indicated in Chapter 2, the status quo of RFS implementation in Australia is unclear. The industry practitioners’ perspective of using RFS as a substitute to the traditional fitout method was not identified either. A holistic and unbiased understanding of the current RFS practice is the basis for seeking methods to encourage RFS implementation in Australia. Particularly, pinpointing the benefits that RFS can contribute is instrumental to increase people’s confidence in it. For this purpose, a range of research instruments were conducted. The summary of the research findings will answer the above questions by highlighting the catalysts encouraging the industry practitioners to apply RFS.

Table 8.1 synthesizes the catalysts that were obtained and justified through the previous research activities. A promising RFS future is attributed to four groups of catalysts, i.e. industry practitioners’ relatively positive awareness of and interest in RFS, recognition and justification of RFS advantages, industry practitioners’ confidence in RFS future, and improved RFS adaptability.

Generally speaking, the industry practitioners with RFS experience have positive awareness of and interest in RFS. Despite that they need more knowledge in making professional designs, consultants are, on average, aware of RFS and interested in new RFS information. Considering that consultants are the main facilitators of new building technologies, their high awareness and interest will contribute to the RFS implementation. Contractors and clients have medium awareness and interest. Contractors are normally not advocators of new technologies due to their segregation.
### Table 8.1 Retrospect of Catalysts for RFS Implementation in Australia

<table>
<thead>
<tr>
<th>Catalysts</th>
<th>Findings of the previous research instruments</th>
</tr>
</thead>
</table>
| Industry practitioners’ awareness of and interest in RFS | • Industry practitioners with RFS experience have high awareness of and interest in RFS (questionnaire);  
• Consultants have high awareness of and interest in RFS although they are not so knowledgeable in the RFS design and construction (questionnaire and interview);  
• Contractors and clients are fairly aware of and interested in RFS (questionnaire, interview and focus groups);  
| Recognition and justification of RFS advantages | • Flexibility is highly recognized (questionnaire, interview, site observations and focus groups);  
• Ergonomics is acknowledged (interview, site observations and focus groups);  
• Lower life cycle cost is justified (LCC comparison);  
• Time-saving for construction and maintenance is identified (interview, site observations and focus groups);  
• Enhanced workplace productivity is proposed (interview and focus groups);  
• Improved office environment is acknowledged (interview, site observations and focus groups).  
| Industry practitioners’ confidence in RFS future | • Industry practitioners with RFS experience have medium willingness to use RFS and have high confidence in a promising RFS future (questionnaire and interview);  
• Industry practitioners without RFS experience have relative high confidence in a promising RFS future although they are not so likely to use RFS (questionnaire);  
• Many perceived physical and non-physical constraints are justified as false problems (interview, site observations and focus groups).  
| Improved RFS adaptability | • RFS is highly recognized for the fitout of office spaces and computer/equipment rooms (questionnaire, interview, site observations and focus groups);  
• The integration of underfloor HVAC system can not only improve RFS integration with building service systems, but also reduce the capital cost and running cost (questionnaire, interview, site observations and LCC comparison);  
• Lots of good practices improve the RFS adaptability for retrofit projects (interview and site observations);  
• The higher initial capital cost can be offset by lower running cost (interview and LCC comparison).  

from the design and planning process under the traditional project delivery approaches; however, they play an important role in putting RFS into office buildings. Clients are the final decision-makers so that their awareness and interest are indispensable. The medium awareness and interest among contractors and clients form a favorable base for RFS adoption in real projects.

The recognition and justification of RFS advantages can persuade the industry practitioners to opt for RFS with confidence. The questionnaire revealed high recognition of RFS enabled flexibility; the low awareness of other RFS merits such as ergonomics, cost saving, time-saving, and improved workplace productivity might be due to the scarcity of RFS practice in the industry. The interview survey, through face-to-face conversation with industry people having hands-on RFS experience, justified most RFS benefits. The site observations explored these perceived merits through on-site experience, and focus groups further confirmed them through discussions with occupants in the RFS facilities. In the end, all the perceived RFS advantages were explored and justified except the LCC benefits, which was tested later through the case study in Chapter 7. All these substantiated RFS advantages will help to add to the competitiveness of RFS in the industry.

The industry practitioners’ confidence in RFS future is, to a large extent, decisive to the RFS implementation. No matter whether they have RFS experience or not, the industry practitioners generally have high confidence in a promising RFS future. Those with RFS experiences also show medium interest in using RFS in the future, which not only confirms the benefits of RFS fitout but also presents an indication of a booming RFS market. Those without RFS experience show relative low willingness to use RFS, which might be due to their concerns about the risks and benefits. For this reason, the industry practitioners need to be further educated with RFS knowledge in order to balance the perceived possible risks and benefits. Many perceived physical and non-physical barriers are justified as false problems, which further add the industry practitioners’ confidence in choosing RFS fitout.

The improved RFS adaptability is also a momentum to encourage RFS application. RFS is generally recognized for the fitout of office spaces and computer/equipment rooms, and underfloor HVAC system is known for its integration into the floor
plenum to add RFS adaptability. Meanwhile, many good practices explored in the site observations, if extended, will enhance RFS adaptability as well, particularly for retrofit projects. The LCC comparison presented a method to justify RFS cost benefits. As per the case study, the slightly higher initial capital cost can be paid back quickly owing to a much lower running cost. All these findings show enhanced RFS adaptability and enlighten the potential widespread application of RFS.

In all, the experienced industry practitioners’ robust awareness of RFS, interest in new RFS information and confidence in a promising RFS future form a good basis for RFS implementation. Moreover, the justified RFS advantages and enhanced RFS adaptability are able to maximize the popularization of the innovative technology.

8.3 Discussion of the Barriers Hindering RFS Implementation

Over the last 20 years, RFS manufacturers made efforts to promote RFS implementation in Australia. The RFS market, although progressive, was hampered by the lack of awareness of and effective solutions to the barriers hindering the RFS application. As one of the research objectives, 20 significant influence factors (SIFs) and 15 real problems were identified from the questionnaire and interview and validated through the site observations and focus groups. The impacts of the SIFs on RFS implementation and the reasons for the real problems are discussed below.

Prior to seeking to use constructability knowledge and structure an appropriate RFS project delivery method to accommodate the recognized barriers, it is necessary to analyze and integrate the SIFs and real problems and their possible solutions with the RFS PDP. It should be noted that the following activities are not a repetition of the previous chapters. Rather, it is an important integration process, forming the base for the constructability study and guideline work later on.

8.3.1 Significant Influence Factors

As shown in Table 5.8, 20 SIFs pertaining to structural constraints, RFS service integration, industry practitioners’ knowledge and cost concerns can influence RFS
implementation. To enhance RFS competitiveness and adaptability, it is worthy of assessing the influences of these SIFs on the project DCOM, as discussed below.

Structural Constraints
Building structures determine the adaptability of RFS uses in both new and retrofit office buildings. Five structural constraints were justified with potential restrictions on RFS implementation and their potential influences on the RFS DCOM are summarized in Table 8.2.

Table 8.2 Influences of Structural Constraints on RFS DCOM

<table>
<thead>
<tr>
<th>SIFs</th>
<th>Influences on RFS DCOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural irregularity</td>
<td>• Raised floor layout design and construction;</td>
</tr>
<tr>
<td></td>
<td>• Arrangement of RFS installation along perimeters;</td>
</tr>
<tr>
<td></td>
<td>• Additional panel cutting;</td>
</tr>
<tr>
<td></td>
<td>• Connectivity between panels and walls;</td>
</tr>
<tr>
<td></td>
<td>• Cool air leakage along perimeters.</td>
</tr>
<tr>
<td>Space volume limitation</td>
<td>• Determination of FFH;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor PVD design and construction;</td>
</tr>
<tr>
<td></td>
<td>• Determination of underfloor HVAC application;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor air distribution;</td>
</tr>
<tr>
<td></td>
<td>• Close-packed underfloor space;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor service maintenance;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor space cleaning.</td>
</tr>
<tr>
<td>Transition difficulties</td>
<td>• Design of ramps and steps;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor PVD design and construction;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor HVAC design and construction;</td>
</tr>
<tr>
<td></td>
<td>• Uneven floor surface;</td>
</tr>
<tr>
<td></td>
<td>• Carpet tile layout design and construction;</td>
</tr>
<tr>
<td></td>
<td>• Arrangement of RFS connectivity to core facilities.</td>
</tr>
<tr>
<td>Overhead HVAC influence</td>
<td>• Determination of underfloor HVAC application;</td>
</tr>
<tr>
<td></td>
<td>• Ceiling renovation;</td>
</tr>
<tr>
<td></td>
<td>• Determination of FFH;</td>
</tr>
<tr>
<td></td>
<td>• HVAC maintenance.</td>
</tr>
<tr>
<td>Structural beam restriction</td>
<td>• Ceiling renovation;</td>
</tr>
<tr>
<td></td>
<td>• Determination of FFH;</td>
</tr>
<tr>
<td></td>
<td>• Determination of underfloor HVAC application.</td>
</tr>
</tbody>
</table>

To avoid lengthy explanation, take the building structure irregularity as an example to show its influence on RFS DCOM. First of all, irregular building designs affect raised floor layout design and construction. On-site practice always chooses a benchmark point or line (normally a wall) for RFS layout to minimize panel cutting; however, irregular building shapes make this decision difficult. Secondly, special arrangements of RFS installation along perimeters and additional panel cutting are often requested due to the structural irregularity. Once panels are cut to adapt to the substandard panel grids, additional pedestals are called for panel stability along the perimeters. However, more often than not, there is not even an appropriate space to
locate the pedestal bases along the perimeters. As such, an improper arrangement of
the above three factors associated with irregular building structure will make the
connectivity between panels and walls unaesthetic and even lead to cool air leaking
from gaps along the perimeters.

Based on the interview feedbacks on the conceptual solutions in Appendix 5, there
is not a better way to accommodate the 5 issues but to design RFS fitout passively to
adapt to these structural constraints in retrofit projects. Particularly, choosing an
appropriate FFH to suit the limited space volume is challengeable. The PVD service,
HVAC service and fire safety service, etc. need to be grouped together in the limited
underfloor space. Two guidelines are conducive to a successful retrofit with RFS.
Firstly, the underfloor HVAC application and ceiling renovation is determined
based on a complete assessment of the building space limitation, overhead HVAC
influence and structural beam restriction. Secondly, the RFS is not recommended
for building core areas in order to minimize the transition difficulties.

For new projects, all these SIFs can be accommodated by professional designs that
integrate RFS features into the building structure. Experienced team members can
estimate a reasonable FFH for RFS and advise on a proper layout method
beforehand and then make decisions on the structural regularity and space volume.
As such, RFS can be used in office spaces and building core areas without transition
difficulties. On the other hand, an innovative structure design of beams and slabs
allows a smooth connection between the lobby and office spaces if RFS is not
desired in the core areas, as shown by the good practices in Chapter 6.

**RFS Service Integration**

According to the interview feedbacks, no significant concerns with underfloor PVD
and HVAC integration are proposed, indicating that UAD and PVD have become
mature technologies for RFS fitout. *Fire safety system accommodation and cables
and wires incompatibility* were justified as SIFs, and their influences on RFS
DCOM are summarized in Table 8.3.
Industry Practitioners’ Knowledge

Industry practitioners’ knowledge of RFS has the most significant influence on RFS implementation. All 6 issues identified from the questionnaire were justified as SIFs by the interviewees. What’s more, another 2 issues were proposed as SIFs by most interviewees, which indicates that the knowledge of RFS is really a critical issue and worthy of attention in the selection of team skills. Their influences of the 8 issues on the RFS DCOM are summarized in Table 8.4.
Chapter 8: Discussion and Findings

Table 8.4 Influences of Industry Practitioners’ Knowledge on RFS DCOM

<table>
<thead>
<tr>
<th>SIFs</th>
<th>Influences on RFS DCOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architects &amp; engineers’ incompetency</td>
<td></td>
</tr>
</tbody>
</table>
- Raised floor layout design;  
- Underfloor PVD design;  
- Underfloor HVAC design;  
- Underfloor service integration; | 
- Building structure regularity;  
- Unsuitable RFS products;  
- Construction coordination;  
- Underfloor service maintenance. |
| Poor design influence on construction | 
- Low construction productivity;  
- Design revision;  
- Delay of construction schedule; | 
- Low product quality;  
- Difficult access to underfloor service installation. |
| UAD influence on productivity | 
- Determination of Underfloor HVAC application;  
- Underfloor service integration; | 
- Construction productivity;  
- Workplace productivity. |
| Clients’ low familiarity with UAD | 
- Determination of underfloor HVAC application;  
- Underfloor service integration; | 
- Project team decision-making;  
- Improper use of air diffusers;  
- Underfloor HVAC maintenance. |
| Contractors’ incompetency | 
- Construction coordination;  
- Construction quality;  
- Abidance by specification;  
- Subfloor treatment; | 
- Use of special tools;  
- Dust and debris etc;  
- Underfloor service integration;  
- Construction innovation. |
| QS’ incompetency | 
- Project LCC;  
- Unsuitable RFS products; | 
- Clients’ decision-making on RFS. |
| Low awareness of RFS | 
- Clients’ decision-making on RFS;  
- RFS marketability;  
- Industry acceptances. |
| Ignorance of RFS implementation | 
- Underfloor service integration;  
- RFS design and construction;  
- RFS operation and maintenance;  
- Establishment of project team; | 
- Construction coordination;  
- Project team decision-making;  
- Use of RFS without complying with product specifications. |

As far as the architects and engineers’ incompetency is concerned, architects may produce flaring building shapes in pursuit of modernism or embodying an abstract spirit, without taking RFS features into account. This is more likely to happen for those consultants without RFS experience. Incompetent architects may also develop poor RFS layout designs that limiting RFS adaptability. Similarly, inexperienced consulting engineers tend to make mistakes in underfloor PVD and HVAC designs. What’s more, when their work is undertaken without a holistic view of the service integration, the results would be disorganized underfloor space, uneven air distribution, hot spots, etc. Consultants often help project managers in construction coordination, and their lack of knowledge will disqualify them for this role.

Given that industry practitioners are generally not educated in RFS fitout, a complete constructability program is worthwhile. As per the CIIA (1996) research, the constructability programs encourage cooperation and communication among...
team members. RFS fitout knowledge inputs can be gained at an early stage of the project. Although they may be unfamiliar with RFS individually, team members can be educated and encouraged to cooperate in all design and construction issues.

**Cost Concerns**

Sustainable design and technology normally leads to a capital cost premium at the first stage because of higher priced materials and relatively small market. However, the additional investment is often offset by significant running cost savings over the project life cycle. This is a general rule, and the recognition of this rule is essential for new technologies. The above research justified 5 SIFs and their influences on RFS DCOM are summarized in Table 8.5.

<table>
<thead>
<tr>
<th>SIFs</th>
<th>Influences on RFS DCOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost obstacle</td>
<td>• Clients’ acceptance of RFS;</td>
</tr>
<tr>
<td></td>
<td>• Construction innovation;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor service integration;</td>
</tr>
<tr>
<td>Underestimate of LCC</td>
<td>• Clients’ acceptance of RFS;</td>
</tr>
<tr>
<td></td>
<td>• Determination of underfloor HVAC application;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor service integration;</td>
</tr>
<tr>
<td></td>
<td>• Construction innovation;</td>
</tr>
<tr>
<td></td>
<td>• Clients’ willingness of additional investment.</td>
</tr>
<tr>
<td>Poor design influence on cost</td>
<td>• Additional capital cost;</td>
</tr>
<tr>
<td></td>
<td>• Additional overhead cost;</td>
</tr>
<tr>
<td></td>
<td>• Total cost overrun</td>
</tr>
<tr>
<td></td>
<td>• Delay of completion time reducing rental revenue;</td>
</tr>
<tr>
<td></td>
<td>• Cost disputes.</td>
</tr>
<tr>
<td>Suspicion of RFS payback ability</td>
<td>• Clients’ acceptance of RFS;</td>
</tr>
<tr>
<td></td>
<td>• Clients’ willingness of additional investment;</td>
</tr>
<tr>
<td></td>
<td>• Determination of underfloor HVAC application;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor service integration.</td>
</tr>
<tr>
<td>Ambiguity of fitout responsibility</td>
<td>• RFS decision-making;</td>
</tr>
<tr>
<td></td>
<td>• Underfloor service maintenance;</td>
</tr>
<tr>
<td></td>
<td>• Determination of underfloor HVAC application.</td>
</tr>
</tbody>
</table>

With respect to the capital cost obstacle, most clients tend to refuse RFS for its higher capital investment without looking at its following benefits such as lower running costs and a better workplace environment. From the project level, the unnecessary concern of capital cost can hinder the project team’s attempts in RFS integration and construction innovation, because both tasks are costly.

To reduce the influences of these cost concerns, the industry practitioners need to be educated with LCC knowledge, changing their focus from initial capital cost to
running cost and evaluating the project feasibility based on LCC analysis. Examples are urgently needed to reveal the LCC benefit of RFS fitout, adding to the industry practitioners’ confidence in RFS implementation. Last but not least, the responsibility of RFS investment should be sorted out in advance to smooth the RFS project plan and construction. Although RFS is recommended to be constructed by developers and reimbursed by higher rental from occupants, the actual settlement of RFS fitout responsibility is a negotiation process between the two parties.

Table 8.6 Categorization of SIFs as per Their Influences on RFS DCOM

<table>
<thead>
<tr>
<th>SIFs</th>
<th>Design</th>
<th>Construction</th>
<th>Operation &amp; Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Structural irregularity;</td>
<td>• Structural irregularity;</td>
<td>• Structural irregularity;</td>
<td></td>
</tr>
<tr>
<td>• Space volume limitation;</td>
<td>• Space volume limitation;</td>
<td>• Space volume limitation;</td>
<td></td>
</tr>
<tr>
<td>• Transition difficulty;</td>
<td>• Transition difficulty;</td>
<td>• Transition difficulty;</td>
<td></td>
</tr>
<tr>
<td>• Overhead HVAC influence;</td>
<td>• Overhead HVAC influence;</td>
<td>• Overhead HVAC influence;</td>
<td></td>
</tr>
<tr>
<td>• Structural beam restriction;</td>
<td>• Structural beam restriction;</td>
<td>• Structural beam restriction;</td>
<td></td>
</tr>
<tr>
<td>• Fire safety system accommodation;</td>
<td>• Fire safety system accommodation;</td>
<td>• Fire safety system accommodation;</td>
<td></td>
</tr>
<tr>
<td>• Cables and wires incompatibility;</td>
<td>• Cables and wires incompatibility;</td>
<td>• Cables and wires incompatibility;</td>
<td></td>
</tr>
<tr>
<td>• Architects &amp; engineers’ incompetency;</td>
<td>• Architects &amp; engineers’ incompetency;</td>
<td>• Architects &amp; engineers’ incompetency;</td>
<td></td>
</tr>
<tr>
<td>• UAD influence on productivity;</td>
<td>• UAD influence on productivity;</td>
<td>• UAD influence on productivity;</td>
<td></td>
</tr>
<tr>
<td>• Clients’ low familiarity with UAD;</td>
<td>• Clients’ low familiarity with UAD;</td>
<td>• Clients’ low familiarity with UAD;</td>
<td></td>
</tr>
<tr>
<td>• Contractors’ incompetency;</td>
<td>• Contractors’ incompetency;</td>
<td>• Contractors’ incompetency;</td>
<td></td>
</tr>
<tr>
<td>• QS’ incompetency;</td>
<td>• QS’ incompetency;</td>
<td>• QS’ incompetency;</td>
<td></td>
</tr>
<tr>
<td>• Low awareness of RFS;</td>
<td>• Ignorance of RFS implementation;</td>
<td>• Ignorance of RFS implementation;</td>
<td></td>
</tr>
<tr>
<td>• Capital cost obstacle;</td>
<td>• Underestimate of LCC;</td>
<td>• Underestimate of LCC;</td>
<td></td>
</tr>
<tr>
<td>• Suspicion of RFS payback ability;</td>
<td>• Poor design influence on construction;</td>
<td>• Poor design influence on cost;</td>
<td></td>
</tr>
<tr>
<td>• Ambiguity of fitout responsibility.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The above four groups of SIFs affect the RFS DCOM from different aspects. A categorization of these factors based on the previous analysis is presented in Table 8.6 in order to highlight their influences on RFS DCOM. The results show that, out of the 20 SIFs, 18 can directly influence RFS design, 16 influence RFS construction and 10 influence RFS operation and maintenance. It is worthy of noting that although half of the SIFs are assumed to have a direct influence on RFS post-construction activities, it does not mean that the other half have no impacts at all in
this regard. These factors can indirectly influence the RFS operation and maintenance through its direct impact on the design and construction. For example, architects and engineers’ incompetency leads to problematic design in UAD and further results in low quality HVAC construction. In consequence, air leaking, uneven air distribution, hot spots, draught, etc. appear in the operation stage. Further justification of this causality will be presented later by the discussion of the post-construction problems.

Based on the above discussions and the interview feedbacks regarding solutions to these SIFs, a range of activities are recommended for thorough contemplation from the project inception onwards as summarized in Table 8.7. These activities should be integrated with the constructability program to achieve maximum benefits.

Table 8.7 Activities to Cope with the SIFs

<table>
<thead>
<tr>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural constraints</strong></td>
</tr>
<tr>
<td>• Explore building structural features and assess RFS adaptability to retrofit projects;</td>
</tr>
<tr>
<td>• Integrate RFS features in building design and encourage structural innovation for new buildings;</td>
</tr>
<tr>
<td>• Accept or reject underfloor HVAC system on a rational basis.</td>
</tr>
<tr>
<td><strong>RFS service integration</strong></td>
</tr>
<tr>
<td>• Assess underfloor service integration;</td>
</tr>
<tr>
<td>• Determine an appropriate FFH for underfloor service integration;</td>
</tr>
<tr>
<td>• Review project cost objective;</td>
</tr>
<tr>
<td>• Predict impacts of any potential incompatibility.</td>
</tr>
<tr>
<td><strong>Industry practitioners’ knowledge</strong></td>
</tr>
<tr>
<td>• Establish a knowledgeable team to enhance project cooperation;</td>
</tr>
<tr>
<td>• Educate project team with RFS construction knowledge;</td>
</tr>
<tr>
<td>• Get early construction inputs into design;</td>
</tr>
<tr>
<td>• Select a suitable project delivery method.</td>
</tr>
<tr>
<td><strong>Cost concerns</strong></td>
</tr>
<tr>
<td>• Enhance industry practitioners’ recognition of LCC;</td>
</tr>
<tr>
<td>• Carry out research to justify the LCC benefit of RFS fitout;</td>
</tr>
<tr>
<td>• Encourage the concept of risks and benefits;</td>
</tr>
<tr>
<td>• Determine RFS fitout responsibility at early stage.</td>
</tr>
</tbody>
</table>

**8.3.3 Real Problems**

Table 5.9 outlined 15 real problems in RFS service operation and maintenance. Particularly, 6 are major problems and 9 are minor ones. The criterion of telling major problems from minor ones is the occurrence frequency. However, there is no reason to underestimate the minor problems just due to its lower occurrence. Once
they occur, these problems have the same or worse effects on office environments. The potential causes for all these real problems are analyzed below.

The first four issues are major problems relating to the UAD operation. Uneven air distribution and hot spots can be attributed to insufficient FFH, close-packed underfloor space, disorganized PVD distribution, or unreasonable air distribution, poor construction coordination, poor maintenance, etc. Cool air leaking and draught can be due to the uneven layout of panels, excessive underfloor pressure and over-supplied air volume. The messy distribution of underfloor cables, wires and pipes, improper use of air diffusers and the ill considered layout of workplace furniture and air diffusers can also lead to draught. Unsuitable air diffusers without sufficient cooling capacity can also give rise to hot spots in computer rooms. No air leakage testing is also a main reason for air leaking in the operation.

Five issues pertain to raised floor connectivity and layout. An uneven raised floor surface is mainly due to improper subfloor treatment, no use of special tools, failure of getting panels back after service maintenance, and unskilled layout of panels and pedestals during the construction process. Poor panel and wall connectivity can result from an irregular building structure, inaccurate panel cutting and the incompetent arrangement of installation along the boundary. Similarly, poor floor connectivity is mainly due to incompetent structure design and unskilful use of ramps and steps to accommodate floor level differences. Inconvenient underfloor access is mainly due to inaccurate layout of panels and pedestals, rigid corner locking methods and inadequate underfloor space. Panel moving apparently results from an uneven subfloor surface, unreliable fixing of pedestal bases and panels, and inappropriate arrangement of gaps between panels and perimeters. Finally, poor construction coordination can potentially result in all the above problems.

The rest of the issues are other problems that can occur in RFS service operation and maintenance. Additional hole drilling is caused by inaccurate estimation of floor outlets in the fitout design. Unskilful drilling of panels without using special tools will lead to mess in the workplace. Noise is mainly caused by inappropriate floor panels and carpet tiles, lack of sound block arrangement in the floor plenum, excessive underfloor air pressure and improper installation of panels and pedestals.
The breakdown of panels with embedded holes is mainly due to arbitrary drilling of panels without considering the panel loading capacity and poor hole drilling. Dust generation is attributed to subfloor concrete cracks, failure to remove construction dust, unintentional introducing-in during maintenance and lack of regular floor plenum cleaning. Trip hazards are mainly owing to improper layout and maintenance of panels, pedestals and carpet tiles. Panel distortion is on account of the placing of panels into substandard panel grids and faulty use of RFS in overloaded environment.

It is apparent that most real problems result from poor RFS design and construction and improper service operation and maintenance. The main reasons leading to the real problems are summarized in Table 8.8.

Table 8.8 Reasons for Real Problems in Post-Construction Stage

<table>
<thead>
<tr>
<th>UAD problems</th>
<th>Problems associated with RFS connectivity and layout</th>
<th>Other problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Insufficient FFH;</td>
<td>• Failure of subfloor treatment;</td>
<td>• Inaccurate estimation of floor boxes in the service design;</td>
</tr>
<tr>
<td>• Close-packed underfloor space;</td>
<td>• Failure of getting panels back after maintenance;</td>
<td>• Unskillful panels drilling without the aid of special tools;</td>
</tr>
<tr>
<td>• Disorganized PVD distribution</td>
<td>• No use of special tools;</td>
<td>• Unsuitable RFS products such as panels and carpet tiles;</td>
</tr>
<tr>
<td>• Improper design of underfloor HVAC system (including air volume and pressure);</td>
<td>• Poor layout of panels and pedestals;</td>
<td>• No sound block arrangement in the floor plenum;</td>
</tr>
<tr>
<td>• Improper use of air diffusers;</td>
<td>• Irregular building structure;</td>
<td>• Poor construction of panels and pedestals layout;</td>
</tr>
<tr>
<td>• Unsuitable selection of floor air diffusers;</td>
<td>• Inaccurate panel cutting;</td>
<td>• Improper design of underfloor HVAC system;</td>
</tr>
<tr>
<td>• No air leakage testing;</td>
<td>• Poor construction coordination;</td>
<td>• Failure to remove dust during construction;</td>
</tr>
<tr>
<td>• Poor maintenance of underfloor services;</td>
<td></td>
<td>• Introducing-in of dust during underfloor service maintenance;</td>
</tr>
<tr>
<td>• Poor design of panels and pedestals layout;</td>
<td>• Unskillful arrangement of RFS installation along perimeters;</td>
<td>• No regular underfloor space cleaning;</td>
</tr>
<tr>
<td>• Poor construction of panels and pedestals layout;</td>
<td>• Poor design and construction of ramps and steps;</td>
<td>• Poor construction coordination;</td>
</tr>
<tr>
<td></td>
<td>• Inappropriate panel and pedestal locking method;</td>
<td>• Improper layout of carpet tiles;</td>
</tr>
<tr>
<td></td>
<td>• Poor construction of workplace furniture layout</td>
<td>• Lack of carpet tile maintenance ;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Use of RFS without complying with product specifications.</td>
</tr>
</tbody>
</table>
A total of 36 reasons are identified after the discussion of the 15 real problems. Considering that a couple of the reasons may give rise to different problems as indicated by the repeated factors in Table 8.8, 31 reasons are finally recognized and categorized under different stages of RFS project life cycle, as shown in Table 8.9. Out of the 31 reasons, 12 are pertaining to the RFS design, 11 pertaining to RFS construction, and 8 pertaining to RFS operation and maintenance. This result indicates that the decision-making in the design and construction stages has a more significant influence on the RFS post-construction activities than that in the actual RFS operation and maintenance stage.

Table 8.9 Category of Reasons for Real Problems in Post-Construction Stage

<table>
<thead>
<tr>
<th>Reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
</tr>
<tr>
<td>Irregular building structure;</td>
</tr>
<tr>
<td>Insufficient FFH;</td>
</tr>
<tr>
<td>Improper design of underfloor HVAC system;</td>
</tr>
<tr>
<td>Poor design of ramps and steps;</td>
</tr>
<tr>
<td>Poor design of workplace furniture layout;</td>
</tr>
<tr>
<td>Disorganized PVD distribution;</td>
</tr>
<tr>
<td>Close-packed underfloor space;</td>
</tr>
<tr>
<td>Unsuitable selection of floor air diffusers;</td>
</tr>
<tr>
<td>Unsuitable RFS products such as panels, pedestals and carpet tiles;</td>
</tr>
<tr>
<td>Inaccurate estimation of floor boxes in the service design;</td>
</tr>
<tr>
<td>Inappropriate panel and pedestal locking method;</td>
</tr>
<tr>
<td>No sound block arrangement in the floor plenum;</td>
</tr>
<tr>
<td>Construction</td>
</tr>
<tr>
<td>Failure of subfloor treatment;</td>
</tr>
<tr>
<td>Poor construction of panels and pedestals layout;</td>
</tr>
<tr>
<td>Improper layout of carpet tiles;</td>
</tr>
<tr>
<td>Poor construction of ramps and steps;</td>
</tr>
<tr>
<td>Poor installation of workplace furniture layout;</td>
</tr>
<tr>
<td>No air leakage testing;</td>
</tr>
<tr>
<td>No use of special tools;</td>
</tr>
<tr>
<td>Inaccurate panel cutting;</td>
</tr>
<tr>
<td>Unskillful arrangement of RFS installation along perimeters;</td>
</tr>
<tr>
<td>Failure to remove dust during construction;</td>
</tr>
<tr>
<td>Poor construction coordination.</td>
</tr>
<tr>
<td>Operation &amp; maintenance</td>
</tr>
<tr>
<td>Use of RFS without complying with product specifications.</td>
</tr>
<tr>
<td>Improper use of air diffusers;</td>
</tr>
<tr>
<td>Introducing-in of dust during underfloor service maintenance;</td>
</tr>
<tr>
<td>Poor underfloor service maintenance;</td>
</tr>
<tr>
<td>No regular underfloor space cleaning;</td>
</tr>
<tr>
<td>Lack of carpet tile maintenance;</td>
</tr>
<tr>
<td>Unskillful panels drilling without the aid of special tools;</td>
</tr>
<tr>
<td>Failure of getting panels back after maintenance;</td>
</tr>
</tbody>
</table>
8.3.4 Identification of Project Level Critical Factors in RFS PDP

After exploring the influences of SIFs and the reasons for real problems, it is easy to find that the two groups have strong correlations. In other words, the influences of SIFs are mostly the reasons for real problems although the former covers more than the latter. A further deliberation of factors in Table 8.2-8.5 and Table 8.9 shows that the 20 SIFs influence the decision-making on a range of critical factors in RFS DCOM, while the 15 real problems are attributed to improper arrangements of these critical factors. With a simple alignment, a total of 36 project level critical factors (PLCFs) are exposed, with 16, 12 and 8 pertaining to RFS design, construction, and operation and maintenance respectively, as summarized in Table 8.10.

Table 8.10 Project Level Critical Factors in RFS DCOM

<table>
<thead>
<tr>
<th>Design</th>
<th>Construction</th>
<th>Operation &amp; maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Structure regularity;</td>
<td>• Subfloor treatment;</td>
<td>• Use of RFS complying with specifications;</td>
</tr>
<tr>
<td>• FFH;</td>
<td>• Panels and pedestals layout;</td>
<td>• Use of air diffusers;</td>
</tr>
<tr>
<td>• Underfloor HVAC system;</td>
<td>• Carpet tiles layout;</td>
<td>• Introducing-in of dust;</td>
</tr>
<tr>
<td>• Ramps and steps design;</td>
<td>• Ramps and steps construction;</td>
<td>• Underfloor service maintenance;</td>
</tr>
<tr>
<td>• Workplace furniture layout design;</td>
<td>• Workplace furniture layout construction;</td>
<td>• Underfloor space cleaning;</td>
</tr>
<tr>
<td>• Orderliness of PVD distribution;</td>
<td>• Air leakage testing;</td>
<td>• Carpet tile maintenance;</td>
</tr>
<tr>
<td>• Underfloor space management;</td>
<td></td>
<td>• Additional panel drilling;</td>
</tr>
<tr>
<td>• Selection of RFS products;</td>
<td></td>
<td>• Getting panels back after maintenance.</td>
</tr>
<tr>
<td>• Estimation of floor boxes;</td>
<td>• Panel and pedestal locking method;</td>
<td></td>
</tr>
<tr>
<td>• Panel and pedestal locking method;</td>
<td>• Sound block arrangement;</td>
<td></td>
</tr>
<tr>
<td>• Sound block arrangement;</td>
<td>• Ceiling renovation in retrofit projects;</td>
<td></td>
</tr>
<tr>
<td>• Cables and wires compatibility;</td>
<td>• Cables and wires compatibility;</td>
<td></td>
</tr>
<tr>
<td>• Fire safety system;</td>
<td>• Capital cost and LCC;</td>
<td></td>
</tr>
<tr>
<td>• Capital cost and LCC;</td>
<td>• RFS service integration.</td>
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<td>• RFS service integration.</td>
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</table>

8.3.5 Causality among SIFs, Real Problems and PLCFs in RFS PDP

To this end, 20 SIFs, 15 real problems, 36 PLCFs have been identified. It is evident that the SIFs have more influence on RFS design and construction than on its operation and maintenance; similarly, the real problems are attributed more to RFS design and construction than to its post-construction activities.
Figure 8.1 outlines the causality among the SIFs, real problems and PLCFs in the RFS project delivery process (PDP). It indicates that the SIFs influence the PLCFs in RFS DCOM which further determine the occurrence of the real problems in RFS operation and maintenance. In clarifying this, two issues need to be noted. Being parts of the RFS PDP, the feasibility and conceptual design stages are not considered in the causality map because they are decision-making stages for the SIFs rather than for PLCFs. Secondly, part of the construction block in the PDP uses dashed, indicating an early construction before the completion of whole design.

**8.4 Constructability Study of RFS Fitout Implementation**

The arrangements of the 20 SIFs influence the RFS service operation and maintenance through the decision-makings on the 36 PLCFs in the RFS DCOM. Seeking construction management methods to accommodate the effects of the SIFs and PLCFs is essential for the RFS implementation. Among these SIFs, 8 pertaining to the industry practitioners’ knowledge reveal a lack of knowledge in RFS
implementation in the industry, 7 pertaining to the structural constraints and RFS service integration call for construction knowledge inputs, and the rest 5 SIFs pertaining to the cost concerns expose the industry practitioners’ low recognition of risks and benefits associated with RFS applications. Apparently, all SIFs relate to RFS construction knowledge. In addition, the 36 PLCFs are all specific construction knowledge relating to the RFS fitout design, construction, operation and maintenance (DCOM). Therefore, the successful RFS fitout implementation, directly and indirectly, depends on the integration of construction knowledge into the RFS project delivery process (PDP).

8.4.1 Constructability Study

As defined in Chapter 1, constructability is portrayed as integrating construction knowledge, resources, technology and experience into the engineering and design of a project (Anderson et al., 1995). Accordingly, constructability is the most appropriate construction management approach for integrating the SIFs and PLCFs into the PDP to achieve a successful RFS implementation.

CIIA (1996) proposed 12 constructability principles, i.e. Integration, Construction Knowledge, Team Skills, Corporate Objectives, Available Resources, External Factors, Program, Construction Methodology, Accessibility, Specifications, Construction Innovation and Feedback. In this section, using these constructability principles to integrate the SIFs and PLCFs with RFS project delivery will be discussed. The CIIA research also revealed that the general aim of these principles is to stimulate thought about constructability and its application, and certain principles are directly applicable to particular projects. However, the earlier questionnaire indicated that the Australian industry practitioners have little familiarity with most of these principles pertaining to RFS fitout. In this context, all the 12 principles will be discussed but with different strengths based on their relations with the SIFs and PLCFs. Particularly, the Integration, Construction Knowledge, Team skills, Corporate Objectives Program and Feedback are studied in detail; the Construction Methodology, Accessibility, Specifications and
Construction Innovations are discussed together; and Available Resources and External Factors are mentioned.

8.4.1.1 Integration

Constructability procedures need to be made an integral part of the RFS PDP (CIIA, 1996). As the strong causality among SIFs, PLCFs and real problems, the constructability should be integrated with the RFS PDP to minimize the negative impacts due to inappropriate arrangements of the SIFs and PLCFs. Employing constructability activities to accommodate the SIFs and PLCFs is the focus of the RFS fitout constructability study.

The 20 SIFs can affect the decision-making on RFS fitout purposes, risks and benefits, team constitution, construction knowledge inputs, project contracting strategy, conceptual design, construction methods, etc. As such, they need to be fully deliberated in the initial constructability session and strategic constructability workshop in the feasibility and conceptual design stages. Early involvement of experienced construction personnel can help to ascertain the impacts of these factors and provide opportunities to accommodate them at the early project stage.

The 16 PLCFs pertaining to RFS fitout design cover most of the key design attributes, affecting the integration of RFS and underfloor service with the whole project, construction methodology and productivity, achievement of RFS fitout purposes and the whole project objectives. Team members should be committed to the deliberation of these PLCFs through open-minded cooperation and communication during the design process. RFS design progress meetings and constructability evaluation workshops are conducive to optimized designs. To maximize the constructability benefits in the RFS fitout detailed design, the traditional assumption that architects design buildings and general contractors construct them need to be changed. Rather, the design needs to be based on a full cooperation and communication process.

Similarly, the 12 PLCFs pertaining to RFS fitout construction cover the main problem-triggers among construction activities. All these PLCFs can be addressed
through accurate construction specifications. However, construction specifications prepared in the design stage might not be strictly followed in the construction. Project managers need to coordinate the construction process holistically, and specialist contractors among different disciplines need to cooperate in order to improve the RFS fitout construction quality. Periodical site progress meetings are used to review all emerging problems, and team members organized to resolve these issues economically and efficiently.

The 8 PLCFs pertaining to RFS operation and maintenance highlight main issues influencing the post-construction activities. Operation and maintenance activities without abiding by the specifications will cause problems and retard the achievement of RFS benefits. Consequently, these PLCFs and corresponding operation and maintenance specifications need to be recognized by owners and occupants in order to achieve high performance. Post-construction reviews are usually used to identify the causes of problems and seek appropriate solutions through optimized design, quality construction and standardized operation and maintenance. The feedback can be used to guide RFS project delivery in the future.

Based on the above analysis, the integration of the SIFs and PLCFs into RFS fitout constructability implementation procedures is shown in Figure 8.2. A more specific RFS fitout constructability framework will be given in the next section.

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**Figure 8.2 Integration of SIFs and PLCFs into RFS Fitout Constructability**

RFS fitout is part of the whole building project, so the RFS fitout constructability procedures should be integrated with the whole project constructability program.
Moreover, early commitment to RFS fitout constructability is essential as the ability to influence the project development is greater in the initial project stages.

Another important issue for RFS fitout constructability integration is the high level of commitment of the client and the project team. Constructability rules are relatively easy to formulate and/or obtain, but there is little evidence of their widespread application during the project DCOM process (Fox et al., 2002). Indeed, most RFS fitout design was committed to by architects and consulting engineers without effective RFS construction knowledge inputs. Designers continue to be blamed for productivity and quality problems due to their lack of understanding of building construction (Harding, 1990). To change this dilemma fundamentally, clients or owners as head of the organization or a senior executive from the project team need to manage and ensure that RFS fitout constructability activities are prepared and executed.

It is recognized that in the initial project stages, while feasibility of the RFS fitout scheme is first being contemplated, it may be difficult to engage all potential project participants. To justify suitability of RFS fitout, construction consultants with RFS experience need to be employed. Personnel may change throughout the life of the project; however, it is important to ensure that the best possible people are engaged and adequate time is allowed for the transfer of key RFS fitout information.

### 8.4.1.2 Construction Knowledge

RFS fitout using underfloor HVAC and PVD systems is relatively innovative and not accepted by most general industry practitioners, as indicated by the survey feedbacks. Although the questionnaire results showed that most consultants perceived themselves to be familiar with RFS fitout and have access to RFS knowledge, they actually overestimated their competency in this respect. The many real problems in RFS service operation and maintenance indicate a lack of RFS construction knowledge among both them and other industry practitioners. Hence, the RFS project planning must actively involve construction personnel with robust RFS construction knowledge and experience.
The construction knowledge inputs are mainly obtained from experienced construction consultants, specialist contractors and manufacturers’ representatives, provided that they can be involved in the early stage of project. Due to the general low awareness of RFS and poor knowledge of RFS implementation, it is very hard to find competent construction consultants. In the current Australian practice, manufacturers and specialist contractors are the main RFS information sources. However, the questionnaire and interview feedback revealed a relatively low agreement with the manufacturers’ involvement. In the long run, specialist contractors should totally replace manufacturers’ roles for the following reasons.

- Specialist contractors with construction knowledge and experience can contribute more to RFS planning than manufacturers.
- Using specialist contractors to replace manufacturers can help to avoid touters of RFS products.
- RFS products are installed by specialist contractors rather than by manufacturers.
- Many of the manufacturers’ local representatives are actually not subsidiary companies of the manufacturers but independent specialist contractors.

Consequently, specialist contractors are the most appropriate construction personnel for knowledge inputs. As such, only specialist contractors are considered in the following discussions relating to RFS fitout construction knowledge inputs. The main areas that specialist contractors’ knowledge and experience can contribute to are presented below.

**Knowledge Support in RFS Planning**

The specialist contractors’ knowledge support can help to bridge the project team’s construction knowledge gap in the RFS fitout planning, integrating the 20 SIFs and 36 PLCFs with RFS PDP appropriately.

Knowledge inputs can reveal key factors in RFS design which may result in crucial problems in RFS construction and operation but are not generally recognized by most architects and consulting engineers. A typical example is the selection of an appropriate FFH for the RFS. If the FFH is too large, it wastes room space and costs additional money. If the FFH is too small, there will not be enough space for
underfloor service distribution. Knowledge inputs can also bring creative solutions to enhance RFS adaptability. Specialist contractors have worked on different projects owned by different clients and designed by different design firms. Such diversification and rotation of work exposes them to alternative ways of integrating RFS into the projects. For example, if the designers plan to use RFS in the building core area but do not provide appropriate design solutions, transition problems will appear the later in RFS construction. Specialist contractors can advise architects how to design the building structure in an alternative way, e.g. giving a slab level difference between the general office area and the building core area to allow smooth transition.

Figure 8.3 shows the construction knowledge support from specialist contractors. With robust construction knowledge and experience, they can expose key issues to the project design team so that the integration of RFS with building design and RFS constructability can be improved. The conceptual and detailed design of RFS requires collaboration between architects, engineers and specialist contractors. The construction knowledge inputs for the planning can be referred to SIFs and PLCFs pertaining to RFS design as shown in Table 8.10.

![Figure 8.3 Construction Knowledge Support from Specialist Contractors](image)

**Coordination Program for RFS Construction**

Poor construction coordination usually leads to low construction productivity and inferior quality, which further generates problems such as uneven air distribution, draught, dust and inconvenient underfloor access.

Project contracting strategies determine who is responsible for the site coordination. Generally speaking, the person is general contractor in D/B/B and D&B contracts,
or management contractor in CM/GC contract. General contractors are normally competent in construction work rather than construction coordination. In Australia, many management contractors are not good at construction coordination either because they lack knowledge in construction, or because they have a general contractor background coming only newly to a management role. Under this scenario, specialist contractors are under pressure to coordinate their work technically and organizationally. However, they are unable to fulfill the self-coordination appropriately due to their lack skills and having to look after a variety of sites in the meantime. Therefore, preparing a construction coordination program is essential.

On the other hand, most problems, particularly those concerning the interface between the specialist work and general construction, only come to light in the construction stage. This means that problems have to be resolved in an *ad hoc* fashion, requiring solid site experience. Nevertheless, architects and consultants are incompetent to prepare the coordination plan. An early involvement of specialist contractors can help to expose potential problems and formulate a practical coordination program for RFS fitout construction.

**RFS Product Selection**

Many of the recognized problems associated with the RFS operation and maintenance are due to improper uses of RFS products. Specialist contractors can contribute in various ways to the RFS product selection at the early design stage.

Without previous RFS experience, architects and consulting engineers are unfamiliar with the specifications of RFS products and applications. Although manufacturers provide products specifications for reference, the specified information is not necessarily customized to the project at hand. Therefore, the products selected by architects and consulting engineers in haste may not adapt to the particular fitout environment. For example, the freelay locking method is suitable for a fitout environment where easy and frequent underfloor access for service maintenances is required. Once specialist contractors start procuring what is specified, they may choose the most suitable products or the best alternatives, based on their on-site installation experience (Gil *et al.*, 2001).
Moreover, specialist contractors have a strong sense of urgency when procuring long lead items or available alternatives such as special diffusers and air conditioning equipment, because they install such RFS products on a regular basis. They also have ongoing relationships with manufacturers and their local suppliers and know their reliability regarding shipping dates and product quality. Therefore, if specialist contractors are involved early in design, they can inform architects and engineers of the lead times for different alternatives and make them aware of the impact that poor manufacturers selection may have on RFS fitout progress.

**Developing Contracting Strategy**

Specialist contractors can assist the project team in evaluating the contracting strategy best suited to the RFS project delivery. When defining the contracting strategy, specialist contractors can contribute to the following aspects.

Specialist contractors can help to define the contract relationship between the RFS fitout and the whole building project delivery. There are two scenarios for RFS fitout: retrofit projects and new building projects. In retrofit, RFS fitout can be taken on as a complete project; while in new building, it is part of the whole building contract. Since RFS fitout is not a standard practice in Australia, delivering RFS project may involve risks, particularly in new projects. Having experience in contracting with different clients, specialist contractors know how to integrate RFS contracts with the whole building contract and assess and allocate the risks to all project stakeholders fairly by writing appropriate clauses into the contracts.

Specialist contractors’ early involvement can help to ascertain their positions in the whole project team. In reality, most specialist contractors are reluctant to join the project team before the bidding because they cannot see any benefits. They need to protect their own benefits while offering construction knowledge support. By joining the project team early, they can negotiate with owners to define their positions and relationships with other project stakeholders. There are a few challengeable contracting strategies for their early participations, which will be discussed later.
8.4.1.3 Team Skills for RFS Planning

The highly interactive nature of the construction industry means that choosing the right people for the project team is often the key to a successful project (CIIA, 1997). For RFS fitout, it is more than a reality since most team members are not well informed in RFS implementation as indicated by the 8 SIFs pertaining to the industry practitioners’ knowledge.

A typical list of project team members include:

- Client – CEO/managing director, or other senior representative for the project;
- Project manager/team leader with robust constructability knowledge and experience;
- All design consultants – architects, structure/civil engineers, electrical engineers, mechanical engineers, quantity surveyors, cost consultants, etc;
- Other consultants – acoustic expert, hydraulics specialists, etc;
- Construction consultants/constructors;
- User and maintenance representatives.

The team skills for RFS fitout projects is not significantly different from that for the normal building projects, except that some construction personnel need to be engaged for construction knowledge support. In tune with the previous discussion of construction knowledge, RFS specialist contractors are encouraged to join the project team as early as possible. The RFS specialist contractors mainly include raised floor contractors, underfloor HVAC contractors, and underfloor PVD contractors, carpet tile contractors, etc.

For maximum benefits to be gained through constructability activities, a competent RFS project team should have robust knowledge of constructability and RFS implementation, willingness to implement RFS fitout constructability and good communication skills. As such, the team members for RFS projects should be appointed based on the above three criteria.

Knowledge of Constructability and RFS Implementation

Team members should be highly experienced with current knowledge of constructability. The benefits of constructability can occur at all stages of the
procurement process, although the Pareto principle dictates that the earlier in the process that constructability considerations is incorporated, the greater will be the potential for time and cost savings and quality improvement (McGeorge and Palmer, 2002). As such, constructability needs to be included from the inception and all team members have to understand and execute it properly. If some team members have not previously been committed to constructability, they should ideally go through constructability training prior to starting work. A full constructability training program can be accessed in the Constructability Manual (CIIA, 1996) and the Client Guide to Implementing Constructability (CIIA, 1997). It is important that constructability is not reduced to a “review” type process where designers commit ideas to paper which are then reviewed for constructability. This is too late. Instead, the activities should incorporate all team members’ brainstorming sessions where alternatives can be proposed and evaluated.

In addition, team members except RFS specialist contractors, should have a reasonable degree of RFS knowledge, which acts as a criterion for appointing team skills. Team members are also encouraged to examine typical RFS fitout cases to acquire RFS design and application information prior to starting their formal work. RFS specialist contractors should have robust RFS knowledge and experience and join the project team at the early stage for RFS construction knowledge support.

**Willingness of Constructability Commitment**

As previously mentioned, RFS success relies on using constructability to integrate the SIFs and PLCFs into project development. The constructability programs may be set up in the early stage but not implemented by the team members, which limits its contribution to the project objectives. So, team members should be committed to constructability of their own accord rather than being involved passively, and make concerted efforts to fulfill the same project objectives.

Since most industry practitioners without RFS experience lack knowledge in RFS implementation, they need good cooperation and communication among the project team to make full use of the early RFS construction knowledge inputs. Particularly, they need to contribute their knowledge and experience in integrating the 20 SIFs with constructability activities in the feasibility and conceptual design stages. They
also need to actively examine the 36 PLCFs and propose the best solutions in the RFS DCOM stages.

Client and project manager play a more important role in the constructability implementation than other team members. They should encourage and supervise the constructability implementation throughout the RFS PDP. Particularly, they need to create the opportunity to allow RFS specialist contractors’ early involvement and make full use of their knowledge inputs. They also need to understand that the resources needed for conducting the constructability reviews could be more than offset by the savings in capital support resources which are currently going towards resolving claims and design revisions, as indicated by the impact of poor design on construction productivity, dispute, revisions as well as project cost overrun.

Communication

Team members should have robust communication skills so that they can work effectively as part of a team and also fully understand the client’s needs. When it comes to RFS fitout, communication is particularly important for RFS information transference in the following three aspects.

Firstly, communication allows team members to understand the client’s needs and the risks and benefits associated with RFS fitout. In the early stage, team members conduct a range of constructability sessions to transform client’s needs into a project brief and accordingly set up project objectives; then, the design team transforms the brief into work drawings. Without proper communication, team members are quite likely to misunderstand what the client wants and what the brief outlines. Similarly, with full communication of their knowledge and project reality, team members are able to judge the risks and benefits associated with RFS applications, evaluate them against project objectives and finally determine the acceptance or rejection of RFS.

Secondly, communication allows specialist contractors to share their knowledge and experience with other team members to the fullest. Project managers or team leaders should create a cooperative atmosphere among specialist contractors and other team members in order to minimize the confrontation in RFS and whole project design and construction arising due to the lack of understanding of the concerns of other
disciplines. For example, without an idea of the amount of underfloor service
distribution needed beforehand, designers may give an inadequate FFH. In reality,
all the 20 SIFs and 36 PLCFs are worthy of full communication within the team in
the early stage in order to identify the RFS construction knowledge inputs.

Thirdly, communication can allow team members to understand what the designers
had in mind. The information process of a building project is not only a matter of
describing requirements and translating them into physical reality but also a matter
of communicating these requirements to different entities, making sure that their
meaning is understood and that these requirements are fulfilled accordingly. In this
sense, communication is a channel of influence aimed at changing personal and
work relationships in order to accomplish organizational or personal goals
(Pietroforte, 1997). This issue is particularly important in a RFS fitout project,
because team members with different levels of RFS knowledge, constructability
experience, cultural backgrounds, motivations and business objectives get together
temporarily for accomplishing superimposed goals. Given their differences, these
individuals tend to value, structure and interpret the same RFS design results in
different ways. So, only frequent communication through the formal constructability
sessions or informal meetings can allow team members, particularly specialist
contractors, to understand the designs correctly.

8.4.1.4 Corporate and Project Objectives

The use of RFS should be subject to corporate and project objectives. The project
team needs to have a clear understanding of the client’s corporate and project
objectives, and then make a rational decision on RFS applications.

The corporate nature determines its objectives. There are two types of building
developers. The first type is government agencies or owners who develop office
buildings for their own occupancy and hence usually pursue the value of investment.
The other type is speculative developers who always go for maximum return of their
capital investment. Developments in science, technology and anthropology, as well
as the shift from regional to global markets have resulted in changing office
building environments. As a result, the first type of building developer appreciates a
sustainable workplace where their staff can work healthily and productively, while the second type understands the importance of developing quality offices to meet the market demands. In a word, many owners and developers are willing to invest more either for the workplace sustainability or for long term market positions.

The project objectives are established by the early client team in the initial constructability session, and may be revised slightly as per the team members’ brainstorming once the project constructability team is established. In formulating the project objectives, it is important to ensure that they are compatible with the corporate objectives. The traditional project objectives such as completing the project on schedule, within budget and with assured quality, are still more or less required by developers and owners. In addition, the government agencies or self-occupying owners may have unprecedented requirements on office quality, involving a range of modern office building characteristics such as healthy workplace environment, improved workplace productivity, low running costs, easy maintenance, etc. Comparatively, to meet market demands, the speculative developers place more emphasis on other project objectives, e.g. modern building technologies, attractions to market, retainability of quality tenants, effective management, low risks, etc.

In line with the corporate and project objectives, team members work collaboratively to evaluate the suitability of RFS. The main assessment criteria are RFS contributions to the project objectives. According to the previously study, RFS fitout can potentially contribute to workplace flexibility and ergonomics, time-saving in construction and maintenance, construction and workplace productivity, and lower running cost and LCC, all of which are conducive to the achievement of corporate and project objectives. Meanwhile, there are also some risks associated with RFS implementation, e.g. RFS adaptability, fitout responsibility, higher capital investment, lack of RFS knowledge and experience in the project team, etc. Despite its great benefits, the decision-making of RFS application should be based on leveraging the benefits and risks, and the corporate and project objectives. The alignment of RFS fitout contributions with project objectives and corporate objectives is outline in Figure 8.4.
During the RFS strategic constructability workshop in the conceptual design stage, the constructability evaluation workshop in the detailed design stage, and the RFS post-construction review stage, the use of RFS against project objectives is examined and reviewed repeatedly to ensure that the preconceived project objectives have been successfully achieved through the application of RFS fitout. If potential problems inconsistent with project objectives are identified, constructability workshops need to be conducted to rectify them in time.

8.4.1.5 RFS Fitout Programs

To achieve RFS benefits and minimize the risks, feasible RFS fitout programs need to be established. The programs consist of an overall program, design program, and
construction program which must be construction-sensitive, integrated with the whole project delivery, and have the full commitment of the project team. The overall program aims to identify the key issues associated with RFS delivery in the feasibility and conceptual design stages. The individual programs involve establishing more detailed information for the RFS detailed design and construction.

**Overall Program**

Based on the collective expertise from different building and construction disciplines, the overall plan aims to pinpoint the key concerns influencing RFS fitout and integration with the whole building project at the early stage. The overall program is shown in Figure 8.5.

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![Figure 8.5 Overall Program of RFS Fitout at the Early Stage of Project](image-url)

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Since RFS fitout is part of a building project, it is essential to make the overall program align with the project objectives. The overall program should involve the establishments of early client team, RFS fitout constructability policy and constructability team and the development of RFS fitout conceptual plan. The 20 SIFs are considered between these activities at the early project stage to ensure that the RFS fitout overall program is realistic and construction sensitive. It is worthy of noting that the overall program is an integral part of the RFS constructability program.

**Design Program**

Design exerts a strong impact on the construction, operation and maintenance. The investigation of the SIFs and real problems exposed 16 PLCFS pertaining to RFS design, as shown in Table 8.10. The design program aims to integrate these PLCFs into the RFS fitout design and whole project design.

![Figure 8.6 Design Program of RFS Fitout](image-url)
Considering that the RFS fitout design is an integrated process, the design program is depicted by a loop diagram in Figure 8.6. The fitout design process consists of four indispensable programs, i.e. RFS design integration, cooperation, innovation and documentation, each of which is extended to two activities. The RFS design integration includes integration between RFS fitout and the whole building project, and integration among different RFS services. For example, the design of underfloor space volume should be integrated with that of the whole building structure. A low FFH may allow a shorter slab-to-slab distance, saving capital investment in the structure. Meanwhile, the design of the floor volume should ensure there is enough space for service realities such as the amount of cables and wires and the size of the pipes.

Similarly, the RFS design cooperation includes cooperation among different service consulting engineers, and cooperation between designers and specialist contractors. The innovations include building structure and service design innovations. The documentation includes RFS design evaluation against project objectives and RFS fitout contract delivery and products procurement. All these activities underpin an integrated RFS fitout design program.

**Construction Program**

Poor construction can result in problems in RFS service operation and maintenance even though the RFS planning and design are comprehensive. The 12 PLCFs pertaining to RFS construction need to be integrated into the construction process through a holistic RFS fitout construction program.

Figure 8.7 depicts the RFS fitout construction program. Again, the program is presented with a loop diagram since the RFS construction is also an integrated process. The 12 PLCFs are taken into account through the construction coordination, integration, cooperation and innovation. The construction coordination requires coordination between the RFS fitout and the whole project schedule, and coordination among different RFS fitout activities. For example, the start of the RFS fitout construction needs to match the schedule of other project activities. The Critical Path Network method is used to ensure that the RFS fitout program and
other construction programs are comprehensively organized. Meanwhile, the construction of different RFS services should be managed appropriately.

Figure 8.7 Construction Program of RFS Fitout

Similarly, the RFS fitout construction integration includes integration among different RFS service installation, and integration between RFS fitout and the whole project construction activities. The cooperation includes cooperation between designers and specialist contractors, and cooperation among different specialist contractors. The innovation includes innovative sequencing of RFS site activities and innovative use of special tools and construction equipment. All these activities underpin an integrated RFS fitout construction program.

8.4.1.6 Construction Methodology, Accessibility, Specifications and Innovation

Construction methodology, accessibility, specifications and innovation can influence the RFS fitout construction process and determine the building quality.
Accordingly, a holistic planning of RFS construction methodology, accessibility and specifications in the design stage is of importance for achieving the project objectives and RFS fitout purposes; innovative construction methods can, to a large extent, simplify the RFS construction and enhance fitout quality.

**Construction Methodology**

The construction methodology adopted for RFS projects must involve the optimization of construction methods and RFS product selection to meet the fitout purposes and whole project objectives. Many RFS service operation problems result from inappropriate construction methods or use of RFS products. For example, the breakdown of a panel is owing to the improper drilling of holes in the panel; the underfloor access is limited by the inappropriate selection of the raised floor corner locking method.

The major construction methods are discussed in the feasibility and conceptual design stages and then refined and established in the detailed design stage. Specialist contractors should inform designers of the possible construction methods for particular design solutions in the early stage and then make the RFS design more generic for construction in the detailed design stage. The appointed construction method should allow efficient and quality construction. A typical case is selecting the method of fixing the steel pedestal base plate to the concrete slab. There are two common construction methods, adhesive fixing and bolted fixing. The choice must consider fitout specifications and construction efficiency. If the fitout space is general office unlikely to be subject to frequent and heavy rolling loads, the adhesive fixing method should be used for its easy construction.

The RFS product selection should consider modularization and accessibility besides the specifications. RFS products are manufactured with a range of specifications, and the product selection should first of all match the fitout environment. Then, the RFS product modularization needs to be considered to simplify the RFS construction process and avoid conflicts among product specifications. Last but not least, accessibility to the selected products should be examined to meet the construction schedule and minimize the on-site store requirements. Products with long lead time and special transportation should be recognized at the early stage. For
example, it is better to use local products of raised floor panels and pedestals which are available at any time and without long-distance shipment.

**Construction Accessibility**

Construction accessibility reveals the availability of indispensable resources such as personnel, materials, space, and equipment on construction sites. Difficult access may severely reduce construction productivity and retard the achievement of the project cost, time and quality objectives. Hence, construction accessibility needs to be considered in advance.

Specifically, specialist contractors must be able to start their work on time. Since most specialist contractors are working on several different projects at the same time, they need to coordinate their own work schedule and allocate staff properly. Their strict adherence of the pre-set RFS fitout schedule will allow other trades to start on time. Material accessibility influences RFS construction as well, because a long lead time and long-distance transportation can delay construction time and increase procurement costs. So, the RFS product procurement needs to be considered as early as possible. The space accessibility is extremely important for the on-site RFS construction. For example, the installation of panels should follow that of the PVD to allow space for easy cable and wire distribution. The equipment availability determines construction productivity and quality. A typical example is the use of panel cutting/drilling machine for irregular shaped panels and holes. Without the right equipment, this drilling is likely to induce stress concentrations in the panels.

**Construction Specifications**

Construction specifications are defined to ensure quality of the RFS fitout construction and in particular to accommodate the 12 PLCFs pertaining to RFS construction. As previously discussed, almost all RFS service problems in the post-construction stage are directly or indirectly due to failure in either defining or complying with the RFS construction specifications. Therefore, the specification development must be undertaken as a project activity distinct from the beginning and with the full commitment of specialist contractors, designers and other team members. Other members who come later to the project must make themselves familiar with the finished specifications prior to commencing their work.
The RFS construction specifications cover all the RFS service installations, which typically include subfloor treatment, construction environment, raised floor installation, carpet tile installation, underfloor PVD distribution, underfloor HVAC installation, ramps and steps construction, etc. In view of the post-construction problems, a range of key issues need to be defined clearly in the corresponding specifications, and they are:

- Rigidness, flatness, level, dryness requirement in the subfloor treatment;
- Temperature and lighting requirements on the construction environment;
- Panel corner locking methods and arrangement along perimeters in the raised floor panel and pedestal installation;
- Cable tray layout in the underfloor PVD distribution;
- Even air distribution and air leakage testing in the underfloor HVAC installation;
- Gradient and connectivity in the ramps and step construction; and
- Dust removal in the whole construction process.

**Construction Innovation**

Based on the fact that with RFS there must be a willingness to accept new ways of doing things, construction innovation aims to explore innovative construction techniques, facilitating on-site activities while ensuring quality. Choosing competent specialist contractors with construction knowledge can help with the exploration of innovative construction techniques. When it comes to the RFS fitout, the constructability can be improved through innovative sequencing of site activities and the use of special tools.

The sequencing of RFS fitout construction should enable the maximization of a continuous work flow for a particular trade. Since most RFS components are standard modules and the construction work is highly repetitive, the sequencing of different specialist contracts should take account of the learning curve benefits applicable to skill intensive work, such as cable and wire distribution, pedestal base plate fixing and panel installation. Moreover, the sequencing of the RFS fitout should minimize congestion of construction activities. An optimized RFS fitout can be carried out in the following conceptual sequencing, as shown in Figure 8.8.
The fitout work starts from the subfloor preparation/treatment, making it rigid, dry, smooth, clean and free from harmful materials. After the raised floor installers go inside to draw grids for the pedestal locations, electrical and mechanical contractors enter and complete the first stage installations for the PVD and HVAC systems. Considering the alignment between cable and duct/piping layout and also for the purpose of accelerating project schedules, electrical and mechanical contractors are encouraged to work concurrently provided that the floor space is large enough to ensure construction productivity. Once the cables and wires, air ducts and piping are
distributed appropriately and dust and debris are removed, raised floor installers come back to fix pedestals and panels. Subsequently, the electrical and mechanical specialist contractors come back for their second stage installation work, connecting cables and wires with PVD servicenters, linking piping with fan coil units, fixing the air diffusers and PVD boxes in the corresponding panels. Finally, the raised floor panel surface is cleaned to stop carpet tiles from curling and slipping, and then modular carpet tiles are laid on the panel surface.

Adoption of innovative tools is conducive to RFS construction productivity and quality as well. A typical example is the use of a laser planometer and aluminum level for the pedestals and panels installation, ensuring the uprightness and squareness of RFS modules. Another example is the use of a plastic membrane to cover the finished raised floor surface for dust prevention and panel surface protection. With the development of new technologies and an accumulation of fitout experience, more innovative tools are expected to enhance RFS constructability.

8.4.1.7 Available Resources and External Factors

The project team needs to consider the influence of available resources and external factors on a RFS fitout implementation. The project team normally has little control over the available resources and external factors whose influences however cannot be ignored. Some factors such as market conditions and financial factors can even determine the viability of the RFS fitout project. Consequently, identifying these factors in the early stage can minimize their negative impacts on the RFS DCOM.

Available Resources

Good design needs available resources to turn it into reality. Ivory-towered design may look good but cannot be implemented due to the limitation of appropriate skills, technology and market. Considering the current RFS practice in Australia, the following two factors deserve deliberation at the early stages of the project.

The geographic locations of project sites can influence the feasibility of using RFS, as the capital cost for a raised floor module changes from city to city. For example, the cost in the Sydney market is five dollars per sqm lower than that in Brisbane.
market, according to the Rawlinsons Guide Version 2003. The geographic location may also reduce accessibility to RFS products, resulting in long lead time and long-distance transportation. Therefore, the influence of geographic locations on RFS implementation is worthy of consideration.

Market conditions are particularly important in the developers’ decision-making. In the feasibility stage, developers need to study the strengths of current and future office markets, investigate the leasing market for RFS facilities, analyze the possible benefits and risks, and finally make rational decisions on the RFS acceptance or rejection. In order to promote the RFS market, the early involvement of user representatives is encouraged for the purpose of risk sharing with developers. In short, developers should not adopt RFS without a full investigation of the market, nor should they give up a RFS fitout just because of the slightly higher capital cost.

**External Factors**

External factors can affect the project feasibility and implementation as well. External factors pertaining to RFS fitout mainly include environmental and financial policies and political influences. The early involvement of knowledgeable and experienced construction personnel can help to expose critical external factors, based on which the project team is able to evaluate their potential influences on the RFS fitout project delivery. For those factors with negative effects, early negotiation with external bodies to find timely and appropriate arrangements is of importance.

Environmental policy is generally advocated by the Australian government. Buildings can affect the environment in a number of ways, e.g. emissions, habitat, high energy usage, etc. RFS, with less construction dust and debris, low pollution to the environment and low energy consumption, can support sustainable construction and operation, which might finally gain the government’s support.

Financial policy is a critical factor for RFS fitouts in a cost-driven market. Overseas experiences tell us that RFS assets have an accelerated depreciation, which can be used for a tax deduction. Although the Australian Tax Office currently does not have a clear regulation in this regard, the industry can potentially justify its rationale and persuade the government to accept it. In an effort to encourage technology
innovation and environmental protection, the government may make a ruling in the near future.

Political influences may hinder RFS application if team members do not recognize them in time. Early exploration of potential political influences can help to assess the feasibility of the RFS project, which often brings potential problems and opportunities to the fore and also creates a greater sense of commitment to the project. It is recommended that the governmental regulatory agencies or local agency experts should be invited to join the initial constructability session to discuss the relevant regulations relating to the RFS fitout. Regulations such as use of local material, local labour and government promotion can be broached at these sessions.

8.4.1.8 Feedback

Last but not least, feedback is conducive to the transfer of knowledge and experience and the evaluation of the success of the project, which is however often ignored by most industry practitioners. According to the CIIA (1996), feedback is organized through two reviews in the post-construction stage, i.e. a review of RFS fitout constructability and a review of RFS service operation and maintenance.

RFS Constructability Review

The RFS constructability review is undertaken immediately after the whole project is completed. Due to the low awareness of RFS and lack of RFS fitout knowledge among industry practitioners, the project team may have encountered a range of difficulties in the process of RFS planning, design and construction. The review should be conducted in three levels.

The first level of constructability review is pertaining to the problem-solution in retrospect. Referring to the design and construction logs, the project team needs to first recall the difficulties encountered and the constructability activities employed to resolve them, and then discuss the strengths and weaknesses of the constructability arrangements. Particularly the SIFs and PLCFs and the effectiveness of the solutions and activities taken to integrate them with RFS fitout delivery need to be evaluated and recorded. For example, conflict appears in embedding the large size of the
underfloor ventilation duct in the standard space between two raised floor pedestals, as presented in Chapter 6. The problem is due to short sighted service designs, but site progress constructability meetings allow the cooperation and communication among designers and specialist contractors to find alternative ways to accommodate this issue.

The second level is pertaining to team skills. The constitution of the project team determines the knowledge and experience available for the project delivery. Whether and how the early involvement of construction personnel such as specialist contractors really contributes to the RFS fitout implementation needs to be assessed. Moreover, how to organize and manage the project team to encourage their full commitment is worthy of reviewing as well.

The third level is pertaining to the contracting strategy. Generally, contracting strategies affect the project delivery through different methods of planning the design and construction processes, based on which different project organization structure and team skills are established. While each contracting strategy has its pros and cons, one method may be more suitable for a RFS fitout project than others because of the urgent need of RFS construction knowledge inputs at the early project stage. On the other hand, considering that the RFS fitout is part of the whole project, a constructability review also needs to evaluate the effectiveness of the appointed contract strategy on the capability of integrating the RFS fitout with whole project delivery.

**RFS Operation and Maintenance Review**

The feedback also applies to the review of post-construction issues. The review should be undertaken by owner, occupants, project manager, designer, contractor and other necessary parties. The review contents include the achievement of perceived RFS benefits, and the operational problems and their possible solutions. The achievement of these benefits gauges the success of the RFS fitout. The problems in RFS operation and maintenance are recorded and analyzed, and the solutions are explored for future reference. Particularly, the 8 PLCFs pertaining to RFS service operation and maintenance need to be provided to the client in time and the compliance with these PLCFs need to be reviewed. The review of RFS operation
and maintenance needs to be conducted before the end of the defects liability period and ideally periodically after that time.

The two review processes should be systemic, objective and open-minded, and involve most of the original project team members. The summing-up of the valuable knowledge and experience gained from the reviews is important to provide guidelines for future projects. It is believed that RFS constructability can be greatly improved if the lessons learned can be reused in future RFS fitout projects.

### 8.4.2 Key Issues pertaining to RFS Implementation

The 12 constructability principles were analyzed previously with different strengths in an aim to integrate the recognized 20 SIFs and 36 PLCFs into the RFS fitout and whole project delivery. The discussions revealed that the integration of constructability into RFS PDP can influence the constructability implementation and maximization of its benefits; the construction knowledge inputs are the key to filling the knowledge and experience gap among industry practitioners, which however depends on the early involvement of specialist contractors; the maximum use of early knowledge inputs needs the full cooperation and communication among team members; the optimization of the project program, construction methodology, accessibility, specifications, innovation, available resources and external factors relates to the selection of project contracting strategies; the construction methodology, specification and minimization of post-construction problems require appropriate RFS products.

While most issues discussed in the constructability study are important, five key issues are highlighted as having the most influence on most factors investigated in the above RFS fitout constructability analysis. These issues are RFS fitout constructability implementation, early involvement of specialist contractors, cooperation and communication in the project team, contracting strategy of RFS fitout and the whole project, and RFS product procurement. Further investigations are conducted on the 5 key issues due to their significant influences on RFS fitout project delivery.
In particular, whether or not specialist contractors have the opportunity to participate at an early stage and whether project team members have the opportunity to cooperate and communicate in RFS DCOM is often a contractual issue. Therefore, the early involvement of specialist contractors, the cooperation and communication in the project team, and the contracting strategy of RFS fitout and the whole project will be discussed together to find the best delivery method for RFS fitout implementation in the Australian construction industry.

8.4.2.1 Framework of RFS Fitout Constructability Implementation

To achieve the maximum benefits, constructability must be integrated with the whole RFS PDP rather than at particular stages. According to the Pareto principle, the decisions taken early in a project life cycle have greater potential to influence the final outcome of the project. Therefore, the constructability policy should become part of the project culture as early as possible. The evaluation of 20 SIFs and 36 PLCFs need to be integrated into the RFS fitout constructability plan. In tune with the CIIA (1996) research and the above discussion of constructability, a RFS fitout constructability framework is developed in Figure 8.9, which presents a series of systemic constructability activities in each project stage.

The framework integrates constructability concepts with the whole RFS PDP. It is hierarchical in nature, which means that lower-level diagrams are decompositions of the upper-level diagrams immediately preceding them. So, the constructability functions in the lower-level diagrams are more specific than the upper-level ones. Three sublevels are applicable to the framework.

The first decomposition shows the integration of constructability in the five stages of the RFS fitout PDP. The feasibility stage and conceptual design stage are grouped together as most decisions on RFS constructability are made during the two stages. It is also because of the difficulty in judging the exact time for any particular decision-making since RFS fitout is part of a building project and RFS constructability is part of the whole project constructability. In this research only the RFS fitout constructability implementation is focused on and its relation to the whole building constructability will be mentioned where applicable.
Integration of Constructability with RFS PDP

**Constructability during RFS Fitout Feasibility & Conceptual Stages**
- **Initial RFS Constructability Session**
  - Establish & educate early client team
  - Determine project objectives & RFS adoption purpose
  - Evaluate RFS risks & benefits (refer to 5 SIFs)
  - Explore RFS constructability inputs
  - Determine RFS fitout contracting strategies
  - Set up RFS constructability policy
  - Create RFS constructability team
  - Assess team’s RFS knowledge (refer to 8 SIFs)
  - Engage RFS fitout specialist contractors early
  - Asses & educate project team with constructability
  - Consider RFS products procurement issue
  - Develop RFS design & const. coordinated plan

**RFS Strategic Constructability Workshop**
- Assess structural constraints (refer to 5 SIFs)
- Assess RFS service integration (refer to 2 SIFs)
- Consult lessons learned for RFS implementation
- Evaluate RFS use against project objectives
- Develop RFS products procurement plan
- Refine & document the resultant design

**Constructability during RFS Fitout Detailed Design Stage**
- RFS Design Process Meetings
  - Examine the 16 PLCFs in RFS design
  - Integrate RFS features with building design
  - Encourage design innovation & cooperation
  - Develop RFS products procurement plan
- Constructability Evaluation Workshop
  - Review RFS use against project objectives
  - Re-examine RFS design adaptability
  - Identify potential impediments for construction
  - Summarize constructability improvements

**Constructability during RFS Fitout Construction Stage**
- RFS Site Progress Meetings
  - Examine the 12 PLCFs in RFS operation & main.
  - Encourage construction innovation
  - Coordinate RFS site construction
  - Record RFS constructability issues
- Constructability during RFS Post-Construction Stage
  - Examine the 8 PLCFs in RFS opera. & maint.
  - Review the influence of constructability
  - Review RFS operation & maintenance
  - Review RFS use against project objectives
  - Update RFS constructability lessons learned

Figure 8.9 Framework for the Integration of Constructability into RFS Fitout PDP
The second decomposition reflects major RFS constructability functions under each major project development stage. Seven constructability functions are presented in this level. In detail, the initial RFS constructability session, the RFS project team selection and the RFS strategic constructability workshop are performed for the integration of constructability with the RFS feasibility and conceptual design stages; design progress meetings and constructability evaluation workshop are for the detailed design stage; RFS site progress meetings are for the construction stage; and RFS post-construction reviews are for the post-construction stage.

The final decomposition represents the specific activities under each constructability function. A total of 37 constructability activities are identified in this level. Each constructability function consists of 5 activities except that the initial constructability session and the strategic constructability workshop include 6 activities individually. The constructability activities under each function are interrelated and act collectively to enhance RFS fitout constructability in each project stage. Many of the activities were discussed in the previous RFS fitout constructability study. Therefore, only the first 6 activities pertaining to the initial RFS constructability sessions are interpreted below as an example to avoid tedious repetition.

The initial RFS constructability session ensures that the early project decision-makers are aware of constructability and its benefits, RFS application and its risks and benefits. The first activity is to establish early client teams and educate them with basic constructability and RFS knowledge. The early client team should include a person with recent experience in RFS design and construction. A competent construction consultant can play this important role. Then the client team needs to determine the project objectives based on a full understanding of the client’s needs and then assess the most suitable RFS fitout for this particular project. In view of the project objectives and RFS fitout purposes, the team members evaluate the risks and benefits associated with the RFS fitout and then determine its suitability. Particularly, the 5 issues pertaining to cost concerns need to be referred to at this stage to clarify the cost and fitout responsibility issues, in case of cost overruns and disputes at a later stage. A decision regarding acceptance or rejection of a RFS fitout is made as an outcome. If RFS is chosen, the client team will explore the RFS constructability inputs based on the available knowledge and experience. After that, the RFS fitout
contracting strategies are determined and its integration with the whole project delivery is deliberated as well. In the end, a RFS constructability policy is established in order to integrate the constructability procedures with the RFS DCOM.

8.4.2.2 Early Involvement of Specialist Contractors, Cooperation and Communication, and Contracting Strategy

The early involvement of specialist contractors and the cooperation and communication in the project team influences the selection of the RFS fitout contracting strategy, and vice versa. With this understanding, the potential methods of specialist contractors’ early involvement and team cooperation and communication are discussed individually at first, after which the most suitable contracting strategy will be determined for the RFS fitout.

Specialist Contractors’ Early Involvement Methods
Traditionally, specialist contractors are selected primarily by the general contractor or the management contractor through competitive bidding after obtaining a set of drawings and specifications defining the project products, which cannot make use of specialist contractors’ knowledge and experience for the project planning and design. Specialist contractors’ early involvement can make up for the team’s deficiency in RFS fitout construction knowledge and experience. Based on their potential roles in the project team, specialist contractors can be involved in the following ways.

Nominated Specialist Contractors
The early client team may name specialist contractors in the feasibility and conceptual design stages for the RFS suitability assessment and construction knowledge support in developing design and construction specifications. When this is the case, the general contractor or the management contractor does not have the right to choose other contractors for those specialists. However, the specialist contractors’ main role in the design stage is to contribute their knowledge and experience to the architects and consulting engineers in RFS fitout design. With specialist contractors’ assistance, the designers can integrate the 20 SIFs and 16 PLCFs into the RFS fitout planning and design on a rational basis. Moreover, the RFS fitout construction specifications can be formulated more acceptably and
realistically. As a compensation for their early efforts, the specialist contractors will be guaranteed the contracts in those specialists later on.

**Design-Build by Specialist Contractors**

With more responsibility in the RFS fitout delivery, specialist contractors may be contracted with the client or design-builder for the planning, design and construction of the RFS fitout. This new method helps facilitate the delivery of specialist contracts involving innovative building technologies. In this way, specialist contractors are engaged early to manage the RFS fitout delivery. This method, if executed properly, can minimize the project time, reduce cost and enhance the RFS fitout quality. However, success of the project relies strongly on the contributions of specialist contractors. Besides construction skills, the basic design and management skills in the RFS design and construction both present big challenges to the specialist contractors. Moreover, how to manage the specialist contractors’ speciality and make it work for the whole project objectives rather than just maintain their own benefits are also worthy of deliberation by the client or design-builder prior to the specialist contractors’ engagement. To cope with these issues, a possible solution is to engage a subcontractor specifically in charge of the RFS fitout delivery. The subcontractor’s role is, to some extent, like a management contractor, and has substantial knowledge and experience in RFS fitout delivery and in establishing good relationships with the RFS specialist contractors. The subcontractor contracts with the client or design-builder and manage the specialist contractors for the RFS fitout project delivery.

**Design Assistants**

Specialist contractors act as design assistants rather than subcontractors in the RFS fitout construction. General contractors or management contractors may have their own preferences in the selection of subcontractors because they have already established good relationship with particular industry partners. Another possible reason for the client’s rejection of the early specialist contractors after the design stage is to save money. The existing good and stable relationship between the general contractor and the appointed subcontractors can minimize construction disputes, guarantee a higher productive construction phase and keep contracting costs low. As such, the client may not intend to interfere with the general contractor or management contractor’s right to appoint subcontractors, however, the design team
needs urgent RFS fitout knowledge and experience assistance in the design stage. Under this scenario, specialist contractors will be employed purely for their construction knowledge inputs.

Based on the above analysis, the nominated specialist contractors and design-build by specialist contractors are more suitable for RFS fitout project delivery. Design assistants style has limited effectiveness because the participating contractors have no guarantee from the clients that they will be given the contracts of RFS fitout construction. Hence, they may not give much assistance because competitors who later bid for the work will have access to their solutions. As a result, nominated contractors and design-build by specialist contractors will be used in the following exploration of cooperation and communication in the project team and the contracting strategy.

**Cooperation and Communication in Project Team**

Besides the early involvement of specialist contractors for construction knowledge inputs, RFS fitout design and construction also rely on the effective cooperation and communication among the project team. Confrontation often arises due to the lack of cooperation and understanding of other disciplines’ concerns. Therefore, the maximum benefits brought by the RFS constructability activities largely depend on team cooperation and communication.

Following the specialist contractors’ involvement methods, the approaches for the cooperation and communication in the project team on the whole project design and RFS fitout design are developed in Figure 8.10 and Figure 8.11. It is worthy to note that the cooperation and communication is not limited to specialist contractors, architects, and consulting engineers, although only the three parties are presented in the two figures. Rather, other team members such as the client’s representative, project manager, quantity surveyor, cost consultant and user’s representative should actively join the exploration of design solutions. The best possible design for a whole project and RFS fitout can be achieved provided that the information is shared freely among the team members and high levels of cooperation are practiced among the different specialists and team members.
Chapter 8: Discussion and Findings

Figure 8.10 shows that both the whole project design and the RFS fitout design are carried out under the collaboration of the architect, the consulting engineers for the RFS fitout design and the consulting engineers for other building services design. The contactors in raised floors, underfloor HVAC and PVD, and other RFS services are engaged by the early client team as the nominated specialist contractors. They do not do the designs themselves; rather, they deliver essential information about the RFS fitout to the project design team, and assist in bidding the optimized solutions for RFS fitout and whole project design. Particularly, based on their knowledge and experience, specialist contractors can inform the project team of the best way to integrate the 20 SIFs and 16 PLCFs into the RFS planning and design at the early stages of project.

Figure 8.11 shows how the whole project design and the RFS fitout design are conducted separately involving different team members. The whole project design is prepared under the collaboration of architect, consulting engineers for other building services design and RFS subcontractor, while the RFS fitout design is undertaken within the RFS fitout design group consisting of RFS subcontractor, raised floor contractor, underfloor HVAC contractor, underfloor PVD contractor and other RFS service contractors. The RFS subcontractor plays a very important role in the cooperation and communication network between the RFS design and the whole project design. To succeed in this challengeable role, the RFS subcontractor needs to
have profound construction knowledge and experience in RFS implementation. Moreover, the RFS subcontractor does not have to do the fitout design himself, but he needs to have robust management skills to encourage the specialist contractors to work cooperatively and also have excellent communication skills to instruct the architect and other building service consulting engineers on the RFS fitout features in order to integrate the RFS design with the whole project design.

The above two figures show the different collaboration ways under different involvement styles of RFS specialist contractors. However, how to use the RFS specialist contractors’ knowledge and experience for the whole project design and construction strongly depends on the project contracting strategy.

**Contracting Strategies of RFS Fitout and the Whole Project**

The discussion on RFS fitout constructability, specialist contractors’ early involvement and cooperation and communication in project team reveals that a proper contracting strategy is essential for the integration of the RFS fitout with the whole project delivery. It should be noted that RFS fitout is regarded as part of a new building project delivery in the following discussion of contracting strategies. The delivery of RFS fitout in retrofit projects will not be considered because it is much more straightforward compared with that in new building projects.
The form of contracting strategy is a critical component in the integration of the design-construction dyad (Puddicombe, 1997). The main contracting methods include D/B/B, CM/GC and D&B, and each of them may have several alternatives after combining special contracting variables; however, D/B/B method basically separates construction from design while CM/GC and D&B can allow a degree of combination between the two. In this sense, CM/GC and D&B are more suitable for the RFS fitout and whole project delivery for the following reasons:

- Management contractor or design-builder can join the project team earlier and facilitate the cooperation and communication between RFS specialist contractors and other project experts;
- Early involvement of construction personnel for non-RFS services can contribute to the project design and enhance the constructability of the whole project;
- CM/GC and D&B can allow early construction and minimize project time.

The earlier questionnaire survey revealed that most industry practitioners did not prefer to use a CM/GC or D&B contracting strategy, which might be due to their unawareness of the contributions of the two methods to project cooperation and communication as well as knowledge inputs. This could be one of the main reasons for the failure to implement RFS fitouts successfully in Australia. To this end, there are two methods for the early involvement of RFS specialist contractors and two contracting forms for the whole project delivery identified. Four contracting strategies come out on top for the integrated delivery of RFS fitout and whole project.

In the context of CM/GC method, Figure 8.12-a shows the integrated contracting strategy for a RFS fitout with the whole project under nominated specialist contractors, and Figure 8.12-b presents the strategy under design-build by specialist contractors. In both cases, the management contractor is responsible for the design and construction of the RFS fitout and whole project. Other main characteristics of the two contracting strategies are presented below.
For the first one, joining the project team at the end of the feasibility stage, nominated specialist contractors are engaged for their RFS fitout construction knowledge inputs, and architect and consulting engineers are for the building and services design including the RFS fitout design. After the conceptual design is completed by the designers and specialist contractors, a management contractor is selected for the management of detailed design and project construction. The management contractor communicates with the design team and has some influence on the conceptual design to improve project constructability. The nominated RFS
specialist contractors and design team work under the management contractor and complete the detailed design. Specifically, the three parties cooperate in the conceptual and detailed design for the RFS fitout. The architect and consulting engineers also work on the design of the building structure and other services with using information from the management contractor. At the completion of the design, the management contractor offers a guaranteed construction sum which must be less than the target guaranteed construction sum, and then invites subcontractors to bid for the construction. Nominated RFS fitout specialist contractors will receive the RFS construction contracts without bidding.

For the second one, a RFS fitout subcontractor is employed in the feasibility stage for the RFS fitout design and construction. With good industry relationships, the RFS fitout subcontractor invites specialist contractors for the RFS delivery. At the same time, the architect and consulting engineers are engaged by the early client team for the design of the building structure and other building services. Similarly, the management contractor is selected at the end of the conceptual design stage to manage the detailed design and project construction. Both the RFS subcontractor and the design team work under the management contractor and complete the detailed design. The architect and consulting engineers do not design the RFS fitout, but they will cooperate with the RFS subcontractor and specialist contractors. Besides the management role, the management contractor also contributes to the design of the RFS fitout and whole project. Again, the management contractor invites subcontractors to bid for the non-RFS service construction once the design is completed and under the target construction sum. Without bidding, the RFS subcontractor organizes specialist contractors to work on the RFS construction under the coordination of the management contractor.

In the context of D&B method, Figure 8.13-a shows the integrated contracting strategy for the RFS fitout and the whole project under nominated specialist contractors, and Figure 8.13-b presents that under design-build by specialist contractors. In both cases, the design-build contractor is in charge of the design and construction of the RFS fitout and whole project. Other main characteristics of the two contracting strategies are presented below.
For the first one, the nominated RFS fitout specialist contractors join the team and work in a similar way as that in Figure 8.12-a. However, the project delivery process is organized differently. The design and construction of the RFS fitout and the whole project is dominated by the design-build contractor who is appointed by the client team at the end of the feasibility stage or in the early conceptual design stage. The design-build contractor appoints a project manager for the management of the whole project including the RFS fitout. The architect and consulting engineers for the design and the construction team for the construction both resides within the design-
build contractor firm. Working under the project manager and cooperating with its design and construction team, nominated RFS fitout specialist contractors assist in the RFS design and undertake its construction.

For the second one, the RFS subcontractor is engaged in a similar way as that in Figure 8.12-b, and organizes specialist contractors for the RFS fitout design and construction. The design and construction teams under the design-build contractor manage the design and construction of the building structure and non-RFS services. The project manager represents the design-builder for management of the whole project. Working under the project manager and cooperating with its design and construction teams, the RFS subcontractor and specialist contractors undertake both the RFS design and construction.

It should be noted that the detailed design stage and the construction stage may overlap to some extent although the four figures present them with horizontal bars separately. Both CM/GC and D&B support fast track delivery in which early complete designs allow early construction.

For the D&B method, alternative ways for the involvement of RFS fitout specialist contractors are available. The specialist contractors do not have to be engaged by the early client team if the design-builder has a certain degree of RFS knowledge and experience to support the client in rational decision-making on the RFS application in the feasibility stage. Then, RFS fitout specialist contractors can be employed by the design-builder as outside expertise in the conceptual design stage, for RFS fitout knowledge inputs and construction or for both design and construction. Ideally, if the design-builder team has substantial expertise in RFS fitout implementation, which may turn to be a reality in the near future, the design-build contractor may not need assistance from outside specialist contractors at all. Under these circumstances, all the project delivery including RFS fitout will be managed by the design-builder firm.

Although all the four main contracting strategies are conducive to the integrated delivery of RFS fitout and the whole project, the nominated specialist contractors under CM/GC contracting strategy is recommended for the following two reasons:
• The relationship between management contractor and client is non-adversarial under CM/GC while it is adversarial under D&B;
• Most RFS specialist contractors are good at supplying construction knowledge inputs rather than doing the RFS fitout design themselves, because they have robust RFS fitout experience but lack design skills.

8.4.2.3 RFS Products Selection Model

Changing business operation patterns and workplace health and productivity issues are reshaping the nature of today’s office buildings fitout. More often than not, load conditions such as equipment loads, human density, foot traffic and rolling loads vary in different office buildings. Human-related work conditions such as air quality, temperature and ventilation, are also dissimilar. As such, RFS components are designed with a variety of products to accommodate these versatile environment fitout needs (Zhang and Yang, 2003a). The RFS product specifications given in Chapter 6 list the currently available products. While these products enriched the RFS functions, improved workplace quality and expanded markets, it also resulted in a degree of difficulty for the project team to identify, assess and select the most appropriate products on a rational basis. Therefore, a systematic RFS products selection method is urgently needed to support RFS implementation. Chapter 6 also presented RFS application specifications pertaining to general office space, computer rooms, and lift lobby in office buildings, which form the basic technical standards for the RFS products selection.

Many problems in RFS service operation and maintenance are due to the improper use of RFS products. Typical examples include the wrong uses of diffusers, panels and carpet tiles leading to draught, panel distortion and trip hazard respectively. Based on the literature of RFS product specification (York, 1992b; Interface, 1997; Tasman, 2001; Tate, 2001), new characteristics of office buildings and specifications developed in Chapter 6, three groups of factors have been identified as being potentially influential to the RFS products selection. The three groups are technical, economic and strategic factors, as described below.
Technical Factors

The three typical fitout environments in office buildings have a set of application specifications, most of which are important technical factors to be abided by. These technical factors largely determine the types of RFS products suitable for each particular office space. Seven technical factors are identified, as shown in Table 8.11. It should be noted that only indispensable RFS products presented in Chapter 6 will be considered in the selection model.

Table 8.11 Analyses of Technical Factors

<table>
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<th>Factors</th>
<th>Analyses</th>
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| Application environment        | • Loads exerted on floor panels are decisive to RFS selections;  
                                 | • Equipment, people and activities occupying the fitout spaces need to be conceived at first;  
                                 | • Equipment loads, level of foot traffic, and frequency and level of rolling loads are calculated to support the selections of panels, understructures and floor coverings. |
| Service life expected          | • What is the expected life of the interior fitout space?  
                                 | • How many years of service are expected from the RFS?  
                                 | • The answers to these questions influence decisions on panels, understructures, floor coverings and service units to be used. |
| Panel surface finish           | • Raised floor panels may be installed ‘bared’ for carpet coated on sites for general offices and lift lobby applications;  
                                 | • Panel surface may be installed with a factory bonded high pressure laminates (HPL) for computer/equipment room uses. |
| Finished floor height (FFH)    | • An appropriate FFH is significant for the successful provision of underfloor services. For example, a preferred FFH must usually be more than 300mm to provide enough space for UAD;  
                                 | • The selection of FFH need to consider the fire safety issues under BCA. |
| Underfloor HVAC system         | • The underfloor HVAC system is optional for office buildings and its application is determined by the building structure, whether or not it can deliver cost savings whilst benefit the comfort and health of end users;  
                                 | • In buildings where much higher heat load is generated by computers/equipments, the underfloor HVAC system is strongly recommended. |
| Underfloor access              | • The frequency of underfloor access for maintenances or upgrades need to be estimated in early stage;  
                                 | • When planning the understructures, the underfloor access requirement should be considered to support easy task and minimum disturbance. |
| System integration             | • The integration of underfloor service is considered in the RFS fitout design;  
                                 | • The delivery of cables & wires is required to be as modular and simple as possible, supporting ‘plug and play’ relocation. |

Economic Factors

Economic factors are crucial to the decision-making in the RFS application and product selection. Although the initial capital cost of RFS is usually believed to be of first importance to clients, developers and occupants, seeking sustainable building for lower operational and maintenance costs are increasingly scrutinized when planning a RFS fitout. Table 8.12 presents brief analyses of the cost concerns.
Factors Analyses

Initial capital cost Considering technical factors, there is generally more than one product available for particular environments for most RFS components. Some components are designed with different life spans or different materials for the same model. Allowing for the service life of RFS, application environment, art policy, as well as RFS system integration, the appropriate component can be narrowed after considering reasonable initial capital cost.

Running cost The running cost is usually much greater than initial capital cost in a building life cycle. So, the relatively low operation and maintenance cost endowed by RFS is expected to stimulate its implementation. Here, the running cost includes operation cost, refurbishment cost and maintenance cost. In order to reduce the running costs, underfloor HVAC system and modular PVD system are recommended because they support low energy consumption and allow flexible and speedy relocation.

Strategic Factors
Strategic factors are those pertaining to issues influencing the design complexity, construction productivity and workplace environment. Based on the previous RFS fitout constructability study, the design requires modularization and standardization, the construction calls for easy accessibility, flexibility, safety and efficiency, and the workplace environment expects flexibility, productivity and healthy and aesthetic interior. In tune with these fitout requirements, seven attributes are identified under this category, as shown in Table 8.13.

Table 8.13 Analyses of Strategic Factors

<table>
<thead>
<tr>
<th>Factors</th>
<th>Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modularization</td>
<td>• Simplified RFS fitout design and minimization of incompatibility;</td>
</tr>
<tr>
<td></td>
<td>• Efficient construction.</td>
</tr>
<tr>
<td>Accessibility</td>
<td>• Avoidance of long lead time;</td>
</tr>
<tr>
<td></td>
<td>• Avoidance of long distance transportation.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>• Easy construction, relocation and maintenance;</td>
</tr>
<tr>
<td></td>
<td>• Accommodating new business and high churns with low cost and disturbance.</td>
</tr>
<tr>
<td>Health</td>
<td>• Healthy RFS construction and maintenance;</td>
</tr>
<tr>
<td>Safety</td>
<td>• Safe RFS construction and maintenance.</td>
</tr>
<tr>
<td>Art policy</td>
<td>• Delicate office spaces;</td>
</tr>
<tr>
<td></td>
<td>• Keeping people concentrating easily on work through an artistic interior.</td>
</tr>
<tr>
<td>Productivity</td>
<td>• Supporting cost-effective and speedy RFS fitout construction and maintenance;</td>
</tr>
<tr>
<td></td>
<td>• Keeping high productive workplace environment.</td>
</tr>
</tbody>
</table>

Process-Based Conceptual Model for RFS Products Selection
After the discussion of the 16 critical factors which may influence the RFS products selection, a process-based conceptual model is formulated in Figure 8.14.
Chapter 8: Discussion and Findings

The conceptual model consists of three steps. It starts from the identification of a particular fitout environment in an office building, which may include general offices, computer/equipment rooms and lift lobbies. It then goes to the process-based selection, in which a pre-conformity among three fitout environments is conducted at first to reconcile or unify some essential technical issues. For example, an equal FFH is encouraged for all the environments to avoid steps and ramps. After that, for a particular fitout environment, technical, economic and strategic factors are considered in sequence and incorporated with the selection of potential RFS products for each component in Stage 1. The final decisions on products for all components for that particular environment are decided based on a comprehensive conformity in Stage 2. The final step is a judgment on whether the product selections for all environments are completed. A positive answer leads to the end of the model, where the final RFS products for an office building are determined. Otherwise, the model will renegotiate another selection process for the uncompleted fitout environment until all environments are considered.

The two-stage process-based selection is further interpreted below. The first stage defines a decision-making process for each component for a particular fitout environment, as shown in Figure 8.15. Technical factors under this environment for component “A” are assessed and as a result, a number of suitable products are presented. Then, economic factors and strategic factors are examined to narrow down

Figure 8.14 Process-Based Conceptual Model for RFS Product Selection
the list of products to more explicit alternatives for component “A”. The same process-based selection is also applied to other RFS components to acquire potential products.

Figure 8.15 Stage 1 – Process-Based Selection for Each RFS Component for a Particular Fitout Environment

The second stage outlines a comprehensive conformity among the available products for all components for that particular fitout environment obtained from Stage 1, as shown in Figure 8.16. The conformity process is a systematic integration process, which reconsiders technical, economic and strategic factors among the narrowed selection of potential products; coordinates and synthesizes these products for the intended application; and finally pinpoints the most appropriate product for each RFS component for that particular fitout environment.

Figure 8.16 Stage 2 – Process-Based Conformity for Each RFS Component for a Particular Fitout Environment

The RFS products procurement model is based on the selection process in which three selection cycles are conducted for the three particular fitout environments. If the building only uses RFS for one or two environments, only one or two cycles are applicable. Moreover, the selection process is an integrated program, not only
considering the match within a fitout environment but also emphasizing the
unification among all environments. It is believed that the model is conducive to the
minimization of post-construction problems due to improper use of RFS products.

8.5 Guidelines for RFS Fitout Implementation

To this end, the catalysts and barriers, constructability and five key issues associated
with RFS fitout implementation have been investigated systematically. All these
research activities endeavored from different aspects to contribute to setting up a
viable method for a RFS fitout in office buildings in Australia. However, a holistic
method of RFS implementation is still unclear. Based on the understanding of the
status quo of RFS market and industry practitioners’ knowledge and experience, this
section aims at establishing guidelines for RFS fitout implementation in the
Australian construction industry.

In line with the sequence of a project life cycle, the RFS fitout implementation
guidelines consist of specific instructions pertaining to each project stage from the
feasibility stage onwards. The strength of the guidelines focuses on guiding the RFS
fitout rather than the whole project delivery; however, its content may involve some
descriptions of whole project progress for the purpose of integrating RFS fitout into
the whole project delivery.

As previously discussed, nominated specialist contractors under the CM/GC method
is highlighted from a set of contracting strategies applicable to the integrated delivery
of the RFS fitout and the whole project. Accordingly, the nominated specialist
contractors under the CM/GC method is chosen as the basic contracting strategy in
the guideline development.

8.5.1 Feasibility Stage

The RFS fitout plan needs to be considered at the feasibility stage due to its
significant impact on the planning, design and construction of the whole project. Five
main activities are highlighted. The early client team is established to develop project
brief and objectives. Then, the RFS fitout purposes should align with the project objectives and its suitability needs to be ascertained based on the assessment of the risks and benefits associated with the RFS use in this particular project. The 5 SIFs pertaining to cost concerns should be followed for risk-and-benefit analysis, which however should not be limited to the 5 SIFs. Any potential factors resulting in risks need to be carefully deliberated as well. On the other hand, due to the general unfamiliarity with RFS implementation as indicated by the 8 SIFs pertaining to industry practitioners’ knowledge, setting up a competent project team involving most design and construction skills, particularly RFS specialist contractors, for construction knowledge inputs is essential to the improvement of RFS fitout constructability. In order to facilitate this process, an appropriate contracting strategy is indispensable. In the guidelines, the contracting strategy with nominated specialist contractors under the CM/GC is chosen.

The early client team consists of the client or the client’s representative and other early client team members, e.g. cost and construction consultants, project advisors, etc. The objectives, team roles and critical details pertaining to the feasibility stage are presented in Table 8.14. Once the RFS fitout purposes is ascertained, the RFS application is determined, the project team is established and the contracting strategy is defined, the RFS fitout and whole project go to the conceptual design stage.

8.5.2 Conceptual Design Stage

The main activities in this stage involve team education, development of conceptual design for the RFS fitout and the whole project and appointment of management contractor. Based on the project brief, the conceptual design is developed under the cooperation of design team and RFS specialist contractors. Prior to the conceptual design, the 7 SIFs pertaining to structural constraints and RFS service integration need to be carefully studied in order to achieve integrated design solutions. Once the conceptual design is completed, the management contractor is selected through competitive lump sum tenders called for design and documentation consultant fees, construction management fees, overheads and profit. The lump sum tender does not include the cost of construction.
Objectives

- Pinpoint the RFS fitout purposes and assess its suitability for the proposed office building project;
- Set up the RFS fitout constructability policy and explore the corresponding construction knowledge inputs;
- Determine contracting strategy for an integrated delivery of RFS fitout and whole project (in this case, the nominated specialist contractors under CM/GC method is selected);
- Establish a knowledgeable project team involving specialist contractors with robust RFS fitout construction knowledge and experience.

Team roles

*Client or client’s representative:*

- Express his/her needs clearly to the early client team;
- Propose a budget for the whole project delivery;
- Organize the activities of the early client team.

*Early client team:*

- Develop a clear project brief and project objectives;
- Rationalize the purposes of RFS fitout application as per the project objectives;
- Make decisions on RFS application and ascertain construction knowledge inputs;
- Organize a knowledgeable project team involving competent RFS fitout specialist contractors particularly;
- Choose an appropriate contracting strategy for an integrated delivery of RFS fitout and whole project.

Critical details

- The client’s needs must be fully understood and translated into a project brief accurately. If interested in adopting RFS fitout for any reasons, the client needs to present it to the team directly and timely in order to avoid unnecessary evaluation work on alternatives in the early stage.
- The purposes of using RFS fitout must be evaluated against the whole project objectives, referring to Figure 8.4.
- The risks and benefits associated with RFS fitout must be justified against the proposed project as per the 5 SIFs pertaining to cost concerns, referring to Checklist A in Appendix 14, based on which a team decision is made as to the suitability of RSF fitout application.
- Construction knowledge inputs for RFS fitout are recognized and the available resources are identified after discussion within the client team.
- The contracting strategy is chosen, based on which the project team is established at the end of the feasibility stage, referring to Figure 8.12-a. The team consist of architect, consulting engineers, quantity surveyor, user representatives, maintenance representatives, project manager representing the client, RFS specialist contractors, etc. Members with RFS fitout experience are preferred.
- The team members’ RFS fitout and constructability knowledge need to be assessed, referring to Checklist B in Appendix 14.
- Initial constructability session is conducted to establish RFS fitout constructability policy and facilitate the above activities in the feasibility stage, referring to Figure 8.2 and 8.9.

The team consists of the project manager representing the client, architect, consulting engineers, quantity surveyor, user and maintenance representatives, RFS fitout specialist contractors, etc. The objectives, team roles and critical details pertaining to the conceptual design stage are presented in Table 8.15. Once the conceptual design is completed, the management contractor is appointed, and coordinated plans for design and construction are prepared, the project goes to the detailed design stage.
### 8.5.3 Detailed Design Stage

At this stage, all efforts aim to ensure everything derived from the conceptual design has been further developed and captured in the detailed design, documented and tendered on their completion. In particular, three main activities are highlighted in
the design development process. Firstly, the detailed design of the RFS fitout and the whole project are developed based on the conceptual design; secondly, the management contractor offers a Guaranteed Construction Sum (GCS) under the TGCS, and prepares trade package documentations. Thirdly, non-RFS specialist contractors are engaged through competitive tendering and the more specific coordinated construction plan is developed by the management contractor with the assistance of specialist contractors. Above all, the 16 PLCFs pertaining to the RFS detailed design needs to be fully studied in the detailed design process.

The team consists of the project manager representing the client, architect, consulting engineers, quantity surveyor, management contractor, the RFS fitout specialist contractors, etc. The objectives, team roles and critical details pertaining to the detailed design stage are presented in Table 8.16. Once the detailed design is completed, non-RFS fitout specialist contractors are appointed, and a more specific coordinated construction plan is prepared, the project goes to the construction stage.

8.5.4 Construction Stage

The construction stage includes three main activities, i.e. construction preparation, execution and completion. Conducted by the specialist contractors, the RFS fitout construction needs to conform to the pre-described specifications. The 12 PLCFs pertaining to RFS service construction need to be followed by the construction team. The RFS fitout construction quality is influenced by four factors, i.e. cooperation and communication among RFS specialist contractors, effective coordination by the management contractor, timely solutions to design problems arising in the construction process, and assistance from non-RFS specialist contractors. Moreover, a successful RFS fitout construction includes not only the appropriate installation of RFS services but also its holistic integration into the whole project construction.

The team consists of the project manager representing the client, architect, consulting engineers, management contractor, RFS specialist contractors, other subcontractors, etc. The objectives, team roles and critical details pertaining to the construction stage are presented in Table 8.17. Once the whole construction works are completed and pass the project acceptance inspection, the project goes to the post-construction stage.
Chapter 8: Discussion and Findings

Table 8.16 Guideline for RFS Fitout Implementation in Detailed Design Stage

| Objectives | • Turn the approved conceptual design into viable detailed design under the TGCS and approved by the project manager;  
|           | • Integrate the RFS fitout detailed design with the whole project detailed design;  
|           | • Prepare non-RFS fitout trade package documentation and engage specialist contractors with competitive tendering;  
|           | • Select RFS products as per the specifications of the RFS fitout detailed design. |

| Team roles | Project manager representing the client:  
|           | • Supervise the construction manager’s work;  
|           | • Approve the detailed design and the GCS presented by the management contractor;  
|           | • Check constructability implementation.  
|           | Architect and consulting engineers:  
|           | • Specify the detailed design as per the approved conceptual design;  
|           | • Specify the RFS fitout detailed design with assistance from specialist contractors;  
|           | • Explore innovative design innovation to enhance RFS fitout integration;  
|           | • Select RFS products as per the detailed design solutions;  
|           | • Formulate construction specifications.  
|           | RFS fitout specialist contractors:  
|           | • Supply construction knowledge to designers for optimized and innovative designs;  
|           | • Assist designers in formulating RFS fitout construction specifications;  
|           | • Select RFS products as per the detailed design solutions.  
|           | Quantity surveyor:  
|           | • Do capital cost planning for the whole project and RFS fitout;  
|           | • Work with the design team for the preparation of RFS product procurement.  
|           | Management contractor:  
|           | • Take over employment of the design team and RFS fitout specialist contractors from the project manager and manage them to achieve best design solutions;  
|           | • Offer a GCS under the TGCS at the completion of the design;  
|           | • Prepare the documentation and tendering for the non-RFS fitout trade packages;  
|           | • Nominate non-RFS fitout specialist contractors as per competitive tendering;  
|           | • Develop coordinated construction plan in depth. |

| Critical details | The design solutions need to accommodate the 16 PLCFs appropriately in the detailed design, referring to Checklist E in Appendix 14.  
|                  | In-depth cooperation and communication are encouraged among designers, RFS specialist contractors and management contractor to explore innovative designs and enhance RFS fitout design integration, referring to Figure 8.6 and 8.10.  
|                  | Construction specifications are developed for RFS fitout delivery with knowledge inputs from specialist contractors.  
|                  | Competent management from the management contractor is essential for supervising the design team to be committed to a quality design in collaboration with RFS specialist contractors, referring to Figure 8.12-a.  
|                  | RFS service products are selected based on the process-based conceptual model, referring to Figure 8.14, 8.15 and 8.16.  
|                  | A GCS without exceeding the TGCS is proposed by the management contractor and approved by the client after the completion of the detailed design;  
|                  | Design documentations for non-RFS fitout trades are prepared by management contractor after the detailed design, and the corresponding specialist contractors are selected through competitive tendering; RFS fitout design documentations are also prepared but accepted by the nominated specialist contractors without tendering.  
|                  | More specific coordinated construction plan and specifications are developed by the management contractor and design team in collaboration with the specialist contractors.  
|                  | RFS fitout design process meetings and constructability evaluation workshop are organized to facilitate the above activities and enhance RFS constructability, referring to Figure 8.9. |
Table 8.17 Guideline for RFS Fitout Implementation in Construction Stage

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Team roles</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Construct RFS services strictly in conformity with the construction specifications;</td>
<td>Project manager representing the client:</td>
</tr>
<tr>
<td>• Integrate the RFS fitout construction with the whole project construction;</td>
<td>• Supervise the construction manager’s work;</td>
</tr>
<tr>
<td>• Construct the RFS service and whole project in time, in budget and with quality.</td>
<td>• Approve the completed construction project;</td>
</tr>
<tr>
<td></td>
<td>• Check constructability implementation.</td>
</tr>
</tbody>
</table>

Architect and consulting engineers:
• Explain ambiguities within the designs and specifications;
• Assist the management contractor and project manager in construction supervision.

Management contractor:
• Coordinate the construction procedures and manage construction sites;
• Ensure proper connection of RFS fitout construction and other trade packages;
• Supervise the construction quality of RFS service and other trade packages;
• Complete the construction work as per the project objectives;
• Take the consequence of any costs over the GCS, while share the savings with the clients if the actual cost of construction is less than the GCS.

RFS fitout specialist contractors:
• Construct the RFS fitout as per the construction specifications;
• Work collaboratively with other specialist contractors to enhance RFS integration and constructability.

Other specialist contractors:
• Construct their own trades as per the construction specifications;
• Work collaboratively with RFS specialist contractors to enhance RFS integration and constructability.

Critical details
• The RFS fitout construction needs to accommodate the 12 PLCFs appropriately in the construction process, referring to Checklist F in Appendix 14.
• RFS products are procured and transported to the construction site in sequence.
• In-depth cooperation and communication are encouraged among all specialist contractors, management contractor and design team for an integrated construction process of RFS fitout and whole project, referring to Figure 8.7.
• Skilful coordination of construction process is critical to the success of RFS fitout and whole project.
• Construction specifications must be strictly followed in the process of RFS service installation.
• RFS fitout construction is strongly recommended to follow the procedures as outlined in Figure 8.8.
• The quality acceptance inspection is conducted at the completion of whole project;
• The cost of construction is summed up at the completion of project with savings shared between management contractor and the client whereas extra cost beard by the management contractor.
• RFS fitout site progress meetings are organized to facilitate the above activities and enhance RFS constructability, referring to Figure 8.9.

8.5.5 Post-Construction Stage

Post-construction activities involve education to occupants on RFS operation and maintenance, a review of the RFS fitout and whole project constructability.
implementation, the identification of problems associated with RFS service operation and maintenance, and exploration of appropriate solutions to these problems through optimized RFS fitout design and construction. In addition, the feedbacks of the reviews and post-construction problems and solutions need to be summarized and recorded for the reference of future projects.

The team ideally consists of project manager, architect, consulting engineers, management contractor, RFS fitout specialist contractors, user and maintenance representatives, etc. The objectives, team roles and critical details pertaining to the post-construction stage are presented in Table 8.18.

### 8.5.6 Framework for the RFS Fitout Implementation

A framework for the RFS fitout implementation guidelines is presented in Figure 8.17, which applies to the whole project life cycle from the feasibility stage to the post-construction stage. The framework has been developed to differentiate between main activities and subsidiary activities as indicated by the broad-brush and single line rectangle boxes respectively. A total of 18 main activities and 39 subsidiary activities are presented in the sequence of the RFS fitout and whole project delivery. The guideline activities start from establishing early client teams and end with the recording of good practices and lessons for future project references. As all the activities have been discussed in the previous guideline tables pertaining to different project stages, they will not be repeated here. However, it should be noted that some subsidiary activities are not depicted in the figure due to the space limitation or partial content repetition.

The concepts described in the guidelines represent a standard practice for the RFS fitout project delivery with nominated specialist contractors under the CM/GC contracting strategy. The development of guidelines for other contracting strategies can use these guidelines as a reference with appropriate variations. Industry practitioners are encouraged to adopt this guideline; however, it is not a legal document and is not intended to supersede or replace contractual arrangements designed to satisfy specific situations.
### Chapter 8: Discussion and Findings

Table 8.18 Guideline for RFS Fitout Implementation in Post-Construction Stage

<table>
<thead>
<tr>
<th>Team roles</th>
<th>Project manager representing the client:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Educate occupants with the right way for RFS service operation and maintenance;</td>
</tr>
<tr>
<td></td>
<td>• Organize the RFS service review against project objectives;</td>
</tr>
<tr>
<td></td>
<td>• Summarize the feedback for future reference.</td>
</tr>
<tr>
<td></td>
<td>Architect and consulting engineers:</td>
</tr>
<tr>
<td></td>
<td>• Summarize any problems and record good practice in RFS fitout design;</td>
</tr>
<tr>
<td></td>
<td>• Seek potential design solutions to problems arising from the RFS service operation and maintenance.</td>
</tr>
<tr>
<td></td>
<td>RFS fitout specialist contractors:</td>
</tr>
<tr>
<td></td>
<td>• Summarize any problems and record good practice in RFS fitout design and construction;</td>
</tr>
<tr>
<td></td>
<td>• Seek potential design and construction solutions to problems arising from RFS service operation and maintenance.</td>
</tr>
<tr>
<td></td>
<td>Management contractor:</td>
</tr>
<tr>
<td></td>
<td>• Review RFS fitout construction process and summarize the lessons for future reference;</td>
</tr>
<tr>
<td></td>
<td>• Review and summarize management practices to enhance team cooperation and communication in the future project for more integrated delivery of similar projects.</td>
</tr>
<tr>
<td></td>
<td>User and maintenance representatives:</td>
</tr>
<tr>
<td></td>
<td>• Learn the right way for RFS service operation and maintenance;</td>
</tr>
<tr>
<td></td>
<td>• Present problems arising from RFS service operation and maintenance.</td>
</tr>
</tbody>
</table>

| Critical details                | • The specifications pertaining to the 8 PLCFs in the RFS post-construction stage need to be advised to the users prior to the operation of RFS services, referring to Checklist G in Appendix 14. |
|                                | • Open-minded constructability review is conducted to expose cruces in the RFS fitout design and construction. |
|                                | • Problems in the post-construction stage are presented by users after a period of RFS service operation and maintenance. |
|                                | • Solutions to the problems need be explored through optimized RFS fitout design and construction by the designers and specialist contractors. |
|                                | • Good practices are recorded for future reference.                                                      |
|                                | • All feedbacks are summarized for the reference of future RFS fitout projects.                          |
|                                | • RFS fitout post-construction review is organized to facilitate the above activities, referring to Figure 8.9. |

#### 8.6 Validation of Research Outcomes

In order to validate the research outcomes, a questionnaire was designed with six Likert scale questions and one open-ended question. The Likert questions were used to examine how strongly the respondents agree or disagree with the 5 key issues influencing RFS fitout project delivery and the effectiveness of the guidelines for the
RFS fitout implementation, on a 5-point scale with 1 representing *strongly disagree* and 5 representing *strongly agree*. The open-ended question was designed to explore the respondents’ further comment on this research.

The questionnaire was developed under the collaboration of the researcher, his principal supervisor and associated supervisor. The questionnaire was sent out through electronic mail to 19 respondents who had been interviewees in this research, on 5 September 2004. After three weeks, a total of 13 feedbacks were received and all of them were useable. The mean value of the feedback to each question is calculated using Microsoft Excel and the result is presented in Table 8.19.

<table>
<thead>
<tr>
<th>Issue 1</th>
<th>Issue 2</th>
<th>Issue 3</th>
<th>Issue 4</th>
<th>Issue 5</th>
<th>Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Value</td>
<td>4.31</td>
<td>4.08</td>
<td>4.62</td>
<td>4.31</td>
<td>4.54</td>
</tr>
</tbody>
</table>

As discussed earlier, the five key issues include the integration of constructability with RFS project development process (Issue 1), early involvement of RFS fitout specialist contractors (Issue 2), cooperation and communication in project team (Issue 3), appropriate contracting strategy to integrate the RFS fitout and whole project delivery (Issue 4) and appropriate RFS product procurement (Issue 5). All the mean values are more than 4, indicating that the five key issues are strongly agreed with significant influences on the RFS fitout project delivery by industry people with RFS experience and knowledge. Meanwhile, the mean value for the assessment of guideline effectiveness is 4.23, revealing a high acknowledgement from the industry practitioners. It should be noted that all the feedback ratings to the above 6 issues are more than 3, which further justifies the validity of the research outcomes.

Most of the comments from the open-ended question acknowledged the value of this research. Typical comments include:

“The guidelines are extremely well thought out and packaged, easily understood and definitely useable.”

“The guidelines are complete and the involvement of nominated RFS specialist contractors is of significant practical importance.”
Chapter 8: Discussion and Findings

[Diagram showing the process of RFS Implementation for the Fitout of Office Buildings]

Legend:
- Key activities
- Activities
- SIFs
- PLCFs
- Team members

Figure 8.17 Framework for RFS Implementation for the Fitout of Office Buildings
Meanwhile, two suggestions are raised for attention. Firstly, one respondent advised that the guidelines should accommodate different procurement methodologies. Secondly, two respondents argued that the impact of the early involvement of specialist contactors on the project team organizational culture should be considered. Due to the time limitation, the two constructive opinions will not be further studied but highlighted in the next chapter for future research.

8.7 Summary

The catalysts stimulating the RFS implementation in Australia were analyzed, based on the previous research findings. The industry practitioners with RFS experience had high awareness of and interest in RFS. For general practitioners, consultants had a high awareness level and interest as well, while other practitioners have medium or low awareness and interest in these respects. All perceived RFS fitout advantages were justified. The industry practitioners showed high confidence in a RFS promising future although those without RFS experience indicated a low willingness to use RFS due to their concerns of risks and benefits. The improved RFS adaptability was also acknowledged by the general recognition of the RFS application environments, the integration of underfloor HVAC system, the identification of many good practices, and the right understanding of RFS LCC and capital cost investment.

The barriers hindering RFS implementation were discussed then, indicating that the 20 SIFs can influence the RFS fitout DCOM while the 15 problems in the post-construction stage are mainly due to improper RFS fitout DCOM. A synthetic process of the discussion results exposed 16 PLCFs, 12 PLCFs and 8 PLCFs pertaining to RFS design, construction, and operation and maintenance respectively. It was also ascertained that the SIFs have more influences on RFS design and construction than on its operation and maintenance while the real problems are attributed more to RFS design and construction as well.

In order to minimize the post-construction problems, the 20 SIFs and 36 PLCFs were integrated into the RFS fitout project delivery through a range of constructability
activities. The 12 constructability principles were studied to identify key issues for RFS fitout project delivery. As a result, the integration of SIFs and PLCFs into RFS fitout constructability implementation procedures was explored; construction knowledge inputs were identified; significant team skills were recognized; the alignment of RFS fitout purposes with corporate and project objectives was investigated; project planning, design and construction programs were studied; construction methodology, accessibility, specifications and innovative RFS fitout sequencing were proposed; available resources and external factors influencing RFS delivery were ascertained; and the necessity of post-construction reviews and feedback mechanisms was argued.

As per the RFS fitout constructability discussion, five key issues were highlighted for further investigation because of their significant influence on the RFS fitout project delivery. Accordingly, a framework for the integration of constructability with the RFS PDP was established. The RFS fitout specialist contractors’ involvement styles and the team cooperation and communication were studied, and then four typical contracting strategies were studied and nominated specialist contractors under CM/GC was recommended as the most appropriate one for the integrated delivery of the RFS fitout and the whole project. In addition, a process-based conceptual model for RFS products selection was developed to minimize RFS service running problems due to the improper use of RFS products.

Based on nominated specialist contractors and the CM/GC contracting strategy, guidelines for the RFS implementation for the fitout of office buildings in Australia was established as the final research outcome. Finally, a questionnaire was used to get industry practitioners’ feedbacks on the five key issues and the guidelines and to validate the research outcomes.
CHAPTER 9
CONCLUSIONS AND CONTRIBUTIONS

9.1 Introduction

Research problems and objectives were identified in Chapter 1 and Chapter 2, which led to the development of a comprehensive research methodology described in Chapter 3. The questionnaire data analysis and findings in Chapter 4 reported the general recognition of RFS, awareness of RFS constructability and proposition to the status quo and future of RFS implementation among the industry practitioners and barriers associated with RFS fitout implementation. Chapter 5 further investigated the RFS fitout advantages and the barriers derived from the questionnaire survey, and exposed 20 SIFs and 15 real problems and their possible solutions through semi-structured interviews with industry practitioners with robust RFS knowledge and experience. Chapter 6 presented the site observation and focus group data analysis and findings, exploring RFS specifications, good practices and problems, justifying RFS fitout advantages and validating the interview findings. Chapter 7 established a LCC comparison model between the RFS fitout and the traditional method and justified the RFS LCC advantage using a case study. Based on the findings obtained from the previous research instruments, Chapter 8 discussed the catalysts and problems for RFS implementation, exposed 36 PLCFs, integrated the SIFs and PLCFs with RFS delivery through constructability activities, further investigated constructability integration, project contracting strategies and product procurement, and finally formulated guidelines for the RFS fitout implementation in Australia.

Based on the findings of previous research instruments and discussions in Chapter 8, this chapter puts forward the conclusions, contributions and implications of the RFS research. Conclusions are discussed at first in line with the research problems and
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objectives, and then as contributions to the academic knowledge base and implications to practice deliberated. After that, the limitations of the study are described and future research areas are recommended.

9.2 Conclusions to Research Objectives

Conclusions are presented in this section in light of the research objectives. Research problems are also answered based on the synthesis of the answers to the research objectives. The objectives originally proposed are:

1. To justify the RFS advantages for office building fitout compared with the traditional fitout method;
2. To identify and present appropriate specifications of RFS products and applications in order to improve the industry practitioners’ awareness on RFS fitout;
3. To identify and seek potential solutions to barriers associated with RFS fitout implementation;
4. To overcome the barriers and integrate their solutions into RFS project delivery using constructability study; and
5. To formulate viable guidelines for RFS fitout implementation in office buildings in the Australian construction industry.

The first and second objectives are intended to answer the first research question: *how to justify the advantages of RFS fitout compared with the traditional methods and improve public awareness of RFS fitout if the Australian industry practitioners lack information in this regard?* The rest three objectives are intended to answer the second research questions: *how to integrate the barriers and their solutions into RFS fitout project delivery if some barriers hindering RFS implementation do exist?*

9.2.1 Objective 1: The Advantages of RFS Fitout Has Been Justified Compared with Traditional Fitout Method

RFS fitout advantages such as flexibility, ergonomics, workplace productivity, time-saving and cost-saving, were argued by different researchers as indicated in Chapter 2. However, there was not a study to review all these RFS merits systematically. In addition, the Australian industry practitioners’ awareness of these perceived RFS
advantages was not clear either. As such, the questionnaire survey was conducted to pinpoint the industry practitioners’ awareness of RFS fitout advantages. With the aid of interview survey, site observations, focus groups and LCC comparison analysis, the above perceived advantages associated with RFS fitout were justified. Since the feedbacks are from the industry practitioners with both robust RFS fitout and traditional fitout experience, the result of the justification is reliable.

**Flexibility**

- Flexibility, as an RFS fitout advantage, is highly recognized among the industry practitioners regardless of their experience and professions.
- According to the questionnaire survey, the awareness of the demonstration of flexibility is only limited to reconfiguration and maintenance. However, this is not the reality. Flexible construction is generally recognized on the construction sites visited. As per their daily occupancy, the real users in office buildings with RFS services reveal a range of demonstration of flexibility:
  - Easy reconfiguration to accommodate task and ambient office space requirement;
  - Easy relocation of PVD outlets and air diffusers for minor reorganizations in individual workstations;
  - Enough space to accommodate the bulky cables and wires particularly for dealing rooms and computer/equipment rooms;
  - Cost-saving and speedy retrofit for the whole space to meet market demands; and
  - Easy access for underfloor service maintenance.

**Ergonomics, Time-Saving and Improved Workplace Productivity**

- Ergonomics, time-saving and improved workplace productivity are poorly recognized among the industry practitioners regardless of their experience and professions according to the questionnaire feedback. However, the inexperienced industry practitioners moderately agree with time-saving, consultants moderately acknowledge the improved workplace productivity, and commercial real estate agents moderately agree with the time-saving owing to the use of RFS fitout.
- The interviews with industry practitioners having robust RFS experience and knowledge shows that ergonomics, time-saving and improved workplace
productivity are all positively acknowledged. This result is inconsistent with the questionnaire feedback, which might be due to three reasons:

- The researcher could interpret the meaning of these terminologies to the interviewees with face-to-face talking;
- The research could enlighten and stimulate the interviewees to comment on all the perceived RFS merits at length and at their best;
- The questionnaire results might not reflect the respondents’ true understanding of RFS merits for some reasons.

- Through the site observations and focus group discussions, the demonstrations of the three RFS fitout advantages are found in the following aspects:

  **Ergonomics:**
  - Better air quality;
  - Enhanced thermal comfort to satisfy individual preferences;
  - Orderliness and cleanliness of the workplace environment;
  - Comfortable ambient lighting minimizing glare; and
  - Accommodation of personal layout preferences.

  **Time-Saving:**
  - Low requirement of accurate subfloor levelness avoiding time-consuming screeding;
  - Floor-level construction work avoiding time for ladder layout and climb;
  - Less time for workplace relocation and reconfiguration;
  - Less time for malfunction serving; and
  - Less time for technology upgrades.

  **Improved Workplace Productivity:**
  - Less absenteeism;
  - Less interruption due to maintenance or relocation;
  - Long time concentration on works due to better workplace environment; and
  - Good feeling during work.

**Cost Benefits**
- The fitout cost of RFS is higher than that of the traditional fitout method, which is perceived by most industry practitioners regardless of their experience and professions according to the questionnaire and interview surveys.
The LCC comparative study found that the major cost differences between the new and traditional methods involve initial capital cost difference and running cost difference, which consists of 14 elements, as shown in Figure 9.1. Prior to the setup of LCC comparison model, assumptions were made to define the application scope of the model. The RFS fitout scenario was supposed to be an existing floor plate without services in for the purpose of neutralization between new buildings and retrofit projects. The project was owner occupied office building space. Finally, a LCC comparison model has been established considering the time value of money, as depicted in Equation (7-1) to (7-6).

Figure 9.1 Elements of Initial Capital Cost Difference and Running Cost Difference

- The case study of the LCC comparison contributes to the following findings:
  - The initial capital cost of RFS fitout is slightly higher ($16,940) compared with the traditional fitout method; however, the running cost in RFS environment is much reduced ($8,212 per year). The main contributors to the higher capital cost of RFS...
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fitout include the raised floor related capital cost and the floor covering cost. The main contributors to the lower running cost include improved workplace productivity, reduced absenteeism, and lower energy consumption.

➢ The NPV of RFS fitout LCC over 10 years term and with a 7% discount rate was $40,734 lower than that of the traditional fitout, and the payback time was 2.31 years. According to the interview survey feedback, a rational payback time that most developers could accept was up to 5 years and the figure might be longer for an owner occupied building. So, it was concluded that the LCC of the proposed RFS fitout project was positive.

➢ The single parameter sensitivity analyses highlighted that the improved workplace productivity has the most significant influence on the LCC comparison. The reduced absenteeism also has a strong influence on the LCC comparison results whereas the discount rate and the reduced energy consumption have weak effects. Furthermore, the multiple parameters sensitivity analyses indicated that the RFS fitout is not desirable provided that both reduced absenteeism and improved workplace productivity are not taken into account. Reversely, under the optimistic condition, the payback time is less than 2 years no matter what kind of discount rate is chosen.

9.2.2 Objective 2: Specifications of Products and Applications Have Been Developed to Improve the Industry Practitioners’ Awareness on RFS Fitout

The questionnaire results revealed that most industry practitioners with RFS experience have higher awareness of and interest in RFS implementation than those without RFS experience. Consultants including architects and consulting engineers have high awareness of and interest in RFS implementation; general contractors and clients have medium awareness and interest; developers have low awareness and interest; and commercial real estate agents have extremely low awareness and low interest. As far as the knowledge in RFS design and construction is concerned, consultants are not as knowledgeable whereas other industry practitioners are extremely lacking in knowledge in this regard. The questionnaire results also indicated that most industry practitioners know RFS applications in general office space and computer rooms, but lack specific knowledge in RFS product classification and applications. Although there are other ways to encourage the industry practitioners’ awareness and interest, the basic way is to enhance industry
practitioners’ awareness of RFS products and application specifications. Accordingly, RFS products specifications and application specifications in office buildings were developed based on the observations to the raised floor company and six office building sites with RFS fitout.

**Specifications of RFS Products**

- The specifications of RFS products describe the *classifications* and *features* of typical RFS components, i.e. panels, understructures (including pedestals and stringers), floor coverings, underfloor HVAC system and underfloor PVD system.
- Main features of each component are presented and explained. Take raised floor panels as an example:
  - Classifications of panels include solid panels, perforated panels and grate panels;
  - Features of raised floor panels include: panels are normally manufactured with 600mm by 600mm in size, but 750mm by 750mm sized panels are also available for special fitout purposes; panels are made with different but enough strength to withstand loads for different fitout environments; as to panel material, it can be concrete core or fibre core for variable needs; Panel surface can be a full hard top sheet with epoxy paint finish or bare top ready for carpet tiles, etc.
  - To give a better idea of the available products, most components were presented with pictures taken on the construction and existing office building sites.

**Specifications of RFS Applications**

- The specifications of RFS applications define the *performance standards* in different fitout environments in office buildings.
  - General office space, computer/equipment rooms, and lift lobby and dealing rooms are found as the most typical environments, in which varying *equipment loads*, *human density* and *foot traffic* exist. The human-related working conditions such as *air quality*, *temperature* and *ventilation* are also changing in these places. Three sets of application specifications were formulated for the four typical fitout environments. Lift lobby and dealing rooms have many common characteristics so that they were grouped together in the development of their specifications.
  - Generally speaking, *medium* and *heavy load* performance standards apply to general office space; *medium*, *heavy* and *extra heavy* standards apply to
computer/equipment rooms; and medium and heavy standards apply to lift lobby and dealing rooms. The load performance standards are defined in Table 6.2 – 6.4. Take the general office space as an example:

- Medium load performance standard applies to general office where people, workstations and normal office equipment occupy, and normal levels of foot traffic and infrequent rolling loads exist.
- Heavy load performance standard applies to heavy duty office where high densities of people and equipment occupy, and extreme levels of foot traffic, heavy equipment loads and frequent rolling loads exist.

- Criteria for typical RFS products selection are presented. For example, solid panels, cornerlock method, PosiTile, swirl diffusers and fan air terminals, etc. are recommended in general office space, while perforated/grate panels, stringers, high pressure laminates, etc. are recommended in computer/equipment rooms.

The RFS specifications will not only inform industry practitioners of the basic classifications and features of typical RFS products but also present them with the performance standards in the typical fitout environments in office buildings.

To this end, the above justification of RFS fitout advantages and formulation of RFS specifications answered the first research question. The questionnaire survey ascertained that most industry practitioners are not aware of RFS fitout advantages, except for flexibility, and lack of knowledge in RFS fitout implementation. Under these scenarios, research activities combining semi-structured interview, site observations, focus group discussions and LCC comparison were carried out, which justified RFS merits and developed specifications of RFS products and applications.

It is believed that all these efforts can contribute to improving the industry practitioners’ awareness of RFS advantages and knowledge.

9.2.3 Objective 3: Barriers Associated with RFS Fitout Implementation Have Been Identified and the Solutions Attained.

The questionnaire highlighted 44 potential issues associated with RFS fitout implementation. Based on their nature, the issues could be potential factors
influencing RFS fitout planning or potential problems in RFS service operation and maintenance. Semi-structured interviews were then conducted to highlight significant influence factors (SIFs) from non-SIFs and real problems from false problems and seek possible solutions to accommodate them. Site observation and focus groups were undertaken to validate these SIFs and real problems.

**Significant Influence Factors**

- A total of 20 SIFs in four categories were identified and validated, as shown in Figure 9.2.

![Figure 9.2 SIFs pertaining to RFS Fitout Planning](image)

- These SIFs can influence RFS fitout planning and should be fully deliberated in the feasibility and conceptual design stage. The decision-makings on these SIFs will directly influence the RFS fitout design, construction, operation and maintenance.
- The conceptual solutions to these SIFs were obtained in the interview survey, and refined in the discussion chapter to the following aspects:
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Structure Constraints:
- Explore building structural features and assess RFS adaptability to retrofit projects;
- Integrate RFS features in building design and encourage structural innovation for new buildings; and
- Accept or reject underfloor HVAC system on a rational basis.

RFS Service Integration:
- Assess underfloor service integration;
- Determine an appropriate FFH for underfloor service integration;
- Review project cost objective; and
- Predict impacts of any potential incompatibility.

Industry practitioners’ knowledge:
- Establish a knowledgeable team to enhance project cooperation;
- Educate project team with RFS construction knowledge;
- Get early construction inputs into design; and
- Select an appropriate project delivery method.

Cost Concerns:
- Enhance industry practitioners’ recognition of LCC;
- Carry out research to justify the LCC benefit of RFS fitout;
- Encourage the concept of risks and benefits; and
- Determine RFS fitout responsibility at early stage.

Real Problems
- Fifteen real problems associated with RFS service operation and maintenance were identified and validated, as shown in Figure 9.2, which consist of 6 major problems and 9 minor problems due to different frequency of occurrence.

![Figure 9.3 Real Problems pertaining to RFS Service Operation and Maintenance](image-url)
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- The conceptual solutions to these real problems were obtained in the interview survey, and refined in the discussion chapter to the 36 project level critical factors (PLCFs) pertaining to the RFS DCOM. These PLCFs include 16 pertaining to RFS fitout design, 12 pertaining to RFS fitout construction and 8 pertaining to RFS service operation and maintenance. They are influenced by decision-making on the 20 SIFs and, if not properly considered, will result in problems in the post-construction stage, as shown in Figure 9.4.

9.2.4 Objective 4: The SIFs and PLCFs Have Been Integrated into the RFS Project Delivery Using Constructability Study

The questionnaire survey indicated that general industry practitioners do not have a holistic knowledge of RFS fitout constructability. Quantity surveyor, construction
and cost consultants’ roles were poorly recognized as essential team skills; D&B and CM/GC contracting forms were generally not appreciated for the improvement of RFS fitout constructability, etc. All these issues may retard the integration of the 20 SIFs and 36 PLCFs into the RFS fitout project delivery. As such, with the aid of the 12 constructability principles, a comprehensive constructability study explored the best way to accommodate these RFS fitout factors. As a result, the following knowledge was gained.

- The 20 SIFs are deliberated in the feasibility and conceptual design stages for a good preparation of RFS fitout project delivery, while the 36 PLCFs need to be accommodated rationally in the RFS fitout DCOM. The integration of these important factors to enhance RFS constructability relies on the full commitment of whole project team.
- The early involvement of specialist contractors is essential for construction knowledge inputs in the RFS fitout planning, construction coordination program, products procurement and contracting strategy.
- The key criteria for appointing team members include knowledge of constructability and RFS implementation, willingness of constructability commitment and communication skills.
- The risks and benefits associated with RFS fitout need to be analyzed at the early stage of the project and aligned with corporate and project objectives in order to assess RFS suitability for this particular project on a rational basis.
- RFS fitout programs ensure that all the planning, design and construction activities can be organized appropriately to support the integration of key factors into the project delivery. Overall program, design program and construction program need to be established for the integration of the 20 SIFs, 16 PLCFs pertaining to RFS fitout design and 12 PLCFs pertaining to construction into the corresponding project stages.
- The optimization of RFS construction methods and the selection of appropriate RFS products can support efficient and quality construction and meanwhile meet the fitout environment needs.
- The availability of personnel, materials and equipment for construction activities is important for the RFS fitout construction. All the indispensable materials and resources need to be considered in advance in the planning and design stages.
The construction specifications need to be defined to ensure the RFS fitout quality and accommodate the 12 PLCFs in RFS fitout construction. Key issues pertaining to RFS service construction include subfloor treatment, construction environment, panel locking methods, air leakage testing, dust removal, etc.

The construction innovation aims to enhance RFS constructability through innovative sequencing of site activities and use of special tools. An innovative sequencing of RFS service construction is recommended to follow.

The project’s geographic location, market conditions, environment policy, financial policy and political issues can influence the RFS fitout project delivery.

Post-construction reviews need to be organized to assess the RFS constructability implementation, identify problems in its performance, and explore solutions and improvements for the future reference. The 8 PLCFs pertaining to RFS service operation and maintenance need to be provided to the clients in a timely manner.

Based on the findings of the constructability study, 5 key issues with significant influences on the RFS fitout project delivery were highlighted, as shown in Figure 9.5. And the further investigation of these issues contributes to the following findings.

**Constructability Framework**

- A framework for the integration of constructability with the RFS fitout project delivery was established, which consists of 7 major constructability functions, i.e.
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Initial RFS Constructability Session, Project Team Selection, Strategic Constructability Workshop, Design Process Meetings, Constructability Evaluation Workshop, Site Progress Meetings, and Post-construction Reviews.

- The 20 SIFs are integrated for deliberation in the Initial RFS Constructability Session, Project Team Selection and Strategic Constructability Workshop in RFS fitout feasibility and conceptual design stages. The 36 PLCFs pertaining to RFS DCOM are examined in the RFS Design Process Meetings, Site Progress Meetings and Post-Construction Reviews in the detailed design, construction and post-construction stages.
- The 37 constructability activities form an integrated program to ensure the achievement of RFS fitout purposes and project objectives.

Contracting Strategy for RFS Fitout and Whole Project Delivery

- **Nominated Specialist Contractors** style is recommended for the early involvement of specialist contractors for construction knowledge inputs.
- Cooperation and communication in the project team can avoid confrontation between different disciplines due to the lack of knowledge, and maximize RFS fitout benefits. Under nominated specialist contractors, the RFS fitout design is developed by architects and consulting engineers with knowledge inputs from RFS specialist contractors.
- **Nominated Specialist Contractors under CM/GC** method is recommended for the delivery of RFS fitout and whole project. Management contractor manage the project team for the detailed design and construction; architects and consulting engineers develop designs for both RFS fitout and whole project; and nominated specialist contractors provide RFS knowledge to the design team in the planning and design stages, and as a reward they are guaranteed the RFS subcontracts without tendering.

Procurement of RFS Products

- Three groups of factors were identified to influence the selection of RFS products, as shown in Figure 9.6. Technical factors largely determine the types of products suitable for the particular environment, while economic and strategic factors help to choose more appropriate products among those satisfying the technical criteria.
Based on these critical factors, the process-based conceptual model is established to support a systematic selection of RFS products in order to minimize the post-construction problems due to improper uses of RFS products.

9.2.5 Objective 5: Guidelines Have Been Formulated to Promote the RFS Fitout Implementation in Office Buildings

The RFS fitout popularization is hindered by many SIFs and PLCFs pertaining to RFS planning, design, construction, operation and maintenance. In the meantime, many good practices in RFS fitout design and construction can largely enhance RFS adaptability and constructability. Nevertheless, the above two issues are both not recognized by most industry practitioners. Formulating guidelines to synthesize all the key factors and research outcomes is of importance to fill in the knowledge gap in the RFS fitout implementation among industry practitioners. The findings of the guidelines include the following aspects.
• Nominated Specialist Contractors under CM/GC method is appointed as the basic contracting strategy for the guideline development.

• The guidelines consist of 5 sections, i.e. Feasibility Stage, Conceptual Design Stage, Detailed Design Stage, Construction Stage and Post-Construction Stage. In each section, the objectives, team roles and critical details are presented. A framework for the guidelines is formulated to facilitate its applications.

- The feasibility stage aims to assess the suitability of RFS fitout and establish a knowledgeable project team to support RFS fitout planning and design. The 5 SIFs pertaining to cost concerns are examined to pinpoint potential risks and benefits. The 8 SIFs pertaining to industry practitioners’ knowledge are assessed to educate the team with appropriate RFS and constructability knowledge. RFS specialist contractors are nominated by the client team for early construction knowledge inputs. Team members include client, construction and cost consultants, and project advisors.

- The conceptual design stage aims to develop viable conceptual designs of the RFS fitout and the whole project, and select management contractor. The 7 SIFs pertaining to structural constraints and RFS service integration need to be evaluated early with construction knowledge inputs from specialist contractors. Once the conceptual design is completed and approved by the client, the management contractor is selected through competitive lump sum tendering. Team members include the project manager representing the client, architect, consulting engineers, quantity surveyor, RFS specialist contractors, and user and maintenance representatives.

- The detailed design stage aims to develop viable detailed design and pinpoint the RFS products. The 16 PLCFs pertaining to design need to be deliberated early to pinpoint and ascertain key design parameters. Innovative and integrated design solutions are explored and RFS fitout construction specifications are developed under the in-depth cooperation and communication among team members. Nominated specialist contractors are awarded the RFS construction contracts automatically, while non-RFS specialist contractors are selected through competitive tendering. Team members include project manager, architect, consulting engineers, quantity surveyor, RFS specialist contractors and management contractor.

- The construction stage aims to integrate RFS service installation with the whole building construction. The 12 PLCFs pertaining to construction need to be examined early in the construction site meetings in order to ascertain key issues in RFS service and whole project construction. RFS products need to be procured and transported to construction sites on time. Construction activities are organized under the coordinated
plan and supervised by the management contractor. RFS construction work needs to strictly conform to the specifications. Team members include project manager, architect, consulting engineers, management contractor, RFS specialist contractors and non-RFS specialist contractors.

The post-construction stage aims to review the RFS fitout constructability implementation, identify problems in the service operation and maintenance, and explore appropriate solutions. Owners and occupants need to be advised of the 8 PLCFs pertaining to RFS service operation and maintenance early in an aim to minimize service problems. The constructability review seeks problems along with the project development and explores betterments to enhance the integration of RFS fitout and whole project delivery. The post-construction problems are investigated as well and solutions through innovative planning, design and construction are gained under the team brainstorming. The good practices and lessons are recorded for the future references. Team members include project manager, architect, consulting engineers, management contractors, RFS specialist contractors, and user and maintenance representatives.

To this end, the second research question has been answered. A total of 20 SIFs can influence RFS fitout planning, 36 PLCFs determine RFS design, construction, operation and maintenance (DCOM), and 15 real problems result from improper RFS DCOM. The RFS fitout constructability study integrates these factors and their solutions into the RFS fitout project delivery process appropriately, which can largely improve the RFS fitout implementation through sufficient preparation, team cooperation, innovative construction, etc. The constructability study highlights 5 key issues with significant influences on the RFS project delivery. Further investigation of these issues contributes to a framework for the integration of constructability with RFS fitout project delivery, nominated specialist contractors under CM/GC as a contracting strategy, and a process-based conceptual model for RFS product selection. Finally, guidelines covering most key research findings present a framework for the industry practitioners’ references in dealing with RFS projects in practice. A questionnaire to the industry practitioners with robust RFS knowledge and experience concluded the validity of the 5 keys issues and the guidelines.
9.3 Contributions to Academic Knowledge Base

Contributions Added to the Point of Departure for Objective 1

As reviewed in Chapter 2, a few researchers attempted to explore the advantages that RFS fitout can contribute to office building environments; however, they normally studied it from the angle of the benefits brought by particular RFS services rather than based on the holistic contributions that RFS are able to present. Furthermore, most existing researches aimed to study the RFS benefits resulting from the innovative technologies rather than going to the RFS service users to get their opinions in this regard. It is the users who have the right to assess the advantages. As a result, their research outcomes are unavoidably fragmentary and ex parte.

In this research, the RFS fitout advantages were investigated holistically. Interviews, site observations and focus groups were employed as the main instruments to obtain first-hand opinions from people with hands-on RFS experiences. RFS cost concerns were ascertained through a study between the RFS and traditional fitout methods on the basis of a LCC comparison model and a case study. In consequence, the RFS advantages such as flexibility, ergonomics, time-saving, improved workplace productivity, and lower LCC were justified.

Contributions Added to the Point of Departure for Objective 2

RFS technology has developed a lot to meet the changing technological, environmental and organizational requirements in office buildings. While this enriched the RFS functions and improved its adaptability, the system is getting more and more sophisticated, which is not accessible to most industry practitioners, particularly to clients and developers. Information provided in most manufacturers’ websites or handbooks is too complicated to be managed by general industry practitioners, whereas information listed in construction guidebooks such as the Rawlinsons Australian Construction Handbook is too simple to guide the design. As a result, the industry is still unacquainted with RFS products and applications.

In this research, site observations were undertaken at one raised floor manufacturing company, four existing office building sites and two construction sites with RFS services. Data of RFS products and applications was recorded and analyzed. Finally,
the specifications of RFS products were formulated to introduce the main features of typical RFS components and the specifications of RFS applications were developed to explain performance standards in typical office fitout environments. The specifications are more understandable to industry practitioners.

**Contributions Added to the Point of Departure for Objective 3**

Despite the many benefits that the innovative fitout can contribute to and the enhanced adaptability that it has achieved, the RFS technology is not prosperously used in office buildings, indicating the existence of barriers hindering its implementation. Although some researchers in the USA outlined problems such as unfamiliarity of RFS and higher capital cost, most problems influencing RFS fitout implementation are still unidentified.

This research has successfully revealed 20 significant influence factors pertaining to RFS planning, 36 PLCFs pertaining to RFS DCOM and 15 real problems in RFS service operation and maintenance. All these findings highlight key issues associated with RFS implementation to industry practitioners and allow them to be well prepared for an integrated delivery of RFS fitout and the whole project.

**Contributions Added to the Point of Departure for Objective 4**

Constructability knowledge system was developed to integrate construction knowledge in project delivery and balance all resources to achieve project objectives and building performance at an optimal level. However, a few researchers (Eldin, 1999; Anderson et al., 2000) indicated that constructability was rarely executed in real projects although it was argued it would enhance project buildability.

This research explored how to apply constructability knowledge for an integrated delivery of a RFS fitout and the whole project. An in-depth constructability study was undertaken to integrate the SIFs and PLCFs into the RFS fitout project delivery, which significantly examined the early construction knowledge inputs, team skills, alignment of RFS fitout purpose and project objectives, RFS fitout programs, innovative sequencing of RFS construction, etc. More importantly, 5 key issues with significant influences on RFS implementation were highlighted and appropriate arrangements were further investigated. These findings underpin the effective
implementation of the constructability programs and optimize the RFS fitout project delivery through a holistic consideration of the SIFs and PLCFs.

**Contributions Added to the Point of Departure for Objective 5**
The research findings contribute to the RFS fitout implementation from different aspects. For example, the SIFs and PLCFs affect the RFS fitout planning and DCOM; the contracting strategy determines the early involvement of specialist contractors, etc. Industry practitioners are unlikely to master and apply so much fragmented knowledge in real projects systemically, which may hence retard the maximization of the benefits that this RFS research can potentially contribute to the Australian construction industry.

As the final outcome, this research successfully developed guidelines covering most of the research findings. The guidelines highlighted the objectives, team roles and critical details pertaining to all RFS fitout project stages. A framework was formulated to facilitate and encourage industry practitioners to implement the guidelines in the practice.

**9.4 Significance to Practice**

**Significance to Clients and Developers**
The questionnaire survey showed that clients and developers are generally not familiar with RFS fitout risks and benefits, products and applications, project delivery method and as a result lack willingness to apply the RFS in the future. The research findings provide answers to the above issues. The RFS fitout benefits were justified; many SIFs, PLCFs and real problems associated with RFS application were identified; and the RFS fitout cost benefits were ascertained through the LCC comparison study. All these activities uncovered the potential risks and benefits for a RFS fitout project. In addition, the specifications of RFS products and applications were developed to improve the clients and developers’ knowledge in RFS. More importantly, the RFS fitout constructability was undertaken and guidelines were formulated to support clients and developers’ management of the project delivery. Clients and developers can apply the research findings to the following areas.
• Clients and developers should make an effort to ascertain the risks and benefits associated with RFS application in this particular project in the early stage by referring to the 20 SIFs. Particularly, developers need to pinpoint the RFS fitout responsibility if the RFS services have originated from occupants’ individual needs.

• Clients and developers seeking to improve the RFS fitout constructability should choose a non-traditional method to allow early involvement of RFS specialist contractors and encourage cooperation and communication among team members. The nominated specialist contractors under the CM/GC method is recommended.

• In selecting a management contractor, clients and developers should assess its management skills and ability to add value and bring innovation to the project, to work in a non-adversarial and collaborative manner. In selecting RFS specialist contractors, clients and developers should set criteria to define their ability in the following aspects:
  ❖ Good communication skills;
  ❖ Willingness to cooperate and communicate with other team members;
  ❖ Robust RFS service knowledge particularly in the 16 PLCFs pertaining to RFS fitout design;
  ❖ Competent construction skills to deal with the 12 PLCFs pertaining to RFS fitout construction;
  ❖ A degree of knowledge in constructability.

• The project manager representing the clients or developers should encourage and lead the constructability programs in the project delivery process, and follow the RFS fitout implementation guidelines for the project procurement.

**Significance to Other Construction Industry Practitioners**

Besides clients and developers, other construction industry practitioners without RFS experience such as architects, consulting engineers and contractors lack knowledge in RFS fitout implementation. They need construction knowledge inputs to integrate the RFS fitout with whole project delivery appropriately. RFS specialist contractors may have a certain degree of knowledge and experience; however they are not aware of the key issues in the RFS design and construction and the appropriate ways to
contribute to the RFS fitout project delivery. The findings of this research provide an insight into the above issues, which can have implications for each party as follows.

Architects and Consulting Engineers

- Keep aware of RFS knowledge and constructability knowledge;
- Actively cooperate and communicate with the early client team to understand the RFS fitout purposes and project objectives;
- Learn to change the design mode from “do-everything-by-yourself” to team work in order to achieve innovative and integrated design solutions, and make full use of construction knowledge inputs from specialist contractors;
- Investigate the influences of the 7 SIFs pertaining to structural constraints and RFS service integration in the feasibility and conceptual design stage to prepare an optimized conceptual design for the integration of RFS into whole project;
- Examine the 16 PLCFs pertaining to RFS fitout design prior to the RFS fitout and whole project detailed design;
- Develop construction specifications as per the 12 PLCFs pertaining to RFS fitout construction in collaboration with contractors and specialist contractors;
- Explore innovative design solutions to accommodate the problems obtained from the post-construction review and keep a file of these problems and solutions for the future references;
- Implement constructability activities in the process of RFS fitout project delivery.

Contractors

- Educate themselves with RFS knowledge and constructability knowledge;
- Balance potential risks and benefits in contracting a project with RFS fitout, particular for management contractors;
- Establish effective interdisciplinary coordination within the design team to allow the early exploration of the 16 PLCFs pertaining to the RFS fitout design;
- Encourage the team collaboration to reach innovative design and construction;
- Develop coordinated construction plans to encourage the integrated construction of RFS fitout and whole project;
- Supervise and coordinate the RFS service construction activities particularly in the sectors outlined by the 12 PLCFs pertaining to RFS construction;
• Promote and implement RFS fitout constructability activities in collaboration with other team members.

Specialist Contractors
• Learn to change their role from subcontractor to designer or design assistant;
• Present construction knowledge to the project team for integrated and innovative design solutions and develop more rational construction specifications;
• Cooperate and communicate with non-RFS specialist contractors in the RFS service construction process;
• Do the construction work strictly in conformity with the specifications while endeavor to explore innovative construction;
• Expend effort to explore design and construction solutions to problems obtained from post-construction reviews and keep a file of these problems and solutions for the future reference.

9.5 Study Limitations

This section considers and explains two limitations of this research that became apparent during the process: research methodology and results of the research.

9.5.1 Limitations in Research Methodology

Research Instruments
The primary research thought was to identify and seek solutions to problems in RFS fitout implementation through questionnaires, interviews, site observations, focus groups, LCC comparative study and constructability study. The questionnaires identified preliminary issues in RFS implementation. The semi-structured interviews exposed SIFs and real problems from the preliminary problems and investigated conceptual solutions. Site observations and focus groups were undertaken to validate the SIFs and real problems. Finally, a constructability study was conducted to investigate these key issues and seek to integrate them into the RFS project delivery appropriately. These research instruments comprised the research methodology. However, this methodology was seldom employed in other studies, which results in a
degree of difficulty for the researcher to prove its validity. To the researcher’s delight, the appropriateness of the research outcomes was highly acknowledged by industry practitioners, which indicates the validity of the research methodology.

**Selection of Variables**

The major research activities to identify the key issues associated with RFS implementation were questionnaire and interview surveys. During the process, the following two issues were dealt with based on an arbitrary decision, which might deserve consideration.

In categorizing the preliminary problems into two groups, i.e. potential influence factors and potential problems, the researcher made decisions based on the judgement of the nature of these factors. That is, whether they are factors influencing RFS fitout planning or problems in RFS service operations and maintenance. As a result, the 44 preliminary issues were divided into 26 potential influence factors and 18 potential problems. Although the decision is rational, it has the possibility for the occurrence of improper categorization of particular issues.

In exploring the SIFs and real problems, the researcher mainly relied on the interviewees’ agreement rating to each question. Their further comments also influenced the researcher’s judgement. Although a great deal of efforts had been expended in analyzing these variables in order to expose the real ones, it was not by any means fully comprehensive due to the interviewees’ and the researchers’ knowledge and experience limitations. Thus, some factors that were thought to be non-SIFs or false problems might be SIFs and real problems, and then be excluded from further investigations.

**9.5.2 Limitations in Results of the Research**

**Data of Life Cycle Cost Comparison**

RFS fitout is not popularly adopted in office buildings in Australia, and underfloor HVAC system is even more rarely used in general office spaces. Furthermore, the industry firms are unlikely to provide their cost data to researchers because they deem it to be a business secret. As a result, all the efforts for the cost data collection
ended in vain although the researcher tried to find an appropriate RFS project from the industry for the LCC case study. In order to conduct the cost comparison between RFS fitout and traditional fitout method, part of the data for the running cost was estimated based on reasonable assumptions. In the future research, a case study based on a real office building project with available cost data is recommended.

Validation of the Results

The discussion of the 20 SIFs, 15 real problems and their conceptual solutions obtained from the interview survey exposed 36 PLCFs that need to be deliberated in the RFS DCOM. Since these PLCFs were direct results of the discussions, the researcher put them together with the SIFs into the constructability study without further validation. However, the constructability study highlighted five key issues with significant influences to a RFS fitout project delivery, and these issues were validated by the high level of agreement from industry practitioners with robust RFS knowledge and experience. In addition, although the appropriateness of the RFS fitout implementation guidelines was acknowledged by industry people, the actual effectiveness of the guidelines has not been tested in the practice due to research time limitations. This deserves further investigation in the future research.

9.6 Recommendations for Future Research

In light of the research findings and study limitations, many areas are highlighted for future research. This section summarizes some of the areas for the references of future research.

• Many key issues relating to RFS fitout implementation were identified in this research; however, these issues were mainly obtained from questionnaire and interview surveys. Although site observations and focus groups were carried out to validate them, the research findings were still influenced by the respondents’ perceptions. Future research is recommended to choose a variety of construction and existing office building sites and further investigate the impacts of these key issues on the RFS fitout implementation. Similarly, comprehensive office building projects might be used to further clarify the advantages of RFS fitout.
• A LCC comparison model was developed in this research to explore the cost difference between the RFS and the traditional fitout method. The model was structured based on considerations of the major elements with initial capital cost differences and running cost differences. The total capital cost investment and total running cost for each method were not calculated. Consequently, it is impossible to estimate the increasing rate of the capital cost investment which is actually what most clients and developers are concerned with. The more sophisticated LCC comparison model can be explored in the future research. In addition, a more comprehensive LCC comparison is recommended if data for the capital cost and running cost is available.

• The findings of this research show that commercial real estate agents have extremely low awareness of RFS and low interest in the relevant information. New building technologies are always attractive to quality occupants pursuing sustainable workplaces, while commercial real estate agents always play a very important role in recommending these technologies to the potential occupants. The agents’ poor knowledge and lack of interest in RFS will unavoidably retard the RFS popularization in the market. Seeking to enhance the agents’ RFS knowledge and encourage them to promote RFS service actively is conducive to RFS implementation, which can be further studied in the future research.

• A few respondents in the final questionnaire revealed that the guidelines should be developed to accommodate different project procurement methodologies and the impact of the early involvement of specialist contractors on the project team organizational culture should be considered. The two constructive topics can be further studied in the future research.

9.7 Closure

This research aimed to explore the RFS implementation for the fitout of office buildings in Australia, specifically to answer two leading questions: 1) how to justify the advantages of RFS fitout compared with the traditional method and improve public awareness of RFS fitout if the Australian industry practitioners lack information in this regard? and 2) how to integrate the barriers into RFS fitout project delivery if some barriers associated with RFS implementation do exist? In
answering the first question, the research employed a questionnaire survey to illustrate the industry practitioners’ poor awareness of RFS, and then justify the RFS endowed advantages through interview surveys, site observations, focus groups and LCC comparison. The public awareness of the RFS fitout was improved through a holistic demonstration of RFS product specifications and application specifications. With respect to the second question, the research conducted questionnaires, semi-structured interviews, site observations and focus groups to expose and justify the SIFs and real problems associated with RFS fitout implementation. Then, these factors and their conceptual solutions were discussed to highlight the PLCFs pertaining to RFS DCOM and then a constructability study was used to integrate these factors into RFS fitout project delivery, based on which 5 key issues with significant influences on RFS project delivery were exposed and further investigated. In the end, guidelines for RFS implementation were formulated as the final research outcome.

This research has made contributions to both the academic community and the construction industry. It justified the advantages associated with the RFS fitout to improve public awareness of and confidence in it, summarized the specifications of RFS products and applications to enhance industry practitioners’ knowledge, explored key issues influencing the RFS implementation and their appropriate solutions to support an integrated project delivery, and formulated guidelines synthesizing all the research findings to promote the RFS fitout implementation. For the construction industry, it highlighted many key issues that the industry practitioners need to study and arrange properly in the RFS project delivery process so that the advantages of a RFS fitout can be achieved maximally.

The study limitations were explored and future research opportunities were recommended at the end of this chapter.
Appendix 1 – Questionnaire Survey

SURVEY ON THE RECOGNITION OF RAISED FLOOR SYSTEM APPLICATION FOR OFFICE BUILDING FITOUT IN AUSTRALIA

The survey deals with obtaining information about owners, occupants, developers, consultants (including architects and consulting engineers), contractors, as well as commercial real estate agents’ recognition on Raised Floor System (RFS) and its application for office building fitout in Australia. The survey questions consist of “5A” sections: awareness, advantages, accessibility, adaptation and adoption of RFS. All responses will greatly assist in facilitating the application of RFS and enhancing workplace environment in Australia.

SECTION 1: Awareness of Raised Floor System

This section aims to identify the respondents’ general conception on raised floor system.

1. Have you ever heard of raised (access) floor?
   [a] Yes
   [b] No  (If no, please go to Question 3.)

2. Based on your answer to Question 1, please identify your opinion to the question below:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Rating (1-least, 7-most)</th>
</tr>
</thead>
<tbody>
<tr>
<td>If “Yes” How much are you familiar with RFS and the components of RFS?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>If “No” How much are you interested in information about RFS and the components of RFS?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
</tbody>
</table>

3. Please identify your opinions to the questions below:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Rating (1-least, 7-most)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much are you satisfied with your current workplace environment, particularly the air quality, thermal condition, or the layout of wire and cable?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>How much are you interested in new information about RFS for office building fitout?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
</tbody>
</table>

SECTION 2: Advantages of Raised Floor System

This section aims to identify the advantages of RFS perceived by the respondents.

4. Please identify the advantages of RFS for office building fitout:

   [a] Flexibility
   [d] Workplace productivity
   [f] Others (please specify):
   [b] Ergonomics
   [e] Time-saving
   [c] Fitout cost-saving
5. Where can the flexibility of RFS be demonstrated?

[d] Relocation  [e] Others (please specify): 

6. Where can the ergonomics of RFS be demonstrated?

[a] Adjustable HVAC  [b] Self-controlled environment  [c] Open communication
[d] Others (please specify): 

7. In comparing to the suspended ceiling-based method, do you think that the fitout cost, installation time and workplace productivity of RFS will be (please tick in the appropriate blank):

<table>
<thead>
<tr>
<th>Compared items</th>
<th>50%~100% lower/shorter</th>
<th>Less than 50% lower/shorter</th>
<th>Equal</th>
<th>Less than 50% higher/longer</th>
<th>50%~100% higher/longer</th>
<th>More than 100% higher/longer</th>
<th>Don’t know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitout cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workplace productivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SECTION 3: Accessibility to Raised Floor System

This section aims to identify the accessibility issues of raised floor system:

8. Do you have access to adequate information/knowledge on RFS application for office building?
   [a] Yes
   [b] No (if no, please go to Question 13.)

9. What project team skills are needed for RFS construction (select all that apply)?

[a] Client  [b] Architect  [c] Engineers
[d] Project manager  [e] Quantity surveyor  [f] Cost consultant
[g] Construction consultant  [h] Others (please specify): 

10. As RFS is a new fitout method for office buildings, what kind of project delivery method do you think is most suitable for RFS construction?

[a] Design/Bid/Build  [b] Design and Build  [c] Construction management/General contractor
[d] Lump sum (except D/B/B and D&B)  [e] Others (please specify): 

11. Based on the current market of office building fitout in Australia, please give your opinions to the questions below:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Rating (1-least, 7-most)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much do you agree that RFS suppliers deliver office interior design will help facilitate RFS application?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>How much do you agree that RFS suppliers deliver construction contract will help facilitate RFS application?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
</tbody>
</table>
12. In which area of RFS are you most interested?

[a] RFS products  [b] RFS design  [c] RFS contracting strategy  
[d] RFS installation  [e] RFS maintenance  [f] RFS reconfiguration  
[g] Associated fitout technologies (e.g. HVAC system, PVD system)  
[h] Others (please specify):

SECTION 4: Adaptability of Raised Floor System

This section aims to identify the adaptability issues of raised floor system:

13. Where RFS is expected to be adopted (select all that apply)?

[a] Office space  [b] Computer/equipment room  [c] Clean room  
[d] Residential use  [e] Commercial building (except office)  
[f] Others (please specify):

14. To achieve flexible office environment, what systems can be integrated with RFS?

[a] Heating, ventilation and air conditioning (HVAC) system  [b] Lighting system  
[c] Power, video/voice and Data (PVD) system  [d] Fire safety system  
[e] Others (please specify):

15. For a workplace retrofit, what are the main physical constraints that limit the use of RFS?

[a] Floor to ceiling height  [b] Ceiling-based HVAC system  [c] Traditional PVD system  
[d] Fire safety system  [e] Others (please specify):

SECTION 5: Adoption of Raised Floor System

This section aims to identify the possibility of your adoption of RFS for your office buildings.

16. Have you already adopted RFS for your office building fitout?

[a] Yes  
[b] No (If choose no, please go to Question 20 and 21.)

17. Please identify your opinion to the question below:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Rating (1-least, 7-most)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much do you agree that RFS is capable of enhancing workplace environment?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
</tbody>
</table>

18. Please list any problems you have experienced with RFS fitout implementation:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
19. As to constructability* issues of RFS, please rate your familiarity on some key principles:

* Constructability is the integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve project goals and building performance at an optimal level.

<table>
<thead>
<tr>
<th>Constructability issues</th>
<th>Rating (1-least, 7-most)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. RFS specifications</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>b. Cost estimate and budgets for RFS</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>c. Available resources for RFS Procurement</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>d. Contracting strategy for RFS projects</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>e. Construction methodology for RFS</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>f. Project team skills for RFS implementation</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>g. RFS reconfiguration and maintenance issues</td>
<td>1 2 3 4 5 6 7</td>
</tr>
</tbody>
</table>

20. What do you think are the main factors (non-physical constraints) hindering RFS application for office building fitout?

[a] Higher capital cost                                  [b] Unfamiliarity with RFS products
[c] Unfamiliarity with RFS procurement    [d] Safety issues (unsafe sense when walking on it)
[e] Reluctance to accept new technology

If you have other reasons, please specify the problems here:


21. Please give your opinions to the questions below:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Rating (1-least, 7-most)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>How probable</em> will you apply RFS for your office fitout in the future when innovations are carried out to successfully solve those problems listed on Q20?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td><em>How much</em> do you agree that RFS will have a promising application for office building fitout in Australia?</td>
<td>1 2 3 4 5 6 7</td>
</tr>
</tbody>
</table>

*The following information is optional and will remain confidential.*

- Your name:______________________________________________
- Your position in the company:____________________________
- Would you like to receive further information on this research? Yes ☐ No ☐
- Your contact details:____________________________________

Thank you for completing this questionnaire.  
The time and effort that you have spent is greatly appreciated.
## Appendix 2 – Feedback Comparison among Different Industry Professionals

<table>
<thead>
<tr>
<th>Code</th>
<th>Variable Names</th>
<th>Measure</th>
<th>Clients</th>
<th>Developers</th>
<th>Consultants</th>
<th>Contractors</th>
<th>C.R.E. Agents</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heard of RFS</td>
<td>yes/ no</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>Familiarity with RFS and its components</td>
<td>Likert 1-7</td>
<td>5.50</td>
<td>3.73</td>
<td>5.45</td>
<td>1.88</td>
<td>4.65</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Satisfactory with current office environment</td>
<td>Likert 1-7</td>
<td>5.08</td>
<td>4.27</td>
<td>4.00</td>
<td>4.38</td>
<td>4.47</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Interest in new RFS information</td>
<td>Likert 1-7</td>
<td>4.08</td>
<td>3.82</td>
<td>3.63</td>
<td>3.63</td>
<td>4.16</td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>Identification of RFS advantages</td>
<td>yes/ no</td>
<td>1.00</td>
<td>1.00</td>
<td>0.86</td>
<td>1.00</td>
<td>0.88</td>
<td>0.96</td>
</tr>
<tr>
<td>5.2</td>
<td>Flexibility</td>
<td>yes/ no</td>
<td>0.42</td>
<td>0.55</td>
<td>0.29</td>
<td>0.36</td>
<td>0.13</td>
<td>0.37</td>
</tr>
<tr>
<td>5.3</td>
<td>Fitout cost-saving</td>
<td>yes/ no</td>
<td>0.25</td>
<td>0.36</td>
<td>0.43</td>
<td>0.45</td>
<td>0.38</td>
<td>0.37</td>
</tr>
<tr>
<td>5.4</td>
<td>Productivity</td>
<td>yes/ no</td>
<td>0.17</td>
<td>0.27</td>
<td>0.71</td>
<td>0.09</td>
<td>0.13</td>
<td>0.24</td>
</tr>
<tr>
<td>5.5</td>
<td>Time-saving</td>
<td>yes/ no</td>
<td>0.42</td>
<td>0.36</td>
<td>0.14</td>
<td>0.36</td>
<td>0.75</td>
<td>0.41</td>
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<tr>
<td>6</td>
<td>Demonstration of flexibility</td>
<td>yes/ no</td>
<td>0.42</td>
<td>0.45</td>
<td>0.43</td>
<td>0.64</td>
<td>0.63</td>
<td>0.51</td>
</tr>
<tr>
<td>6.1</td>
<td>Construction</td>
<td>yes/ no</td>
<td>0.83</td>
<td>1.00</td>
<td>0.86</td>
<td>1.00</td>
<td>0.88</td>
<td>0.92</td>
</tr>
<tr>
<td>6.2</td>
<td>Reconfiguration</td>
<td>yes/ no</td>
<td>0.67</td>
<td>0.82</td>
<td>0.57</td>
<td>0.64</td>
<td>0.75</td>
<td>0.69</td>
</tr>
<tr>
<td>6.3</td>
<td>Maintenance</td>
<td>yes/ no</td>
<td>0.50</td>
<td>0.73</td>
<td>0.29</td>
<td>0.64</td>
<td>0.38</td>
<td>0.53</td>
</tr>
<tr>
<td>6.4</td>
<td>Relocation</td>
<td>yes/ no</td>
<td>0.58</td>
<td>0.64</td>
<td>0.71</td>
<td>0.45</td>
<td>0.38</td>
<td>0.55</td>
</tr>
<tr>
<td>7</td>
<td>Demonstration of ergonomics</td>
<td>yes/ no</td>
<td>0.33</td>
<td>0.55</td>
<td>0.86</td>
<td>0.73</td>
<td>0.50</td>
<td>0.57</td>
</tr>
<tr>
<td>7.1</td>
<td>Adjustable HVAC</td>
<td>yes/ no</td>
<td>0.42</td>
<td>0.45</td>
<td>0.43</td>
<td>0.45</td>
<td>0.88</td>
<td>0.51</td>
</tr>
<tr>
<td>7.2</td>
<td>Self-controlled environment</td>
<td>yes/ no</td>
<td>0.50</td>
<td>0.73</td>
<td>0.29</td>
<td>0.64</td>
<td>0.38</td>
<td>0.53</td>
</tr>
<tr>
<td>7.3</td>
<td>Open communication</td>
<td>yes/ no</td>
<td>3.50</td>
<td>2.60</td>
<td>2.57</td>
<td>4.40</td>
<td>3.25</td>
<td>3.31</td>
</tr>
<tr>
<td>8</td>
<td>Fitout cost comparison</td>
<td>Likert 1-6*</td>
<td>2.89</td>
<td>2.20</td>
<td>2.71</td>
<td>4.10</td>
<td>2.25</td>
<td>2.93</td>
</tr>
<tr>
<td>9</td>
<td>Installation time comparison</td>
<td>Likert 1-6*</td>
<td>3.25</td>
<td>3.00</td>
<td>3.83</td>
<td>3.40</td>
<td>3.33</td>
<td>3.39</td>
</tr>
<tr>
<td>10</td>
<td>Workplace productivity</td>
<td>Likert 1-6*</td>
<td>0.83</td>
<td>0.45</td>
<td>0.86</td>
<td>0.82</td>
<td>0.00</td>
<td>0.61</td>
</tr>
</tbody>
</table>

* 1 = ‘50–100% lower’, 2 = ‘≤ 50% lower’, 3 = ‘equal’, 4 = ‘≥ 50% lower’, 5 = ‘50–100% higher’, 6 = ‘> 100% higher’

# 1 = ‘50–100% shorter’, 2 = ‘≤ 50% shorter’, 3 = ‘equal’, 4 = ‘≥ 50% longer’, 5 = ‘50–100% longer’, 6 = ‘> 100% longer’
### Appendix 2 – Feedback Comparison among Different Industry Professionals

<table>
<thead>
<tr>
<th>Code</th>
<th>Variable Names</th>
<th>Measure</th>
<th>Mean or Percentage</th>
<th>Clients</th>
<th>Developers</th>
<th>Consultants</th>
<th>Contractors</th>
<th>C.R.E. Agents</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Team skills for RFS construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.1</td>
<td>Client</td>
<td>yes/ no</td>
<td>0.80</td>
<td>1.00</td>
<td>0.83</td>
<td>1.00</td>
<td>n/a</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>12.2</td>
<td>Architect</td>
<td>yes/ no</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.89</td>
<td>n/a</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>12.3</td>
<td>Engineer</td>
<td>yes/ no</td>
<td>0.60</td>
<td>1.00</td>
<td>1.00</td>
<td>0.78</td>
<td>n/a</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>12.4</td>
<td>Project manager</td>
<td>yes/ no</td>
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<td>17</td>
<td>RFS application areas</td>
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<td></td>
<td></td>
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<td>1.00</td>
<td>0.88</td>
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<td>0.13</td>
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<td>Commercial building (except offices)</td>
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## Appendix 2 – Feedback Comparison among Different Industry Professionals

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<th>Mean or Percentage</th>
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<td>Subsystems integrated with RFS</td>
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<td>Clients Developers Consultants Contractors C.R.E. Agents Overall</td>
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<td>18.1</td>
<td>HVAC</td>
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<td>0.33 0.36</td>
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<td>PVD</td>
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<tr>
<td>18.4</td>
<td>Fire safety system</td>
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<td>0.50 0.64</td>
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<td>19</td>
<td>Physical constraints for retrofits</td>
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<td>19.1</td>
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<td>Familiarity on RFS constructability issues</td>
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<td>Cost estimate and budgets for RFS</td>
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<td>Available resources for RFS procurement</td>
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<td>22.4</td>
<td>Contracting strategy for RFS projects</td>
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<td>22.5</td>
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<td>Unfamiliarity with RFS procurement</td>
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<td>24</td>
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Appendix 3 – Potential Issues Identified from Questionnaire and the Consolidation

The open-ended question in the questionnaire survey identified a total of 54 potential issues associated with RFS fitout implementation, as presented below.

1. Floor to ceiling height for a retrofit project with/without underfloor air;
2. Initial structure design restricts building retrofit with RFS;
3. Transition issues to other areas – different height to lift system, existing door, stair landing, toilets etc;
4. Inappropriate height to existing windows, cabinets, ablution blocks etc;
5. The existing conduits and ducts built in ceiling-based HVAC system;
6. Traditional cable and wire distribution method on each floor;
7. The existing beam/girder influencing the design of new ceiling under RFS fitout;
8. In underfloor systems, excessive data cabling acts as an air barrier preventing even spread of cold air;
9. For computer rooms, underfloor air conditioning does not allow an easy solution to dealing with Hot Spot;
10. No evidence or cases show the links between underfloor air delivery and productivity;
11. Most clients do not understand what underfloor air delivery (UAD) is but all familiar with RFS;
12. It is hard to deal with hot air delivery through underfloor plenum;
13. It is hard to deal with dehumidification for underfloor air system;
14. Water distribution should be incorporate in the underfloor plenum;
15. The fire safety system is hard to be accommodated in the RFS fitout;
16. Underfloor height vs. BCA requirement for sprinkler systems;
17. Existing cables and wires are not compatible with new PVD systems;
18. It is hard to locate ambient lighting system using RFS fitout without ceiling (power supply);
19. Problems exist in the integration of ambient lighting and task lighting;
20. Dust/water leaks into socket/outlets and underfloor plenum/distribution boxes;
21. The initial design of wire distribution in each level restricts RFS adaptability;
22. The integration and mutual harassment among power, data and other signal distributions;
23. The integration of RFS with existing structure and service system has not been fully considered by architects;
24. Poor design of RFS fitout is one of the main reasons resulting in poor RFS construction productivity;
(25) The floor surface composed of panels is uneven;
(26) The link between pedestals and subfloor is unfirm;
(27) The connectivity between panels and walls is poor;
(28) The connectivity between different floor level is not aesthetic;
(29) Panels tend to be moving due to poor installation;
(30) The laying of panels limits ongoing accessibility;
(31) Panels do not present well and have problems with lifting at corners etc;
(32) Dust and debris are often built up during construction and operation;
(33) Leak-testing of RFS is not so good;
(34) Contractors’ unfamiliarity with RFS products and installation specifications;
(35) Building is usually owned by a developer who rents the shell to others – fitout is the occupier’s responsibility;
(36) Lack business case analysis – particularly disparity between developer and tenant business cases;
(37) Additional hole drilling results in costs and mess;
(38) Quantity surveyors who are unclear of life cycle costing are not interested in new systems like RFS;
(39) Cool air from underfloor plenum is often leaking from the interstice between panels;
(40) Draught is rising due to underfloor air delivery method;
(41) Travel of sound appears;
(42) Metal edges are fracturing due to panel movement;
(43) Holes in panels induce stress concentrations leading to further cracks;
(44) It is not actually flexible to relocate cables, wires and outlets;
(45) Panels are hard to relocate for its distortion;
(46) Breakdown of body components inside floor carpet tiles creates trip hazards;
(47) Lifting of facial component on panels creates trip hazards;
(48) Disposal required of panels drilled for cable passes when fitout changed exposing holes to pedestrian traffic;
(49) The most significant obstacle has been the capital cost of RFS;
(50) Owners/clients only stress capital cost rather than life cycle cost;
(51) Poor design (e.g. inadaptability) is one of the main reasons leading to cost overrun;
(52) Maintenance costs are not actually as low as expected;
(53) RFS costs significantly more compared with traditional fitout methods; for most clients, it does not pay off nearly soon enough;
(54) Discontinuity between initial capital costs and ongoing operational costs – different parties have different cost drivers throughout the building life cycle.
Some of the above 54 issues may overlap. The consolidation and combination of the 54 issues into the 44 issues are presented in the following table. Issue A1 to Issue E18 are listed in Table 5.1.

<table>
<thead>
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Appendix 4 – Semi-Structured Interview Questions

Interview Survey on Raised Floor Application Implementation

Interview Purposes:

- To acquire industry practitioners’ opinions on the perceived advantages associated with RFS fitout implementation;
- To further investigate the potential influence factors and problems associated with RFS fitout implementation,
- To seek advices on appropriate solutions to the above real influence factors and real problems

Section 1: Exploration of RFS fitout advantages

A range of advantages associated with RFS fitout were identified in the research literatures; however, they were not highly recognized by industry practitioners as per the earlier questionnaire survey. This might be due to the lack of RFS practices in the Australian construction industry. As per your experience and knowledge, please comment on the following issues.

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<th>Disagree</th>
<th>It depends</th>
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<td>(2) Ergonomics</td>
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<td>(3) Workplace productivity</td>
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<td>(4) Time-saving</td>
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<td>(5) Fitout cost-saving</td>
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</table>

Other Advantages:

Comments:
Section 2: Exploration of Potential Influence Factors

A range of factors was identified from the previous questionnaire survey with potential influence to RFS fitout implementation. Please present your opinion on the following issues.

Part 1 – Structural Constraints

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<th>Disagree</th>
<th>It depends</th>
<th>No comments</th>
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<td>(1) The initial building structural regularity restricts building retrofit with RFS.</td>
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<tr>
<td>(2) The space volume (distance between slab and slab) is a problem.</td>
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<td></td>
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</tr>
<tr>
<td>(3) Transitions to lift system, existing doors, stair landings and toilets are problems.</td>
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<td></td>
<td></td>
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<tr>
<td>(4) Inappropriate height to existing windows, cabinets, etc. is a problem.</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) The existing overhead HVAC system configuration influences RFS application.</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>(6) The existing cable and wire distribution method influences RFS application.</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7) The existing structural beams influence RFS application.</td>
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Solutions to the above issues:

Other potential issues and solutions:

Part 2 – RFS Service Integration

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<th>Disagree</th>
<th>It depends</th>
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</tr>
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<td>(8) It is hard to deal with hot air delivery for UAD.</td>
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</tr>
<tr>
<td>(9) It is hard to deal with air dehumidification for UAD.</td>
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<tr>
<td>(10) Water distribution is hard to be incorporated in underfloor plenum.</td>
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<tr>
<td>(11) The fire safety system is hard to be accommodated in the RFS fitout.</td>
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<tr>
<td>(12) Existing cables and wires are not compatible with new PVD systems.</td>
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<tr>
<td>(13) It is hard to locate ambient lighting if using RFS fitout without ceiling.</td>
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<tr>
<td>(14) The mutual harassment exists among power, data and other signal distributions.</td>
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</tbody>
</table>

Solutions to the above issues:

Other potential issues and solutions:
**Part 3 – Industry Practitioners’ Knowledge**

<table>
<thead>
<tr>
<th>Potential Influence Factors</th>
<th>Agree</th>
<th>Disagree</th>
<th>It depends</th>
<th>No comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(15) The integration of RFS with building structure and services has not been fully considered by most architects.</td>
<td></td>
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<tr>
<td>(16) Poor design is one of the main factors resulting in low construction productivity.</td>
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<tr>
<td>(17) No evidence and cases show the links between UAD and productivity.</td>
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<tr>
<td>(18) Most clients do not understand UAD although they know raised floors.</td>
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<tr>
<td>(19) Contractors have a low familiarity with RFS products and installation.</td>
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<tr>
<td>(20) Most QSs do not care life cycle cost and are not interested in new systems.</td>
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</tbody>
</table>

**Solutions to the above issues:**

**Other potential issues and solutions:**

**Part 4 – Cost Concerns**

<table>
<thead>
<tr>
<th>Potential Influence Factors</th>
<th>Agree</th>
<th>Disagree</th>
<th>It depends</th>
<th>No comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(21) The most significant obstacle is the capital cost of RFS.</td>
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<tr>
<td>(22) Owners only stress capital cost rather than LCC.</td>
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<tr>
<td>(23) Poor design is one of the main reasons resulting in cost overrun.</td>
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<tr>
<td>(24) Maintenance costs are not actually as low as expected.</td>
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<tr>
<td>(25) RFS costs significantly more compared with traditional fitout method and for most clients, it is not paid back nearly soon enough.</td>
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<tr>
<td>(26) Building is owned by the developers while fitout is occupants’ responsibility.</td>
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</tbody>
</table>

Solutions to the above issues:

**Other potential issues and solutions:**
Section 3: Exploration of Post-Construction Issues

A range of RFS post-construction issues were proposed from the earlier questionnaire survey. Please present your opinion on the following issues.

<table>
<thead>
<tr>
<th>Potential Problems</th>
<th>Agree</th>
<th>Disagree</th>
<th>It depends</th>
<th>No comments</th>
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<tbody>
<tr>
<td>(27) Excessive cable and wire distribution prevents even spread of underfloor cool air.</td>
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<td>(28) UAD does not allow an easy solution to deal with hot spots in computer rooms.</td>
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<td>(33) The connectivity between different floor levels is not aesthetic.</td>
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<td>(35) It is not actually flexible to relocate cables, wires and outlets.</td>
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<td>(36) Additional hole drilling results in costs and mess;</td>
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<td>(37) Much travel of sound appears.</td>
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<td>(38) Holes in panels induce stress concentrations leading to further cracks.</td>
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<td>(39) Panels tend to be moving due to poor installation.</td>
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<tr>
<td>(40) Panels are hard to relocate for its distortion.</td>
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<tr>
<td>(41) Dust is often built up during construction and operation.</td>
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<tr>
<td>(42) Water always leak into floor outlets and underfloor plenum.</td>
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</tr>
<tr>
<td>(43) Lifting of facial components on panel creates trip hazards.</td>
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<tr>
<td>(44) Panels with cable passes expose holes to pedestrian traffic when fitout changes.</td>
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</tbody>
</table>

Solutions to the above problems:

Other potential problems and solutions:
### Appendix 5 – Results of Interview Data Analysis – Structural Constraints

<table>
<thead>
<tr>
<th>Code</th>
<th>Descriptions</th>
<th>Conceptual solutions (key points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>SIF</td>
<td>• Adapt RFS to the existing building structure characteristics in the whole fitout design;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• For new buildings, integrate RFS features into the building structure design.</td>
</tr>
<tr>
<td>A2</td>
<td>SIF</td>
<td>• Determine whether UAD will be used in general office space considering space volume and client’s requirements;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Balance an appropriate FFH for UAD distribution and the available space volume in the initial RFS and UAD design;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Consider the disposal of ceiling and ceiling services in the initial fitout plan if using UAD.</td>
</tr>
<tr>
<td>A3</td>
<td>SIF</td>
<td>• Recommend not to use RFS in the building core area in a retrofit project other than a new building; otherwise, ramps and steps are needed to meet the transition requirements;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• For new buildings, compass the RFS configuration in the initial structure design for the building core area;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Outside building core areas, relace the incompatible existing doors with new ones.</td>
</tr>
<tr>
<td>A4</td>
<td>Non-SIF</td>
<td>• Apply a proper interior design with a view to the features of windows, cabinets etc.</td>
</tr>
<tr>
<td>A5</td>
<td>SIF</td>
<td>• Integrate the disposal of the ceiling-based air system with the applications of RFS and UAD;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Keep the ceiling-based air system for future change or in case of any UAD failure if the space volume permits.</td>
</tr>
<tr>
<td>A6</td>
<td>Non-SIF</td>
<td>• No advice as to the traditional cable and wire distribution since it gets no influence to the RFS application;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Carry out proper maintenance to the underfloor cable and wire system for the proper operation of other underfloor services.</td>
</tr>
<tr>
<td>A7</td>
<td>SIF</td>
<td>• Combine the ceiling renovation with the existing structural beam and the UAD configuration in the initial fitout design;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Present a proper decoration for the structural beam and upper slab if the ceiling panels are removed.</td>
</tr>
</tbody>
</table>
## Appendix 6 – Results of Interview Data Analysis – RFS Service Integration

<table>
<thead>
<tr>
<th>Code</th>
<th>Descriptions</th>
<th>Conceptual solutions (key points)</th>
</tr>
</thead>
</table>
| B1   | Non-SIF      | • It is just a design issue, and consultants opt for a specific heating approach for the UAD;  
|      |              | • Consider a higher supply temperature compared with the ceiling-based air system. |
| B2   | Non-SIF      | • It is just a design issue, and consultants opt for a specific air dehumidification approach for the UAD;  
|      |              | • Consider a higher supply temperature compared with the ceiling-based air system. |
| B3   | Non-SIF      | • Coordinate the layout of water piping with the installation of UAD. |
| B4   | SIF          | • Consider the requirement of the fire specification in the BCA when deciding a FFH;  
|      |              | • Appoint appropriate fire protection approaches for underfloor void with different height;  
|      |              | • Organize a knowledgeable project team to coordinate the FFH and the fire safety issues. |
| B5   | SIF          | • For a major retrofit, remove the old cable and wire system and replace them with new compatible ones;  
|      |              | • If recycling the old cable and wiring system, consultants need to consider their compatibility with the system upgrade. |
| B6   | Non-SIF      | • It is just a design issue and many approaches are viable to delivery ambient lighting without ceiling. |
| B7   | Non-SIF      | • The possibility of harassment has been excluded by the quality of RFS products. |
## Appendix 7 – Results of Interview Data Analysis – Industry Practitioners’ Knowledge

<table>
<thead>
<tr>
<th>Code</th>
<th>Descriptions</th>
<th>Conceptual solutions (key points)</th>
</tr>
</thead>
</table>
| C1   | SIF          | • Educate architects and consulting engineers and enhance their knowledge of raised floors and underfloor services;  
|      |              | • Establish a knowledgeable consulting team to assist the architects and consulting engineers to design the RFS fitout;  
|      |              | • Provide architects and consulting engineers access to construction knowledge and methodology of RFS for the whole building design and fitout. |
| C2   | SIF          | • Educate architects and consulting engineers with RFS knowledge and minimize the mistakes in their designs;  
|      |              | • Implement a rational constructability program to coordinate the diverse fitout trades and procedures. |
| C3   | SIF          | • Setup a feedback mechanism to explore the impact of UAD upon workplace productivity in the industry;  
|      |              | • Undertake a strategic research to justify the causality between UAD and workplace productivity. |
| C4   | SIF          | • Carry out a strategic research to justify the advantages of UAD;  
|      |              | • Present live UAD cases to the industry to show the merits of UAD in order to facilitate its application. |
| C5   | SIF          | • Educate general contractors and improve their knowledge of RFS;  
|      |              | • Engage specialist contractors to deliver the different trades of RFS;  
|      |              | • Coordinate and supervise different trades effectively and systematically;  
|      |              | • Employ consultants to facilitate the RFS construction and supervision. |
| C6   | SIF          | • Educate developers and owners to value the LCC at first and then urge QS to consider it;  
|      |              | • Educated QSs and equip them with knowledge of LCC;  
|      |              | • Set up a mechanism to consider LCC in the initial project plan. |
| C7   | SIF          | • Justify the numerous advantages of RFS through research case studies;  
|      |              | • Enhance RFS recognition in the industry and expand its market acceptability. |
| C8   | SIF          | • Strengthen the constructability concept among the industry practitioners;  
|      |              | • Embed constructability knowledge from the inception of RFS projects;  
|      |              | • Educate project team members with RFS knowledge;  
|      |              | • Call manufacturers and construction personnel to join the project team for technology support;  
|      |              | • Select an appropriate delivery method to facilitate constructability review programs. |
## Appendix 8 – Results of Interview Data Analysis – Cost Concerns

<table>
<thead>
<tr>
<th>Code</th>
<th>Descriptions</th>
<th>Conceptual solutions (key points)</th>
</tr>
</thead>
</table>
| D1   | SIF          | • Conduct an unbiased research to compare the capital cost between the traditional fitout approach and the RFS fitout approach;  
|      |              | • Justify the numerous advantages of RFS vs. its probably higher capital cost;  
|      |              | • Enhance RFS recognition in the industry and expand its market acceptability  
| D2   | SIF          | • Strengthen the industry’s attention to building life cycle cost;  
|      |              | • Educate owners, developers and occupants and let them embed the life cycle cost awareness in the whole project  
|      |              | • Justify the numerous advantages of RFS vs. its probably higher capital cost.  
| D3   | SIF          | • Do a realistic cost planning in feasibility analysis of the RFS fitout project;  
|      |              | • Educate architects and consulting engineers with RFS knowledge and minimize the mistakes in the designs;  
|      |              | • Call manufacturers and construction personnel to join the project team for knowledge support;  
|      |              | • Select an appropriate delivery method to keep the continuity between design and installation in case of cost overrun.  
| D4   | Non-SIF      | • Improve people’s recognition of maintenance issue, such as cost;  
|      |              | • Set up a mechanism to collect data for evaluating the maintenance cost associated with a RFS facility.  
| D5   | SIF          | • Undertake a research to study the payback time for RFS application;  
|      |              | • Integrate UAD into RFS to shorten the payback time potentially;  
|      |              | • Apply RFS for modern business operation in an aim to shorten the payback time.  
| D6   | SIF          | • Pinpoint the responsibility of RFS construction at the early stage of project;  
|      |              | • Recommend RFS to be constructed by developer and reimbursed by higher rental and other benefits;  
|      |              | • Conduct a holistic study of the associated risks and benefits before owners/developers or occupants determine the RFS fitout.  

## Appendix 9 – Results of Interview Data Analysis – Post-Construction Issues

<table>
<thead>
<tr>
<th>Code</th>
<th>Descriptions</th>
<th>Conceptual solutions (key points)</th>
</tr>
</thead>
</table>
| E1   | Real-major   | • Present a proper design, installation and maintenance of UAD, such as supply air pressure and volume;  
|      |              | • Determine an reasonable FFH considering the UAD application;  
|      |              | • Coordinate the UAD operation with the layout of other underfloor services, especially the cable and wire distribution;  
|      |              | • Educate facility staff to get access to the underfloor services without wrecking the air balance. |
| E2   | Real-major   | • Present a proper design, installation and maintenance of UAD considering the characteristics of computer/equipment rooms;  
|      |              | • Determine an reasonable FFH considering the UAD application for computer/equipment rooms;  
|      |              | • Coordinate the UAD operation with the layout of other underfloor services, especially the cable and wire distribution;  
|      |              | • Select appropriate perforated panels or grills to add the cooling capacity around hot spots;  
|      |              | • Educate facility staffs to get access to the underfloor services without wrecking the air balance. |
| E3   | Real-major   | • Present a proper design, installation and maintenance of UAD, such as supply air pressure and volume;  
|      |              | • Conduct air leaking test and air balance for UAD in the design and installation;  
|      |              | • Locate and fix pedestals, floor panels and carpet tiles properly as per the specifications;  
|      |              | • Take strict precautions for the break of air balance due to improper service maintenances. |
| E4   | Real-major   | • Present a proper design, installation and maintenance of UAD, such as supply air pressure and volume;  
|      |              | • Conduct air balance for UAD in the design and installation;  
|      |              | • Educate occupants and inform them of the right way to run UAD, e.g. free the diffuser surface from blocking or covering;  
|      |              | • Conduct a regular maintenance to sustain the proper operation of the UAD. |
| E5   | Real-minor   | • Subfloors must be pre-treated to be rigid, dry, smooth, flat, level and free from harmful materials before the RFS installation;  
|      |              | • Install pedestals with the aid of laser planometers and by professionals;  
|      |              | • Select appropriate panels for particular environment;  
<p>|      |              | • Get panels back accurately as before after the maintenance work. |</p>
<table>
<thead>
<tr>
<th>Code</th>
<th>Descriptions</th>
<th>Conceptual solutions (key points)</th>
</tr>
</thead>
</table>
| E6   | Real-minor   | • Design the building with regular shape if possible for easy raise floor layout;  
|      |              | • Employ professionals to do the panel cutting;  
|      |              | • Pay attention to the panel and pedestal installation along the junctions of walls and floor panels; |
| E7   | Real-minor   | • Coordinate and plan the connectivity between different levels elaborately in the initial design;  
|      |              | • Select ramps with appropriate gradient for the connectivity in the floor office area considering disable access. |
| E8   | Real-minor   | • Choose suitable panels and appropriate panel and pedestal locking method;  
|      |              | • Install panels and pedestals strictly conforming to specifications;  
|      |              | • Carry out regular maintenance on floor panels and pedestals. |
| E9   | False problem| • A proper design and installation can assure flexible relocations of cables, wires and outlets. |
| E10  | Real-major   | • Do an accurate cooling capacity calculation for the cooling of main frames;  
|      |              | • Predict the number of holes as accurately as possible considering floor diffusers, outlet boxes, etc;  
|      |              | • Employ professionals to drill boxes in panels with special tools if extra holes are needed; |
| E11  | Real-minor   | • Integrate the block of sound transferring with the construction of underfloor smoke and fire dividers;  
|      |              | • Choose proper panel and carpet tile products for particular fitout environments. |
| E12  | Real-minor   | • Choose proper panel products for particular fitout environments;  
|      |              | • Use appropriative tools to drill holes in panels;  
|      |              | • Consider the location of holes in an aim to minimize panel distortion and reduction of carrying capacity;  
|      |              | • Estimate the reduction of the panel carrying capacity due to the drilled holes. |
| E13  | Real-minor   | • Pre-treat subfloors to be rigid, dry, smooth, flat, level and free from harmful materials before the RFS installation;  
|      |              | • Use a reliable method to fix pedestals on the subfloors;  
<p>|      |              | • Choose a proper locking method to locate panels on the corner of pedestals considering the application environment. |</p>
<table>
<thead>
<tr>
<th>Code</th>
<th>Descriptions</th>
<th>Conceptual solutions (key points)</th>
</tr>
</thead>
</table>
| E14  | Real-minor   | • Choose proper panel products for particular fitout environment;  
|      |              | • Install the pedestals and floor panels strictly in conformity with the specifications;  
|      |              | • Carry out regular maintenance to identify potential problems. |
| E15  | Real-major   | • Prime the subfloors with an approved primer in advance in case of dust generation due to concrete crack;  
|      |              | • Make sure that dust is cleaned at the completion of all subcontractors’ jobs;  
|      |              | • Coordinate and supervise different trades for dust cleaning in the management log of the project;  
|      |              | • Take strict precautions for dust leaking into the plenum during service maintenance;  
|      |              | • Carry out regular cleaning to remove dust from the plenum. |
| E16  | False problem| • Do regular check of the outlet box and underfloor plenum. |
| E17  | Real-minor   | • Locate floor panels and pedestals accurately and firmly as per the specifications;  
|      |              | • Lay carpet tiles on the panel surface properly;  
|      |              | • Carry out regular maintenances to find malfunctions of the floor coverings. |
| E18  | False problem| • Use new panels to replace the panels with holes once they are not needed for those particular locations. |
Appendix 10 – Focus Group Questions

Focus Group Purposes:

- To explore the occupants’ opinions on the real problems concluded by the interview survey;
- To acquire the occupants’ propositions with respect to the perceived RFS fitout advantages.

Section 1: Exploration of Real Problems

A range of real problems associated with RFS service operation and maintenance were identified in the earlier survey research. In order to validate these findings, please comment on the following issues from the viewpoints of an occupant of RFS facilities.

<table>
<thead>
<tr>
<th>Real problems resulting from the earlier survey research</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Excessive cable and wire distribution prevents even spread of underfloor cool air.</td>
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</tbody>
</table>

Comments:

Section 2: Exploration of RFS Fitout Advantages

Based on the day-to-day experience on the RFS facilities in your workplace, please comments on the perceived RFS fitout advantages, such as flexibility, ergonomics, time-saving for maintenance, workplace productivity, etc.
Appendix 11 – Fitout Plan Drawing

Fitout Plan Drawing
Appendix 12 – HVAC Distribution Plan

HVAC Distribution Plan
Appendix 13 – LCC Comparison Model

Part 1 - General Information

<table>
<thead>
<tr>
<th>Project Location:</th>
<th>Gardens Point Campus, QUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Fitout Method:</td>
<td>Overhead HVAC &amp; Power Pole PVD</td>
</tr>
<tr>
<td>RFS Fitout Method:</td>
<td>Underfloor HVAC and PVD Distribution</td>
</tr>
<tr>
<td>Building Type:</td>
<td>Owner Occupied Office Building</td>
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</tbody>
</table>

General Information

<table>
<thead>
<tr>
<th>Project floor area</th>
<th>183 sqm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of floors</td>
<td>1</td>
</tr>
<tr>
<td>Total workstations</td>
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</tr>
<tr>
<td>Private offices</td>
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</tr>
<tr>
<td>Open plan workstations</td>
<td>3</td>
</tr>
<tr>
<td>Resource room</td>
<td>1</td>
</tr>
<tr>
<td>Kitchen room</td>
<td>1</td>
</tr>
<tr>
<td>Staff room</td>
<td>1</td>
</tr>
<tr>
<td>Corridor</td>
<td>1</td>
</tr>
<tr>
<td>Irregular Floor Plate Max Length</td>
<td>21 m</td>
</tr>
<tr>
<td>Irregular Floor Plate Max Width</td>
<td>11 m</td>
</tr>
</tbody>
</table>

LCC Comparison Parameters

<table>
<thead>
<tr>
<th>Interest rate</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation rate</td>
<td>3%</td>
</tr>
<tr>
<td>Discount rate</td>
<td>6.796%</td>
</tr>
<tr>
<td>consider</td>
<td>7%</td>
</tr>
<tr>
<td>Counted life term</td>
<td>10 years</td>
</tr>
</tbody>
</table>
Part 2 - Initial Capital Cost Differences

Raised Floor Related Capital Cost Difference

The unit rate in the Rawlinsons guide includes the installation cost. Medium grade (general office) Corner lock stringerless system.

<table>
<thead>
<tr>
<th>RFS fitout environment</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net raised floor area</td>
<td>170</td>
<td>sqm</td>
<td>$120</td>
<td>$20,400</td>
</tr>
<tr>
<td>PVA paint to slab</td>
<td>170</td>
<td>sqm</td>
<td>$6</td>
<td>$1,020</td>
</tr>
<tr>
<td>Ramps</td>
<td>2</td>
<td>each</td>
<td>$500</td>
<td>$1,000</td>
</tr>
<tr>
<td>Handrail</td>
<td>6</td>
<td></td>
<td>$165</td>
<td>$990</td>
</tr>
<tr>
<td>Step to plant room</td>
<td>1</td>
<td></td>
<td>$138</td>
<td>$138</td>
</tr>
<tr>
<td><strong>Subtotal cost</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$23,548</strong></td>
</tr>
</tbody>
</table>

Traditional fitout environment

**Subtotal cost** $0

**Cost difference** $23,548

HVAC Related Capital Cost Difference

The unit rate in the Rawlinsons guide includes the installation cost. Krantz floor diffusers are chosen for air supply.

Fan coil unit: Rawlinsons Guide low/medium pressure 950l/s (2000fcm) $ 5,400-6,000.

Water cooled chillers: 50KW with cost $23,000.

Underfloor HVAC system

<table>
<thead>
<tr>
<th>Underfloor HVAC system</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krantz floor diffusers</td>
<td>26</td>
<td>each</td>
<td>$150</td>
<td>$3,900</td>
</tr>
<tr>
<td>Vertical air handling unit</td>
<td>1</td>
<td>each</td>
<td>$5,400</td>
<td>$5,400</td>
</tr>
<tr>
<td>Chiller</td>
<td>1</td>
<td>each</td>
<td>$23,000</td>
<td>$23,000</td>
</tr>
<tr>
<td>Ductwork 1 with 1.5m girth</td>
<td>22</td>
<td>m</td>
<td>$100</td>
<td>$2,200</td>
</tr>
<tr>
<td>Bend for ductwork 1</td>
<td>1</td>
<td>each</td>
<td>$130</td>
<td>$130</td>
</tr>
<tr>
<td>Ductwork 2 with 1.0m girth</td>
<td>10</td>
<td>m</td>
<td>$80</td>
<td>$800</td>
</tr>
<tr>
<td>Bend for ductwork 2</td>
<td>1</td>
<td>each</td>
<td>$70</td>
<td>$70</td>
</tr>
<tr>
<td>Ceiling return air diffuser</td>
<td>9</td>
<td>each</td>
<td>$82</td>
<td>$738</td>
</tr>
<tr>
<td><strong>Subtotal cost</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$36,238</strong></td>
</tr>
</tbody>
</table>

Overhead HVAC system

<table>
<thead>
<tr>
<th>Overhead HVAC system</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average cost estimate</td>
<td>183</td>
<td>sqm</td>
<td>$230</td>
<td>$42,090</td>
</tr>
<tr>
<td><strong>Subtotal cost</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$42,090</strong></td>
</tr>
</tbody>
</table>

**Cost difference** -$5,852
PVD Related Capital Cost Difference

For underfloor PVD distribution, the cable and wire are mainly distributed in the floor plenum; however, part of the cables and wires are supplied in the ceiling plenum in the next level and poked through the floor slab to the upper floor plenum. Tray will be considered in both plenums. Lighting is not considered. Most Installations have been considered in the material supply cost. Consider each workstation has two power points, one voice outlet and two data outlets.

<table>
<thead>
<tr>
<th>Underfloor PVD distribution</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical and Data Horizontal Distribution</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power cables</td>
<td>408</td>
<td>m</td>
<td>$9</td>
<td>$3,672</td>
</tr>
<tr>
<td>Telephone cable</td>
<td>408</td>
<td>m</td>
<td>$7</td>
<td>$2,856</td>
</tr>
<tr>
<td>Data cables</td>
<td>408</td>
<td>m</td>
<td>$3</td>
<td>$1,224</td>
</tr>
<tr>
<td>Tray</td>
<td>29</td>
<td>m</td>
<td>$25</td>
<td>$725</td>
</tr>
<tr>
<td>Tray bend</td>
<td>1</td>
<td>each</td>
<td>$28</td>
<td>$28</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>1</td>
<td>each</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Slab Penetration and Sealing</td>
<td>1</td>
<td>each</td>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td><strong>Workstation Electrification</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVD servicenter</td>
<td>16</td>
<td>each</td>
<td>$152.50</td>
<td>2,440</td>
</tr>
<tr>
<td>Conduits</td>
<td>80</td>
<td>m</td>
<td>$3</td>
<td>240</td>
</tr>
<tr>
<td><strong>Additional installation cost</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Put cables into the conduit</td>
<td>8</td>
<td>hour</td>
<td>$40</td>
<td>$320</td>
</tr>
<tr>
<td><strong>Subtotal cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$13,005</td>
</tr>
</tbody>
</table>

Power pole distribution

As per Rawlinsons for a 7-20 story office building, the average cost for electrical is $143.25 per sqm including lighting cost $44.25 per sqm, so the average electrical cost without lighting is $99 per sqm, which is approximately equal to the average cost gained through the following break-up estimation.

| Power pole Distribution: | 40      | m    | $45     | $1,800 |
| Ducted skirting (steel)  | 35      | m    | $16.23  | $568   |
| Power outlet in corridor and service areas | 5 | each | $80 | $400 |
| Power outlet in office areas | 11 | each | $70 | $770 |
| Telephone outlet         | 8       | each | $115    | $920   |
| Data outlet               | 18      | each | $104    | $1,872 |
| Tray                      | 29      | m    | $25     | $725   |
| Tray bend                 | 1       | each | $28     | $28    |
| Fire alarm                | 1       | each | $1,000  | $1,000 |
| Power cables              | 490     | m    | $9      | $4,406 |
| Telephone Cables          | 490     | m    | $7      | $3,427 |
| Data cables               | 490     | m    | $3      | $1,469 |
| **Subtotal cost**         |         |      |         | $17,385 |

**Cost difference**  
- $4,380
Floor Covering Related Capital Cost Difference

Cost includes installation cost.
For RFS fitout, a modular tiles 600×600 mm is used.
For traditional fitout, resilient carpet wool tufted medium use is chosen.

<table>
<thead>
<tr>
<th>RFS fitout</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpet Tiles</td>
<td>183</td>
<td>sqm</td>
<td>$75</td>
<td>$13,725</td>
</tr>
<tr>
<td>Subtotal cost</td>
<td></td>
<td></td>
<td></td>
<td>$13,725</td>
</tr>
<tr>
<td>Traditional fitout</td>
<td>183</td>
<td>sqm</td>
<td>$47.00</td>
<td>$8,601</td>
</tr>
<tr>
<td>Subtotal cost</td>
<td></td>
<td></td>
<td></td>
<td>$8,601</td>
</tr>
<tr>
<td>Cost difference</td>
<td></td>
<td></td>
<td></td>
<td>$5,124</td>
</tr>
</tbody>
</table>

Earlier Owner Occupancy Saving

Due to the floor-based HVAC distribution and PVD distribution, it is believed that 20% of fitout time can be saved, which will reduces the school lease of other areas for the administrative operation.
The original fitout time is 90 days
RFS fitout time is 72 days
The normal annual rental for the office space in Brisbane $200 per sqm

<table>
<thead>
<tr>
<th>Office lease cost associated with RFS fitout</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual office lease cost</td>
<td>183</td>
<td>sqm</td>
<td>$200</td>
<td>$36,600</td>
</tr>
<tr>
<td>Actual office lease cost</td>
<td>0.19726</td>
<td>year</td>
<td>$36,600</td>
<td>$7,220</td>
</tr>
<tr>
<td>Subtotal cost</td>
<td></td>
<td></td>
<td></td>
<td>$7,220</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Office lease cost associated with traditional fitout</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual office lease cost</td>
<td>183</td>
<td>sqm</td>
<td>$200</td>
<td>$36,600</td>
</tr>
<tr>
<td>Actual office lease cost</td>
<td>0.246575</td>
<td>year</td>
<td>$36,600</td>
<td>$9,025</td>
</tr>
<tr>
<td>Subtotal cost</td>
<td></td>
<td></td>
<td></td>
<td>$9,025</td>
</tr>
<tr>
<td>Cost difference</td>
<td></td>
<td></td>
<td></td>
<td>-$1,805</td>
</tr>
</tbody>
</table>

Considering that the potentially rented office space is located in the campus, a reduced rental saving is:

Cost difference $-1,500
Part 3 - Running Cost Differences

HVAC Churn Related Cost Saving

According to the FMA Office Churn Report, an average churn rate of 36% takes place in office buildings, with an average cost of $2482 per person. According to the school record, in the past 10 years three major office relocations were conducted, representing a churn rate of 33.3%.

Appointed churn rate is 36%

<table>
<thead>
<tr>
<th>Underfloor HVAC system</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor-based air diffusers</td>
<td>26</td>
<td>each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diffusers relocated</td>
<td>9.36</td>
<td>each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for relocating a diffuser</td>
<td>0.2</td>
<td>hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour cost</td>
<td>2</td>
<td>hour</td>
<td>$32</td>
<td>$60</td>
</tr>
<tr>
<td><strong>Subtotal cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$60</td>
</tr>
</tbody>
</table>

| Overhead HVAC system   |           |      |           |      |
| Ceiling air diffusers  | 12        | each |           |      |
| Number of diffusers relocated | 4.32   | each |           |      |
| Time for relocating a diffuser | 3     | hour |           |      |
| Labour cost            | 12.96    | $45  | $583      |      |
| **Subtotal cost**      |          |      |           | $583 |

**Cost difference** $-523

PVD Churn Related Cost Saving

According to the FMA Office Churn Report, an average churn rate of 36% takes place in office buildings, with an average cost of $2482 per person. According to the school record, in the past 10 years three major office relocations were conducted, representing a churn rate of 33.3%.

Since this is an university office, no new workstations are considered for churn. A total of 8 workstations are supposed since there are 3 personal offices, 3 workstations in open area, and a resource room which may involves computers, photocopiers and fax machines, scanners, etc.

Appointed churn rate is 36%

<table>
<thead>
<tr>
<th>Underfloor PVD distribution</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workstation total</td>
<td>8</td>
<td>each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workstation furniture relocated cost</td>
<td>4</td>
<td>hour</td>
<td>$32</td>
<td>$369</td>
</tr>
<tr>
<td>PVD box total</td>
<td>16</td>
<td>each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVD box relocated cost</td>
<td>1</td>
<td>hour</td>
<td>$32</td>
<td>$184</td>
</tr>
<tr>
<td><strong>Subtotal cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$553</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power-pole PVD distribution</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workstation total</td>
<td>8</td>
<td>each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workstation furniture relocation cost</td>
<td>4</td>
<td>hour</td>
<td>$32</td>
<td>$369</td>
</tr>
</tbody>
</table>
Power pole relocation cost 
2 hour $45 $259
Power point relocation cost 
0.5 hour $45 $130
Data outlet relocation cost 
0.5 hour $45 $146
Telephone outlet relocation cost 
0.5 hour $45 $65
Subtotal cost $968

Cost difference -$415

Reduced Energy Consumption Benefit

Overall energy savings for UAD vary depending on the system design. As per CBE research, UAD energy savings up to 20% is possible when compared with a conventional HVAC system. These savings include reductions in cooling energy consumption for conditioning air as well as reductions in central fan energy for distribution.

In this model calculation, only the cooling energy saving is considered.
Electricity cost $0.15 per kWh

<table>
<thead>
<tr>
<th>Underfloor HVAC system</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling capacity</td>
<td>12.53</td>
<td>kW</td>
<td></td>
<td>$4,511</td>
</tr>
<tr>
<td>Everyday running time</td>
<td>8 hour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation every year</td>
<td>300 day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling energy consumption cost</td>
<td>30072 kWh</td>
<td>$0.15</td>
<td>$4,511</td>
<td></td>
</tr>
</tbody>
</table>

Subtotal cost $4,511

<table>
<thead>
<tr>
<th>Overhead HVAC system</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling capacity</td>
<td>15.56</td>
<td>kW</td>
<td></td>
<td>$5,600</td>
</tr>
<tr>
<td>Everyday running time</td>
<td>8 hour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling energy consumption per year</td>
<td>300 day</td>
<td>0.15</td>
<td>$5,600</td>
<td></td>
</tr>
<tr>
<td>Energy cost</td>
<td>37332 kWh</td>
<td>0.15</td>
<td>$5,600</td>
<td></td>
</tr>
</tbody>
</table>

Subtotal cost $5,600

Cost difference -$1,089

Reduced Absenteeism Benefit

The enhanced workplace environment can reduce the absenteeism by up to 30% reported by Tate Access Floors. However, in this research a conservative estimation considers a reduced absenteeism of 2-day per year per staff.

<table>
<thead>
<tr>
<th>Absenteeism benefit</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>day</td>
<td></td>
<td>$40,000</td>
</tr>
</tbody>
</table>

People located in this area 6 person
Salary per year on average $40,000
Working day 300 day
Total salary saving per year $133.33 $1,600

Cost difference -$1,600

Improved Workplace Productivity Benefit
The enhanced workplace environment can improve the workplace productivity by 3-7% reported by Tate Access Floors. However, in this research a conservative estimation considers an improved workplace productivity of 2% per staff.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved workplace productivity</td>
<td>2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working day</td>
<td>300 day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working day saving</td>
<td>6 day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>People located in this area</td>
<td>6 person</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salary per year on average</td>
<td>$40,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total salary saving per year</td>
<td>36 day</td>
<td>$133.33</td>
<td>$4,800</td>
</tr>
</tbody>
</table>

Cost difference: -$4,800

Cleaning Cost Difference

Consider an annual cleaning of underfloor plenum and air diffusers for underfloor HVAC. Consider an annual cleaning of ceiling air diffusers for overhead HVAC.

**Cleaning cost of underfloor HVAC**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Unit rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underfloor plenum cleaning cost</td>
<td>7 Hour</td>
<td>$35</td>
<td>$245</td>
</tr>
<tr>
<td>Number of floor air diffusers</td>
<td>26 each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for each diffuser cleaning</td>
<td>0.15 hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air diffuser cleaning cost</td>
<td>3.97 hour</td>
<td>$35</td>
<td>$139</td>
</tr>
<tr>
<td>Subtotal cost</td>
<td></td>
<td></td>
<td>$384</td>
</tr>
</tbody>
</table>

**Cleaning cost of overhead HVAC**

| Number of air diffusers | 12 each|       |
| Time for each diffuser cleaning | 0.4 hour|       |
| Air diffuser cleaning cost | 4.8 hour | $35       | $168   |
| Subtotal cost            |       | $168    |

Cost difference: $216
Part 4 - LCC Comparison

**Summary of Initial Capital Cost Differences**

<table>
<thead>
<tr>
<th>Cost Difference</th>
<th>RFS fitout</th>
<th>Traditional fitout</th>
<th>Cost difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raised floor related cost difference</td>
<td>$23,548</td>
<td>$0</td>
<td>$23,548</td>
</tr>
<tr>
<td>HVAC related cost difference</td>
<td>$36,238</td>
<td>$42,090</td>
<td>-$5,852</td>
</tr>
<tr>
<td>PVD related cost difference</td>
<td>$13,005</td>
<td>$17,385</td>
<td>-$4,380</td>
</tr>
<tr>
<td>Floor covering related cost difference</td>
<td>$13,725</td>
<td>$8,601</td>
<td>$5,124</td>
</tr>
<tr>
<td>Earlier owner occupancy saving</td>
<td>$0</td>
<td>$1,500</td>
<td>-$1,500</td>
</tr>
<tr>
<td><strong>Subtotal cost difference</strong></td>
<td></td>
<td></td>
<td>$16,940</td>
</tr>
</tbody>
</table>

**Summary of Running Cost Differences**

<table>
<thead>
<tr>
<th>Cost Difference</th>
<th>RFS fitout</th>
<th>Traditional fitout</th>
<th>Cost difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC churn related cost saving</td>
<td>$60</td>
<td>$583</td>
<td>-$523</td>
</tr>
<tr>
<td>PVD churn related cost saving</td>
<td>$553</td>
<td>$968</td>
<td>-$415</td>
</tr>
<tr>
<td>Reduced energy consumption benefit</td>
<td>$4,511</td>
<td>$5,600</td>
<td>-$1,089</td>
</tr>
<tr>
<td>Reduced absenteeism benefit</td>
<td>$0</td>
<td>$1,600</td>
<td>-$1,600</td>
</tr>
<tr>
<td>Improved workplace productivity benefit</td>
<td>$0</td>
<td>$4,800</td>
<td>-$4,800</td>
</tr>
<tr>
<td>Cleaning cost difference</td>
<td>$384</td>
<td>$168</td>
<td>$216</td>
</tr>
<tr>
<td><strong>Subtotal cost difference</strong></td>
<td></td>
<td></td>
<td>-$8,212</td>
</tr>
</tbody>
</table>

**LCC Analysis**

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash flow</td>
<td>-$16,940</td>
<td>$8,212</td>
<td>$8,212</td>
<td>$8,212</td>
<td>$8,212</td>
<td>$8,212</td>
<td>$8,212</td>
<td>$8,212</td>
<td>$8,212</td>
<td>$8,212</td>
<td>$8,212</td>
</tr>
<tr>
<td>Net cash flow</td>
<td>-$16,940</td>
<td>$7,674</td>
<td>$7,172</td>
<td>$6,703</td>
<td>$6,265</td>
<td>$5,855</td>
<td>$5,472</td>
<td>$5,114</td>
<td>$4,779</td>
<td>$4,467</td>
<td>$4,174</td>
</tr>
<tr>
<td><strong>Accumulated cost</strong></td>
<td>-$16,940</td>
<td>-$9,265</td>
<td>-$2,093</td>
<td>$4,610</td>
<td>$10,875</td>
<td>$16,729</td>
<td>$22,201</td>
<td>$27,315</td>
<td>$32,094</td>
<td>$36,560</td>
<td>$40,735</td>
</tr>
<tr>
<td>Payback time</td>
<td>2.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV over 10 years</td>
<td></td>
<td>$40,735</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Part 5 - Sensitivity Analysis

Both single parameter sensitivity analysis and multiple parameters sensitivity analysis are conducted.
For single parameter sensitivity analysis, the discount rate, reduced energy consumption, reduced absenteeism and improved workplace productivity are considered.
For multiple parameters sensitivity analysis, extreme optimistic and pessimistic conditions are considered upon the co-effect of the discount rate, reduced absenteeism and improved workplace productivity.

Single Parameter Sensitivity Analyses

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discount rate = 10%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>-$16,940</td>
<td>-$9,475</td>
<td>-$2,689</td>
<td>$3,481</td>
<td>$9,089</td>
<td>$14,188</td>
<td>$18,823</td>
<td>$23,037</td>
<td>$26,868</td>
<td>$30,350</td>
<td>$33,516</td>
</tr>
<tr>
<td><strong>Discount rate = 5%</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>-$16,940</td>
<td>-$9,119</td>
<td>-$1,671</td>
<td>$5,422</td>
<td>$12,178</td>
<td>$18,612</td>
<td>$24,739</td>
<td>$30,575</td>
<td>$36,133</td>
<td>$41,426</td>
<td>$46,467</td>
</tr>
<tr>
<td><strong>Reduced energy (+10%)</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-$16,940</td>
<td>-$9,164</td>
<td>-$1,897</td>
<td>$4,895</td>
<td>$11,243</td>
<td>$17,175</td>
<td>$22,720</td>
<td>$27,901</td>
<td>$32,744</td>
<td>$37,269</td>
<td>$41,499</td>
</tr>
<tr>
<td><strong>Reduced energy (-10%)</strong></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-$16,940</td>
<td>-$9,367</td>
<td>-$2,290</td>
<td>$4,324</td>
<td>$10,505</td>
<td>$16,282</td>
<td>$21,681</td>
<td>$26,727</td>
<td>$31,443</td>
<td>$35,850</td>
<td>$39,969</td>
</tr>
<tr>
<td><strong>Reduced absenteeism = 4 days</strong></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>-$16,940</td>
<td>-$7,770</td>
<td>$799</td>
<td>$8,809</td>
<td>$16,294</td>
<td>$23,289</td>
<td>$29,827</td>
<td>$35,937</td>
<td>$41,648</td>
<td>$46,984</td>
<td>$51,972</td>
</tr>
<tr>
<td><strong>Reduced absenteeism = 0 day</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>-$16,940</td>
<td>-$10,761</td>
<td>-$4,986</td>
<td>$411</td>
<td>$5,455</td>
<td>$10,169</td>
<td>$14,574</td>
<td>$18,692</td>
<td>$22,539</td>
<td>$26,136</td>
<td>$29,497</td>
</tr>
<tr>
<td><strong>Improved productivity = 4%</strong></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-$16,940</td>
<td>-$4,780</td>
<td>$6,585</td>
<td>$17,206</td>
<td>$27,133</td>
<td>$36,410</td>
<td>$45,080</td>
<td>$53,183</td>
<td>$60,756</td>
<td>$67,833</td>
<td>$74,448</td>
</tr>
<tr>
<td><strong>Improved productivity = 0%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-$16,940</td>
<td>-$13,752</td>
<td>-$10,772</td>
<td>-$7,987</td>
<td>-$5,384</td>
<td>-$2,952</td>
<td>-$679</td>
<td>$1,446</td>
<td>$3,431</td>
<td>$5,287</td>
<td>$7,021</td>
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Multiple Parameters Sensitivity Analyses

<table>
<thead>
<tr>
<th>Year</th>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced absenteeism = 4 days and improved productivity = 4% with discount rate = 10%</td>
<td>Payback time = 1.30 years, NPV (over 10 years) = $72,842 and accumulated costs are</td>
<td>-$16,940</td>
<td>-$3,657</td>
<td>$8,419</td>
<td>$19,397</td>
<td>$29,377</td>
<td>$38,449</td>
<td>$46,697</td>
<td>$54,195</td>
<td>$61,012</td>
<td>$67,208</td>
</tr>
<tr>
<td>Reduced absenteeism = 4 days and improved productivity = 4% with discount rate = 7%</td>
<td>Payback time = 1.26 years, NPV (over 10 years) = $85,685 and accumulated costs are</td>
<td>-$16,940</td>
<td>-$3,284</td>
<td>$9,478</td>
<td>$21,405</td>
<td>$32,552</td>
<td>$42,970</td>
<td>$52,706</td>
<td>$61,806</td>
<td>$70,310</td>
<td>$78,258</td>
</tr>
<tr>
<td>Reduced absenteeism = 4 days and improved productivity = 4% with discount rate = 5%</td>
<td>Payback time = 1.23 years, NPV (over 10 years) = $95,886 and accumulated costs are</td>
<td>-$16,940</td>
<td>-$3,024</td>
<td>$9,229</td>
<td>$22,851</td>
<td>$34,872</td>
<td>$46,320</td>
<td>$57,224</td>
<td>$67,608</td>
<td>$77,498</td>
<td>$86,916</td>
</tr>
<tr>
<td>Reduced absenteeism = 0 day and improved productivity = 0% with discount rate = 10%</td>
<td>Payback time = 28.70 years, NPV (over 10 years) = -$5,809 and accumulated costs are</td>
<td>-$16,940</td>
<td>-$15,293</td>
<td>-$13,796</td>
<td>-$12,435</td>
<td>-$11,198</td>
<td>-$10,073</td>
<td>-$9,050</td>
<td>-$8,121</td>
<td>-$7,276</td>
<td>-$6,507</td>
</tr>
<tr>
<td>Reduced absenteeism = 0 days and improved productivity = 0% with discount rate = 7%</td>
<td>Payback time = 15.71 years, NPV (over 10 years) = -$4,216 and accumulated costs are</td>
<td>-$16,940</td>
<td>-$15,247</td>
<td>-$13,665</td>
<td>-$12,186</td>
<td>-$10,804</td>
<td>-$9,512</td>
<td>-$8,305</td>
<td>-$7,177</td>
<td>-$6,123</td>
<td>-$5,137</td>
</tr>
<tr>
<td>Reduced absenteeism = 0 days and improved productivity = 0% with discount rate = 5%</td>
<td>Payback time = 12.92 years, NPV (over 10 years) = -$2,952 and accumulated costs are</td>
<td>-$16,940</td>
<td>-$15,215</td>
<td>-$13,572</td>
<td>-$12,007</td>
<td>-$10,516</td>
<td>-$9,097</td>
<td>-$7,745</td>
<td>-$6,458</td>
<td>-$5,232</td>
<td>-$4,064</td>
</tr>
</tbody>
</table>
Appendix 14 – Checklist for Guidelines

The recognized 20 SIFs and 35 PLCFs are referred in the project delivery to enhance RFS fitout constructability. Particularly, the 5 SIFs in Checklist A and 8 SIFs in Checklist B are examined in the feasibility stage; the 5 SIFs in Checklist C and 2 SIFs in Checklist D are studied in the conceptual design stage; the 16 PLCFs in Checklist E, the 11 PLCFs in Checklist F and the 8 PLCFs in Checklist G are examined in the detailed design stage, construction stage and post-construction stage respectively.

Checklist A – Cost Concerns

- Capital cost obstacle
- Underestimate of LCC
- Poor design influence on cost
- Suspicion of RFS payback ability
- Ambiguity of fitout responsibility

Checklist B – Industry Practitioners’ Knowledge

- Architects & engineers’ incompetency
- Poor design influence on construction
- UAD influence on productivity
- Clients’ low familiarity with UAD
- Contractors’ incompetency
- QS’ incompetency
- Low awareness of RFS
- Ignorance of RFS implementation

Checklist C – Structural Constraints

- Structural irregularity
- Space volume limitation
- Transition difficulties
- Overhead HVAC influence
- Structural beam restriction

Checklist D – RFS Service Integration

- Fire safety system accommodation
- Cables and wires incompatibility
Appendix 14 – Checklist for Guidelines

Checklist E – PLCFs pertaining to RFS Fitout Detailed Design

- Structure regularity
- FFH
- Underfloor HVAC system
- Ramps and steps
- Workplace furniture layout
- Orderliness of PVD distribution
- Underfloor space management
- Selection of RFS products
- Estimation of floor boxes
- Panel and pedestal locking method
- Sound block arrangement
- Ceiling renovation in retrofit projects
- Cables and wires compatibility
- Fire safety system
- Capital cost and LCC
- RFS service integration

Checklist F – PLCFs pertaining to RFS Fitout Construction

- Subfloor treatment
- Panels and pedestals layout
- Carpet tiles layout
- Ramps and steps
- Workplace furniture layout
- Air leakage testing
- Panel cutting
- RFS installation along perimeters
- Removal of dust
- Use of special tools
- Construction coordination

Checklist G – PLCFs pertaining to RFS Service Operation and Maintenance

- Use of RFS complying with specifications
- Use of air diffusers
- Introducing-in of dust
- Underfloor service maintenance
- Underfloor space cleaning
- Carpet tile maintenance
- Additional panel drilling
- Getting panels back after maintenance
Appendix 15 – Questionnaire for Validation

Questionnaire and interview surveys were conducted to study raised floor system (RFS) implementation for office building fitout in Australia. According to your feedback, five key issues are finally identified to have significant influence on RFS fitout project delivery, as presented in Question 1. In order to improve the research activities and validate the research outcome, we would like to invite your comments on the following issues.

Question 1: By circling the relevant number, please rate the response that best describes your agreement level as to the following issues which can significantly influence raise floor project delivery:

<table>
<thead>
<tr>
<th>Key Issues</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) The integration of constructability with RFS project development process</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>(2) Early involvement of RFS fitout specialist contractors</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>(3) Cooperation and communication among project team</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>(4) Appropriate contracting strategy to integrate the RFS fitout and whole project delivery;</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>(5) Appropriate RFS product procurement to avoid post-construction problems due to improper use of RFS products.</td>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

Question 2: By circling the relevant number, please rate the response that best describes your agreement level as to the effectiveness of the “Guidelines for the RFS Fitout Implementation” which is attached in the email.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>(6) Please rate your opinion of the Guidelines.</td>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

Question 3: If you have any comments on this research, please write it down below:

**************************************************************************
Thank you for completing the questionnaire! Please return this page by fax to 07-38641170 or email to g2.zhang@qut.edu.au.
REFERENCES


References


References


References


Tate. (2001). Tate Building Technology Platform Brochure, Tate Access Floor Company.


