THE INTEGRATION
BETWEEN DESIGN AND MAINTENANCE
OF
OFFICE BUILDING AUTOMATION:
A DECISION SUPPORT APPROACH

by
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A thesis submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

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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:______________________________
ACKNOWLEDGMENTS

This thesis represents more than a research project to me. It is a new start for my life, not only the culmination of the richest learning experience. Never say never, everything is possible. Sincerely, I must express my gratitude.

First of all, praise and thanks must be to God for God’s mercy that the project can be completed. I am convinced that it is the grace given from God.

In reality, it would not have been possible to complete this research without the generous support, assistance and encouragements of several friends and staff members at Queensland University of Technology, special thanks to Research Administrator Denise Redfern and Computing Services Officer Ian Foote who provided administration and technical support and various contributions during the process of this research.

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Frank Lin June 2005
ABSTRACT

This research explores the barriers and limitations of the interaction between building development processes in an attempt of an integrated decision support approach to improve building design for effective maintenance in the field of office building automation.

Extensive coverage of literature and practice in office building industry over the last two decades indicates a wide diffusion and application of the information and communication technologies (ICT). While this has resulted in the adoption of advanced system integration in buildings, system redundancy and excessive expenditures are causing a major impact on the overall efficiency and has burdened building owners and occupiers with escalating maintenance costs. This phenomenon stimulates and warrants the re-examination of integrated building development, not just on system integration but also on the interdisciplinary development process integration particularly linking design and maintenance.

Studies in this field revealed existing problems such as the inherent professional fragmentation, lack of historical information and service data, the first cost mentality of owners and developers, difficulties in forecasting future conditions and changes early in the design stage. With extensive use of qualitative information, this situation presents a great potential for the development of a decision support system exploring the communication and integration of design and maintenance phases, which has been one of the primary objectives of this research.

In addition to literature studies, a questionnaire survey and a case study to identify industry concerns, feasible solutions, and practical procedure oriented approaches through knowledge extractions were carried out. A set of guidelines, a checklist for its implementation and prototype system for computerized decision support to design and maintenance of building automation systems were also produced. These strategic approaches to balance design and maintenance will help facilitate appropriate decision making in the early design stage for sustainable maintenance of buildings.
Keywords

Office building, Intelligent buildings, Integration, Design, maintenance, Information and communication Technology (ICT), Decision support system, Building Automation System (BAS), building performance, energy conservation, maintainability, sustainable.
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ABBREVIATIONS

BA  Building Automation
BACNet  Building Automation Control Network
BAS  Building Automation System
BMS  Building Management System
CA  Communication Automation
CAPEX  Capital Expense
RH  Relative Humidity
CPU  Central Processing Units
DDC  Direct Digital Control
DGP  Data Gathering Panel
EMS  Energy Management Control
EMCS  Energy Management and Control System
FA  Fire Automation
IB  Intelligent Building
ICT  Information and Communication Technology
IDEC  Indirect Evaporative Cooling
IEQ  Indoor Environment Quality
LAN  Local Area Network
MA  Management Automation
OA  Office Automation
SBASPRO  Office Building Automation Decision Support Pro
OPEX  Operation Expense
PDS  Project Delivery System
PI  Proportional and Integral
PID  Proportional and Integral and Derivative
PMV  Predicated Mean Vote
SA  Security Automation
TCP/IP  Transmission Control Protocol/ Internet Protocol
VAV  Variable Air Volume
CHAPTER 1
Introduction

1.1 Research Background
1.2 Research Problems and Proposition
1.3 Research Objectives
1.4 An Overview of Research Methodologies
1.5 Outline of Thesis
1.6 Definitions and Terminology
1.7 Summary
1.1 Research Background

The research primarily explores some of the barriers and limitations in the building conception process and endeavours to provide the strategies for the improvement of effective decision-making in the office building automation field through the integration of design and maintenance associated with the development of a decision-support computer-based approach.

On a global scale, much new technology has been developed over the past two decades. The information and communication technology (ICT) has also offered an easy and affordable tool for industries, including the construction and building industry which has had comparatively less growth than other industries such as the motor and aeronautical industry (Council on Tall Buildings and Urban Habitat 1995). The situation of building industry indicates that it should move with the times to enhance the improvements in the building process.

Observed from the literature reviews, due to the long lifetime of buildings, the specific features and unique characteristics which exist in the professionals of the building industry and various problems and conflicts with service and maintenance may cause non-sustainable consequences, such as excessive energy consumption, increased service schedules and costs, and sick building syndromes. Subsequently, among them some of the existing gaps and overlaps in design could be barriers for building improvement. It would rely on the exploration of a new strategic integration approach to improve on the current situation.

The integration of existing knowledge and techniques among different fields has been studied and is commonly recognized as an effective method to overcome the current constraints to improvement in the present era as well as a decision support approach, which can be applied for linking of different parities such as design and construction, design and scheduling, design and planning. The integrated approach has been explored and introduced into the construction industry.

Efforts in construction automation have facilitated system integration with effective functions. However, the integration development across the different phases is still in the infant stage which is only exploring ideas and concepts. The integration activities
have mostly focused on the improvement of respective system effectiveness in isolated phases such as architectural design, engineering design, construction, production planning, production automation, and building use and maintenance (Matti, H. 2000). Hence, in order to overcome the known barriers, integration can be directed to and focused on process integration i.e. integration across different phases such as design and maintenance. The exploration of process integration could be a feasible alternative for building improvement. Additionally, in light of growing concerns about the overall life-cycle performance and the comfort of buildings, process integration would also potentially be in the viable exploration a knowledge-based decision process to optimise building performance.

The office building is getting smarter because of availability of advanced information and communication technologies (ICT) which facilitate the adaptability of building automation systems and satisfy the users’ prospects increasingly in the real world. The building systems have advanced and become integrated with new technologies. However, has it promoted the overall benefits and occupant-satisfaction during the life of buildings? This deserves rethinking and exploring, consequently an integrated approach could be an alternative for solving the current problems relating to the inherent separated processes in the building industry.

Findings from the observation of building operation practices in the past several years associated with office building maintenance have encouraged an exploration of the feasibility of providing total solutions in the maintenance-based design issues of office building automation. Thus this research has concentrated on the sphere of office building automation design and management including maintenance to discover what is now known to respond to the practical requirements, and to develop an applicable decision support platform for the advanced development of office building automation.
1.2 Research Problems and Proposition

With an expectation to extend the life of systems and ensure the function and performance of buildings, the industry and researchers are gradually paying more attention to the subjects of total efficiency and overall performance throughout building process. However, people without a direct ongoing 'relationship' with the building may be less concerned to care for it. Developments in maintenance have tended to focus on efficiency rather than effectiveness, losing sight of motivational matters (Wood, B. 2003).

The main problem in the building care is the lack of 'intelligence' in a variety of aspects - lack of data, particularly historical relevant data, lack of research into the behaviour and durability of materials, and lack of forethought applied to the maintenance field. There are also possible problems of interpretation and misunderstanding between design works and the maintenance staff, such as in the design and maintenance of building materials and components or systems, specifically communicating among designers and maintainers, which related to the diverse disciplines, skills, and techniques. It would be desirable to give the maintainor understanding of the building design aspect, and to learn what was intended in the initial design to cover the lifetime of the building.

In practice, available data for the ongoing needs of operation and maintenance are insufficient or inappropriate and out of date, especially in the environment of increasing occupants’ expectations, which mainly related to historical data related to the actual operational conditions. Above all, forecasting the future changes and performance of buildings is difficult in the early design stage. Resolution of such problems is more likely with a continuing relationship from the design phase, through construction to operation and maintenance with continuous, encouraging and responsible attitudes and facilitating actions.

Previous research efforts also demonstrated the limitations such as:

- The lack of adequate up-to-date knowledge
- The advanced technologies are not yet provided for in the time and budget limits
• The building professionals do not recognise the importance of the interaction between design and maintenance
• Generally, developers just focus on the initial capital cost, but the “first capital cost” is only 20% of the operational costs of a building over the life of the building.
• Difficulty in obtaining the systematic information from the feedback of the maintenance.

Those problems and limitations result in the declining environment. The existing old buildings comprise the major part of the stock of buildings. The huge and increasing expenditures for the routine maintenance and the retrofit have burdened the owners and occupants, which were already over budget, thus the situation has made them seriously thinking about strategic solutions. The implication on the overall performance of buildings along with the energy and money loss has also been of concern. It is the time to take effective action to solve the problem. Consequently, focusing on the office building automation field in this research, a possible proposition would be:

“Could possible alternatives be created to help the improvement of the problems which exist between the design and maintenance of office building automation during the lifetime of buildings?”
1.3 Research Objectives

Based on the observation of the building maintenance in practice, an individual equipment problem in a building can cause the failure of the whole building systems. However, was it related to the reliability during the maintenance process or the robustness of the design, or maybe both? The appropriate answer will rely on using appropriate tools for assessing the systems during the building lifecycle. It also depends on the realization of the original design and the building operation and management process including the maintenance.

In common building operations, the owners/occupants and service providers generally lack the knowledge to distinguish between design and maintenance, and the effective solutions for the problems on hand; the evaluation methods of building performance and applicable guidelines are also insufficient. Moreover, the research findings from the literature survey illustrate the limitations as well. These findings have been backed by:

(1) Author’s professional experience over 10 years in the office building construction and management field, and quality control and assurance for 15 years in the aeronautical vehicle maintenance fields.

(2) Scarce literature on linking the building design and maintenance.

(3) Initial discussions with Queensland based building operation.

For these reasons, the research has been justified in focusing on the integration of design and maintenance in the office-building field and proposes to develop a computer-based decision support for improving the building status.

The intention of the research is to explore an integration attempt for the building design and maintenance process. In order to reach this goal, concentration on a specific system would be necessary that provides both a pilot instruction and a feasibility study for the future development. In office buildings, the Building Automation System (BAS) which is the main brain and the heart of systems, plays a key role in the building operation and maintenance.
The growth of the BAS is set to enhance the performance of buildings and allows the building gain a high level of intelligence, which is associated with the depth of communication between the different phases, such as design and maintenance. However, the right choice and maintenance of applicable BAS and related subsystems is not only the responsibility of the designers, but also of building owners and maintainers who need to gain learn about the selection, integration and maintenance of the whole systems. To fulfil their liabilities and expectations, adequate knowledge and sufficient current information will come from the outside sources. This presents a great potential for the development of integrated decision support systems for communicating different phases such as design, operation and maintenance during the process. Most of the earlier research development in decision support addressed the solution of isolated problems in the building process or the initial related stages of projects such as design and planning, scheduling, estimating, costing and maintenance. Efforts on integration and communicating during the building phases, such as building design and maintenance are rare. The previous research efforts stopped short at the conceptual stage.

In modernised office building developments, Intelligent Building (IB) is not only the result of the application of various technologies to satisfy the expectations and requirements of the occupants; however, it seems a long way to go to change all of our buildings from traditional ones to intelligent ones. Intelligent and sustainable buildings are still at the developmental and experimental stage; more work is required to explore and record their performance in use. The “Maintenance issue” has few research works or reports; the integration of “design” and “maintenance” might not yet be explored and deserves greater concentration.

Therefore, this research project has been developed to study the relationship between design and maintenance in office building automation, and to seek the possible solutions for some of the problems discussed in the domain of office buildings. The research objectives have been proposed as:

1. To identify the barriers and limitations of building automation practice between the design and maintenance phases.
2. To establish a guide for effective enhancement between design and maintenance of office building automation system.
3. To develop a computerised decision support prototype for ease in integrating the design and maintenance in office building automation.

In this research, it will be shown that integration will facilitate the sharing of information between designers and maintainers using computerised knowledge-based decision support packages in making decisions to ensure design effectiveness, and to improve the reliability of maintenance with the building automation systems. The intention of this research is to explore a new integrated approach providing the knowledge support and guidelines for the design and maintenance phases of the building automation to reduce poor design which has a negative impact, and to improve maintainability during the practical implementing processes, and eventually to optimise the total performance and increase the long-term value. In simplification, this research aims at the integration of design and maintenance in building automation system (BAS) by using a decision support approach to demonstrate a way for BAS in office building as shown in Figure 1-1.

![Figure 1-1: Research Objectives](image-url)
1.4 An overview of Research Methodologies

In this research, the integration development between design and maintenance of office building automation was based on a comprehensive understanding of the characteristics, major functions of the subject and the relationship of the design and maintenance tasks.

Collection of the relevant information associated with building automation practice, research findings and professional survey was the preliminary step. At the same time, the research also needed a pilot computerised system design to explore the applicable alternatives and evaluate the feasibilities for the whole prototype system, then to develop other functions required for decision making to accomplish the whole integration decision support system. Moreover, the research had to explore the relevant design issues in relation to the maintenance of office building automation system (BAS) and develop possible strategies for improving the performance and optimisation of the operation and maintenance process in the long term. The key methodologies for this research consist of:

- Literature study
- General research approaches
- Industry surveys and case study
- Knowledge acquisition
- System design and development
1.5 Outline of Thesis

The thesis consists of ten chapters as follows:

**Chapter 1:** Introduction: to describe the research background to learn the problems, then to give a proposition for the research objective justification; to outline the research methodology, scope and limitations as well.

**Chapter 2:** Literature study: to present the literature findings in relation to the proposed research problems to construct the core focused elements and ensure the direction of research and development.

**Chapter 3:** Research methodology: to justify the research paradigm and methodology for the first hand data collection of induced/deduced knowledge, to ensure carrying out this proposal, and investigating the limitations.

**Chapter 4:** Research design and development: to justify the research methodologies for the designated objectives and to design the necessary research activities.

**Chapter 5:** Survey, data analysis, and case study: to present the survey questionnaire results and analysis in relation to the research problems and industry practice, as well as to verify the research direction and scope through the case study of building.

**Chapter 6:** Knowledge extraction: to extract the relevant BAS knowledge in relation to the design and maintenance, and to explore the applicable strategies as well.

**Chapter 7:** Guidelines Development: to outline the relevant guidance including raising awareness, feasible strategies and operational checklist.

**Chapter 8:** Development of decision support system: to present the process of system design and development, then demonstrate the prototype system.

**Chapter 9:** Verification and discussion: to review the research progress and the computerized decision support prototype system.

**Chapter 10:** Conclusions: to conclude the research efforts and contribution and discuss further implications and implementation.
### 1.6 Definitions and Terminology

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<tr>
<td>Office building</td>
<td>“a building containing offices where work is done”</td>
<td>WordNet 2.0</td>
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<td>Intelligent building</td>
<td>“An Intelligent Building is designed and constructed based on an appropriate selection of quality environment modules to meet the user's requirements by mapping with the appropriate building facilities to achieve long-term building value.”</td>
<td>So (1999)</td>
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<td>Integration</td>
<td>“the sharing of something by somebody using some approach for some purpose.”</td>
<td>Betts et al. (1995)</td>
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<td>Design</td>
<td>“To invent, create, or construct according to plan”; It also can be defined as “a plan or scheme, conceived in the mind, of something to be done: the preliminary conception of an idea that is to be carried into effect by action.”</td>
<td>Encarta dictionary; Hamilton G. &amp; Harrison A. (1986)</td>
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<tr>
<td>Maintenance</td>
<td>“To sustain the integrity of the physical assets by repairing, modifying or replacing them as necessary to provide and control their reliability.”</td>
<td>Encarta dictionary</td>
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<td>Information &amp; communication technologies (ICT)</td>
<td>“The study of the technology used to handle information and aid communication.”</td>
<td>WWWICT</td>
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<td>Decision support System</td>
<td>“interactive computer-based systems, which help decision makers utilise data and models to solve unstructured problems” “a DSS supports complex decision making and increases its effectiveness”</td>
<td>Scott-Morton (1971) Turban et al. (2001)</td>
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<td>Building automation system (BAS)</td>
<td>“Building Automation Systems (BAS) optimise the start-up and performance of HVAC equipment and alarm systems. BAS greatly increases the interaction of mechanical subsystems within a building, improve occupant comfort, lower energy use and allow off-site building control.”</td>
<td>BAS Load Management</td>
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<td>Building performance</td>
<td>“Building performance mandates, namely, indoor air quality, acoustical quality, visual quality, thermal comfort quality, spatial quality, energy, building integrity.”</td>
<td>NEEC National Energy Efficiency Committee</td>
</tr>
<tr>
<td>Energy conservation</td>
<td>“Using energy efficiently or prudently; saving energy.”</td>
<td>WWWEC</td>
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<tr>
<td>Maintainability</td>
<td>“Is the ease, accuracy, safety, and economy of maintenance in order to improve the effectiveness and efficiency of maintenance.” “The ease with which a software system or component can be modified to correct faults, improve performance, or other attributes, or adapt to a changed environment”. “Ease of maintenance, commonality of hardware, modular assembly, and Murphy-proofing”</td>
<td>ASHRAE 2003 IEEE 90 Neubeck 2004</td>
</tr>
<tr>
<td>Sustainable</td>
<td>“Meets the needs of the present without compromising the ability of future generations to meet their own needs”</td>
<td>Agenda 21</td>
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1.7 Summary

In summary, the rapid advancement of computer technology has made it possible to explore the potential of integration between building design and maintenance partitioners. There is also a sustained drive for research into decision support systems in construction practice. However, several areas of problems and limitations in the design and maintenance in practice, such as the inappropriate application of systems and some deficiencies resulting from the limits of time and budget, highlight the potential for the research proposed here.

This presents an opportunity for a computer-based integration approach for decision support in the building process. The perception and benefits of integration have been recognised and accepted in the industry. Supported by advanced information and communication technologies (ICT), the trend toward better integration in building process will create more advantage for the future.

This chapter has opened the discussion for the topics of the thesis. It has introduced the research problems, limitations and propositions. The research background of the office building automation practice was described, the research objectives was proposed, the methodology was overviewed, the definition was presented, and the structure of thesis was outlined. On this foundation, the thesis can proceed with a detailed description of the research.
CHAPTER 2
LITERATURE STUDY

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   2.2.2 ICT Application in the Building Process
   2.2.3 Reviewing the Current Building Process
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2.7 Summary
2.1 Introduction

This chapter presents the relevant literature. It aims to build a foundation for the research development. The literature review is defined as: ‘the selection of available documents (both published and unpublished) on the topic, which contains information, ideas and evidence written from a particular standpoint to fulfil certain aims or express certain views on the nature of the topic and how it is to be investigated, and the effective evaluation of these documents in relation to the research being proposed’ (Hart 1998). The literature study needs to span the data and information to identify the research issues by reviewing the relevant literature.

Literature survey is a documentation process of a comprehensive review of the published and unpublished work from secondary sources of data in the areas of specific topics 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 research framework for the current investigation can be built and developed; a good literature survey also leads logically to a good problem statement (Sekaran 2003; Fellows and Liu 2003 ), then to gain good forward results. Meanwhile it also has to ensure that no important variable that has in the past been found repeatedly to have had an impact on the problem is ignored (Sekaran 2003). The literatures must be considered in the context of theory and other literatures- the methodologies, data, analytic techniques etc., and therefore they will be an on-going process till the deadline of this research is reached (Fellows and Liu 2003).
To fulfil the research objectives, this research has reviewed five aspects of literatures as shown in Figure 2-0 in the context of research focus:

1. Building integration
2. Decision support approach
3. Design and maintenance for office building
4. Building automation systems (BAS) for office building
5. Other relevant literatures

Figure 2-0: Scopes of Literature Study
The literature study will initiate from reviewing the building integration of both in building systems and building processes. To achieve the benefits of the integration, an effective approach is needed. The research has proposed to explore a decision support for this purpose on the building processes such as design and maintenance. In office building, BAS plays a key role. It will be taken to demonstrate the integration exploration to share information and create close relationships between design and maintenance. The integration activities should rely on the relevant information such as TQM, Building Commissioning (BC), Life Cycle Costing (LCC) and other literatures. There will be reviewed to develop useful strategies.
2.2 Building Integration

2.2.1 Status of the Office Building Industry

The principal characteristic of a major office building was stated by Sullivan (1896) as: “It must be tall- every inch of it must be tall. The force and power of height must reside in it- the glamour and pride of enthusiasm”. Yet the high-rise is insufficiently characterised by height alone; it must be higher than all others, at least for a time. (Eisele & Kloft 2002). ‘High- higher- highest’ has become the trend of office building construction. It has driven the building industry to apply cutting edge technology on product and system innovation in the functional performance enhancement to pursue the highest standards for office buildings.

However, in reality, office building projects are often constructed under constraints of the time and budget and driven by some specific purpose, either for political or economical reasons which can compromise the project. After all, the builders need to cope with and balance between a variety of requirements during the process.

With yet another attempt at the worlds’ tallest building completed in Taipei this year, it seems that the office building industries around the world are facilitated by design, construction and operation the tallest landmarks on each, as evidences in Table 2-1. However, inevitably, a question would be asked: “Does the remarkable feature of height cope with the practical demands and technical supports, or does it create non-technical compliance?”
Nevertheless, the gap existing in the different fields is still a challenge for the construction and building industries; it also presents opportunities for breakthrough and growth. Over viewing the development of the building construction industry, the information technology (IT) computer support was introduced during the 1960s to the building process by structural engineers. Since then the islands of automation for construction according to Figure 2-1 (Matti, H. 2000) has shown it is slowly growing and the gap has gradually been reducing. For example, the isolated digital islands have been created for design (2D/3D CAD, visualization, engineering calculations), construction (quantity take off, resource management), maintenance/use (facility management), and resource supply (components/material databases). IT creates great changes that affect work content, team work and collaboration, project organisation, building product and process descriptions (models) and Information and Communication Technology (ICT) based tools.
The changes are inevitably relevant to the construction industry and have an effect on the building process. Accessing external vendor product information, regulations, and community information would be crucial for the practice. A great need and potential exists for the development of its application in specification, design, implementation, and evaluation of tomorrow’s building process support systems into the complex building process which will combine with deep knowledge and ICT tools.

Predictably, the building products will themselves also contain embedded and integrated IT support (Intelligent and responsive buildings) in the future. The building processes will be more integrated, and supported to reduce gap. Information produced during the whole building process will be used to a higher degree for the maintenance and provide subsequent experience data for the enhancement of new building designs and databases.
2.2.2 ICT Application in the Building Process

Information and Communication Technology (ICT) has rapidly advanced to provide support for business and industries including the construction and building industries. This technology provides applicable tools and infrastructure to increase the efficiency of the process, enhance communication and facilitate relationships during the building process.

A close look at the role of ICT and its capacities in the whole building process from sketch/concept, design, construction, operation & maintenance (O&M), use, to building demolition/ recycling will present a bright prospect for the future, though the past and present application status seems to be growing slowly as seen in the description of Matti’s islands of construction automation. However, in light of the ICT capabilities that ICT will continue to play a key role from now on is a great possibility. The building process, through realistic integration, will be able to access a much better decision making support in the very early phase of the design process. The improved IT supports knowledge management, communication on all levels, decision support, planning, information processing, intelligent building, collaboration, systems design and integration (Christiansson, p. 2000).

In brief, ICT has provided several useful applications in the effective building systems and processes. And it has also provided a sustainable infrastructure for the advanced development with immediacy for the building industry. The status of ICT applications in the building process can be outlined as:

- ICT provides knowledge and tools which can be used in all phases of the building process from design concept to operation, maintenance and demolition of buildings.
- ICT provides potential for the development of building systems and design support tools for the building process.
- ICT supplies for building process integration to facilitate:
  - Computerised building process systems
  - Conceptual modeling of the building process
o Realisation of Intelligent Buildings (IB): ICT provides methods, systems, and techniques for design, operation and maintenance, and administration of buildings as well as environmental improvement.

o Integrated Databases: it includes concepts and requirements for technical and building process.

The advent of Information and Communication Technologies (ICT) has changed the building industry in various fields; however, in the current state of the building industry, the scope of the design service is still isolated within the traditional boundaries. To create unique designs (production stage), the designers are operating alone, seldom to extend their service and interest to the rest of the building process. On the other hand, the buildings after delivery are operated by the building owners or tenants (operation and maintenance stage), but in practice, the support tools are still inadequate or not enough to support the building in the long term. This presents a potential and need for the development of ICT support. ICT needs to support the total building life cycle after the design and construction stage: asset management, operation and maintenance (Matti H. 2000).

2.2.3 Reviewing the Current Building Process

According to Christiansson (2004), despite efforts and the advanced developments in systems and products automation and integration as above mentioned, the implementation in the building process automation has been rather slow due to:

- The building process is one of the most complex and less formalized applied processes (short series of products, changing participants from project to project, changing production sites, and cultural differences).
- Building process participants using different ICT tools, languages and model formalisms.
- Rich spectrum of user interfaces with different characteristics.
- Low client understanding that IT pays back (because of better early decisions in alternative solutions, higher quality and better documented end products).

In the building system integration process, along with the ICT technologies rapid growth, smart and sustainable buildings are becoming a buzzword in the office
building industry over recent years. One of the distinctive characteristics of a smart building is that its design and construction requires the integration of complex new technologies into the fabric of the building for more effective operation (Drewer, S. & Gann, D. 1994). Therefore the main features of smart buildings are often associated with advanced automation equipment and services for monitoring and controlling purposes. The sustainable buildings will have an aim of reducing the negative impacts on the environment and resources during its design, construction and operation, while producing a healthy, productive and socially supportive built environment; hence they require the sustained process integration for lifetime of the building. Reviews of the building process can be summarised as the follows:

◊ The performance of buildings is very dependent on the quality of the whole building process such as design and the operation and maintenance of the building’s internal systems. Conventionally, these two phases of building process take place independently of each other (LAMSAC 1981). However, each individual process involved in the building development, from building design, construction, to the operation and maintenance, is related and dependant on the others and the degrees of their interaction significantly influences the end result (Chanter B. et al., 1996).

◊ Buildings also require lifetime support and service of their operation and maintenance. Technological assistance for this is now becoming available in the form of building automation systems (BASs) – which offer proven benefits in building performance and energy conservation (CIBSE 2000; Novak B. 2004). It is likely that in the building delivery, the effectiveness and efficiency of BASs will be a main concern of building owners and operators for years to come.

◊ It is being increasingly recognized, particularly for new construction projects, that BASs are the most cost-effective way of building management and energy conservation. In addition, advanced BASs help increase comfort levels and healthy living/working conditions. Intelligent/green buildings need to be built with sustainable materials through intelligent design and construction methods. The process does not stop when the building is complete – proper operation of building systems will ensure that the building remains intelligent and sustainable throughout its lifetime. A BAS plays a key role in supporting intelligent/green
design by reducing energy conservation and improving indoor environmental quality (CIBSE 2000; Moult R. & Matasek, D. 2001).

The expectations placed upon office buildings have experienced extraordinary changes over the years from the basic function of office working space to the modern dynamic and comfortable workplace equipped with advanced automated technologies. However the levels of adoption and complexities of new technologies alone which have integrated several various systems do not really make a building smart. The comprehensive functionality of a smart building will need to rely on the extensive integration of building service systems, such as HVAC; electric power; communication; safety and security; transportation; sanitation, etc. It is also dependent on the integration between these systems and the building structure as well as the infrastructure of the communication.

Hopefully, optimised systems integration can be fully accomplished through the process integration from strategic planning of the building development, typically starting at the initial design stages of the building and ending up with a life long process of building maintenance and upgrade (Arkin & Pacink 1997).

On the other hand, office buildings are being developed with advanced systems around the world, however building performance problems are also common on a global basis; likely system breakdowns, control failures, frequent service intervals may intertwine with high running cost and the inability to produce desirable user comfort levels or flexibility, which are all contradictive to sustainability principles (Coggan, D.A. 1997; Fellows M. C. T. C. R. 2000). As these problems are often associated with the design, selection, installation and operation of building systems, a question is “How can we facilitate a smarter design for more sustainable building performance and maintenance?” In summary, current barriers and limitations on the building system and process caused the process not being integrated effectively.

The following sections will demonstrate the details of the findings from the literature reviews in five areas: (1) building integration; (2) decision support; (3) design and maintenance for office building; (4) BAS for office building (5) other relevant literatures.
2.2.4 Integration Application in Building Process

The contributions from previous research have concluded that the useful and practical approach for the resolution of the inconsistent and insufficient current knowledge in building practices, and the decision based approach with knowledge based support could be applied extensively at present with the exploration of integration. In comparison to numeric based computations such as estimation, there is a lack of computer support for problem solving and decision making during all stages of the project development. In the light of this, decision support systems and integration are becoming a highlight for research and will continue to be applied in the construction and building practice.

2.2.4.1 Implications of Integration

A generic concept of integration was defined by Betts et al. (1995) as: “the sharing of something by somebody using some approach for some purpose”. When the construction and building process consists of many interlinked stages as discussed earlier, it is naturally logical and efficient for information to be processed consistently and on an integral basis. This has also proved to be practical with the arrival of new techniques and methods. There are also research attempts to provide the readily useable linkages between the construction tasks such as the use of knowledge-based processing between design and planning for decision support and integration (Yang & Lin 1998).

However, from the previous literature reviews and observations in the building practice, it is rare that integration between different fields such as design and maintenance, particularly in attempts to advance the stand alone reliable competencies to discover the real energy and cost savings with a built better environment.

During the office building design stage, consultants often do not have sufficient understanding on maintenance issues for the operation of the building. As a result, there is often a lack of effective solutions for service, upgrade and maintenance problems during the life-span of the building. For automated and intelligent buildings, with their wide range of technology adaptation and upgrading capacity, the
issue between demand and lack of response is more critical. Previous efforts on integrated building development phases, particularly between design and maintenance, are very rare with only a few related topics exploring ideas. This situation presents a great potential for developing an integrated decision support system for the integration of and communication between design and maintenance phases during the conception stage of an office building project.

In practice, the designers have time or budget pressures and the lack of up-to-date information about the applicable systems for the life-cycle process. Research needs to explore an approach for the decision support and examine the potential for the advanced development in the office building automation.

2.2.4.2 Potential Strategies of Balance between Design and Maintenance

To deal with the sheer volume of information, knowledge and decision points, a potentially feasible alternative is to facilitate ‘smarter’ design of building systems for the benefit ‘more sustainable’ maintenance. Being smart here refers to the specific approach of using feedback from maintainers, accessing historical information on failed as well as completed design-build examples, and studying alternative decisions that may impact on maintenance during the building design process. ‘Sustainable’ maintenance advocates the practice for maintenance teams to be involved early in design able to access comprehensive documentation of building systems and other components, obtain better understanding of design intentions, and practice proactive maintenance rather than reactive service work and emphasize performance improvement.

Consistent integration between design and maintenance will not only optimise output from these two stages of work but will also support other stages of the building development by way of information support. Potential strategies for better balance between design and maintenance will stem from (Lin & Yang 2003):

◊ Easy access of information from previous examples and historical data.

◊ Adequate and prompt support to each other between all professionals involved.

◊ Increase of the efficiency in maintenance practice through improved understandings.
Integration of multi-disciplines throughout project development.

2.2.5 Integration and Building Automation Systems (BAS)

This section examines the issues of the integration and office building automation systems primarily from the building systems technology perspective. The building systems and facilities provide for the requirements of end users by the various system services during the life of building. From the literature reviews, most contentious issues associated with building systems can be recognised and summarised as failures in the communication, coordination, and integration of building systems information between designers and maintainers. Building systems coordination and integration are the responsibilities of the architectural technical coordinators and project managers.

Furthermore, it is also necessary to plan building process integration as early as possible during the whole process, and needs designers continue their service for the life of the building. Automating and integrating building systems into the complete design process, and coordinating them throughout the manufacturing, construction, and operating/maintenance phases, can minimise costly errors and problems, and increase the serviceability of building systems.

2.2.5.1 What is Intelligence?

Before the issues of the integration and BAS which is the major aspect of intelligent building are discussed, to gain an understanding of the real implications, it obviously would be necessary and helpful to explore subject deeply.

Intelligence is an expressive topic for human beings. Almost everybody is impressed with Einstein's achievements in “general relativity”. There is universal agreement that Einstein, an enormously creative thinker, was highly intelligent. He is the portrait of an intelligent person. All definitions of intelligence have a common denominator related to innovation and adaptability. However, it is hard to define intelligence, and not much agreement has been definitely reached (Pfeifer & Scheier 1999).

The introductory explanation on intelligence in the Penguin Dictionary of Psychology reflects this lack of consensus: "... Few concepts in psychology have
received more devoted attention and few have resisted clarification so thoroughly” (Reber 1995). Nevertheless, definitions can provide a source of perception such as:

1. A definition (Garmonsway 1969) includes: ability to understand, reason and perceive; quickness in learning; mental alertness; ability to grasp relationships; and information.

2. The Journal of Educational Psychology (JEP 1921) collected and summarised the definitions of intelligence as: the ability to carry on abstract thinking; having learned or ability to learn to adjust oneself to the environment; the ability to adapt oneself adequately to relatively new situations in life; a biological mechanism by which the effects of a complexity of stimuli are brought together and given a somewhat unified effect in behaviour; the capacity to acquire capacity; the capacity to learn or to profit by experience.

3. The commonsense notions of intelligence, is commonly related to the thinking and problem solving; the competence to speak, read, and write; intuition and creativity; learning and memory; emotions; surviving in a complex world; perceptual and motor abilities and consciousness. They also include the distinction of degrees of intelligence. This symposium of commonsense notions in intelligence will be providing a sense of the variety of abilities and components involved in what we, scientists and laypeople, think of as intelligence (Rolf Pfeifer and Christian Scheier 1999).

As we have seen, intelligence is multifaceted and not restricted to one characteristic. Such intelligence may be sought today in people and in buildings! Until recently this was in short supply in both. On the other hand, the Abdu'l-Baha demonstrated: “That is, they believe that minds are equal to begin with, but that training and education will result in mental variations and differing levels of intelligence, and that such variations are not an inherent component of the individuality but are the result of education: that no one hath any inborn superiority over another.” (Abdu'l-Baha 2001). It implies that the intelligence of the individuals could be improved by means of education and training, specifically in the support of advanced technologies; similarly, building intelligence could be promoted by means of upgrade and innovation, and sustained optimisation through a strategic approach as well.
2.2.5.2 What is an Intelligent Building?

The definition of Intelligent Building (IB) is still as diverse as that relating to the intelligence of human beings. In a rough sense, an intelligent building is “one equipped with the telecommunications infrastructure that enables it to continuously respond and adapt to changing conditions, allowing for a more efficient use of resources and increasing the comfort and security of its occupants”. A broad spectrum of the implications and definitions of intelligent buildings in the IB development are summarised and mapped in Table 2-2 and Figure 2-2.

Table 2-2: Hierarchical Summary of Development of Intelligent Buildings

<table>
<thead>
<tr>
<th>Year</th>
<th>Organisation</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>United Technology Building Co. (UTBS) USA</td>
<td>&quot;Intelligent Building&quot; originated to denote buildings which incorporated sophisticated telecommunications facilities, building management and data networking services which provided shared tenant services to the occupants.</td>
<td>So and Tanaka 1990</td>
</tr>
<tr>
<td>1988</td>
<td>Intelligent Building Institute (IBI) USA</td>
<td>An IB was one which provides a productive and cost-effective environment through optimisation of its four basic elements, i.e. structure, systems, services and management and the interrelationships between them.</td>
<td>Caffrey 1988</td>
</tr>
<tr>
<td>1991</td>
<td>Nippon Telegraph and Telephone (NTT) Japan</td>
<td>Japanese IBs focused on four aspects: (1) Receiving and transmitting information and supporting management efficiency; (2) Ensuring satisfaction and convenience for the people working in them; (3) Building management to provide more attentive administrative services with lower cost; (4) Fast, flexible and economical responses to changing sociological environments, diverse and complicated office work and active business strategies. Regarding cultural considerations, IBs must maintain an effective working environment, run automatically and comprehensively, and be flexible enough to adapt to future changes in the needs of the working environment.</td>
<td>Fujie and Mikami 1991</td>
</tr>
<tr>
<td>1992</td>
<td>DEGW Europe</td>
<td>An alternative European model of IB was developed to identify three phases in the development of intelligent buildings: (1) Automated buildings (1981-1985), (2) Responsive buildings (1986-1991), (3) Effective buildings (1992- present). The definition of IB in Europe is increasingly more on the users' requirements than the technologies.</td>
<td>DEGW 1992</td>
</tr>
<tr>
<td>1994</td>
<td>The European Intelligent Building Group (EIBG)</td>
<td>An IB was defined as one that &quot;creates an environment which maximises the effectiveness of the building's occupants while at the same time enabling efficient management of resources with minimum life-time costs of hardware and facilities&quot;</td>
<td>EIBG 1994</td>
</tr>
<tr>
<td>1995</td>
<td>The Public Works Department of Singapore</td>
<td>An IB must fulfil three conditions: the building should have (1) advanced automatic control systems, (2) good networking infrastructure, and (3) adequate</td>
<td>Choi 1995</td>
</tr>
</tbody>
</table>
From the literature reviews into office building over the last two decades, development has mapped a great future as seen in Figure 2-2 for the so-called Intelligent Building (IB). IB was initiated in 1981 in the USA, originally denoting automation in office buildings. At that stage the focus of the building industry was to employ the technologies for good visible features. Then gradually they became

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<table>
<thead>
<tr>
<th>Year</th>
<th>Government</th>
<th>Telecommunication Facilities</th>
<th>New Official Definition for IB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>USA</td>
<td>Telecommunication, Building Management, Networking, Services</td>
<td>&quot;An Intelligent Building is designed and constructed based on an appropriate selection of quality environment modules to meet the user's requirements by mapping with the appropriate building facilities to achieve long-term building value&quot;</td>
</tr>
<tr>
<td>1988</td>
<td>Japan</td>
<td>Efficient, Convenience, Cost, Responses</td>
<td></td>
</tr>
</tbody>
</table>
| 1991 | DEGW       | Optimisation                  | "An Intelligent Building is "3A" or "5A". "3A" means the building contains three automatic functions: communication automation (CA), office automation (OA) and building management automation (BA). IBs integrated the fire alarm function or an independent fire automation system (FA) and a comprehensive maintenance automation system (MA) with the various automation systems in the building."
| 1992 | EIBG       | Advanced Automation          | |
| 1994 | Singapore  | Advanced                    | "An Intelligent Building is designed and constructed based on an appropriate selection of quality environment modules to meet the user's requirements by mapping with the appropriate building facilities to achieve long-term building value" |
| 1995 | China      | End-user's Satisfaction      | "An Intelligent Building is designed and constructed based on an appropriate selection of quality environment modules to meet the user's requirements by mapping with the appropriate building facilities to achieve long-term building value" |
| 2002 | China      | Quality                      | "An Intelligent Building is designed and constructed based on an appropriate selection of quality environment modules to meet the user's requirements by mapping with the appropriate building facilities to achieve long-term building value" |
```

Figure 2-2: The Development of the Intelligent Building
concerned with the building’s productive, cost effective environment to optimise the building’s efficiency for greater convenience and quicker responses (UTBS 1981; IBI 1988; NTT 1991). The office buildings were being developed by means of the providing good infrastructure for automatic systems, communication and networking systems. Through the optimisation process, they were not only adapting the advanced products of technology, but also increasing the system effectiveness, efficiency and minimizing the cost of hardware and software as well.

From 1989 to 1995, intelligent buildings were progressing into the boom stage in Asia including Japan, Singapore, Malaysia, China and Taiwan; developers did invest and produce massive numbers of office buildings by applying the advanced automation systems so-called 5A i.e. CA, OA, BA, FA, and MA. During this stage, the building industry benefited from the fast growth of IT, telecommunications and networking services, especially, office buildings which used many modern and advanced technological features (DEGW 1992; EIBG 1994; Choi 1995; So 2002).

From the definitions of IB around the world as in Table 2-2, the different features have outlined with varying emphasis either on technologies or on user's requirements as in Figure 2-2. In simplicity, the definition of IB will be: "an IB is designed and constructed on an appropriate selection of quality environment modules to meet the user's requirements by mapping to the appropriate building facilities to achieve long-term building value" (So, 2002). It implicates the needs of the building developers/owners/occupants (deliverable items) and the enabling technologies (systems and services) which will generate values for the building, i.e. productivity, market values and energy conservation etc.

However, a good quality environment and long-term value of the building was always beyond the end users’ expectation and satisfaction. It would be a great opportunity for reviewing the advantages of good infrastructures and the weakness in not taking care of the consumers’ real requirements, and considering the relationship between technology and intelligence, and the desire of human beings to search for a strategic total solution.

Consequently, an exact definition of Intelligent Building (IB) is not critical in the practice except in the application of advertising and marketing. IB is an integrated
product composed of various technological systems and products which would be a typical example of the systems’ integration. Nonetheless, the key issue should be located on what IB does, not just on what IB is. It should be kept in mind that the integration is to ensure that the functionalities of IB meet with the expectations of occupants. Hence, the integration will not end at the system integration; it should be extended to the life-time operation and maintenance. Therefore, the contribution of IB should be continually backed by advanced integration in building processes to enhance maintenance activities.

2.2.5.3 Development and System Evolution of Intelligent Buildings

The development of intelligent buildings was closely linked to the growth of Information Technology (IT). Over the past decade, the focus of computer usage moved from mainframe to mini and on to the rapid increase in use of personal computers (PC). The popularity in using of personal computers has seen massive progress in the PC based environment.

The development and popularisation of information processing and communication technologies have given rise to an advanced information society in which the ability to access and process information at high speeds has come to play a significant role. Intelligent buildings provide a basis upon which even further development can be made in the future. In recent years, digital communications have become commonplace, enabling computers to communicate at ever-increasing speeds and leading to the development of high-speed communications networks. Furthermore, diversification of communications services is improving the value of information and communications which are viewed as utilities.

Building automation systems have also benefited from the advanced data processing and communications technologies, leading to a broader range of building service functions. In the new century, a major trend will probably be the development of diverse communication technologies, ranging from the transmission of audio and text to the transmission of still and moving images, and in addition, the development of multimedia systems incorporating all of these features. It will continue to be focused on providing (Wood B. 1999):
◊ Visual services for the transmission of pictures with high definition and stereoscopic images,

◊ Intelligent services that exhibit awareness, recognition, comprehension and inference, and

◊ Personal mobile communications services with enhanced portability.

It was aimed at achieving a greater degree of coordination between information processing and communications technologies. This should lead to intelligent buildings with an even higher level of integration (Akihiko, et al., 1993) able to integrate telecommunication system with office automation and building automation systems as shown in Figure 2-3.

![Figure 2-3: Evolution of Intelligent Building](image)

2.2.6 **Interdisciplinary Building Systems Design and Maintenance**

The fragmented abilities of building professionals are helpful for the development of existing expertise in the specialised fields, but it is an obstacle for interdisciplinary collaboration between design and maintenance. Although computer hardware technology has progressed rapidly in recent years and the relative cost of this
technology has decreased during this same period of time, software technology in the building industry has not kept pace with this computer hardware revolution. With today's hardware it is possible not only to develop office building design software that is integrated across the design and maintenance disciplines, but also to communicate such information directly to software systems in the other segments of the industry.

A fully automated and integrated office building development and operating/maintaining system is now a feasible objective. The obstacles are mainly administrative and political, not technical. Problems of communication and coordination that in the past have overwhelmed the process of designing a building can be minimised in the future through process integration to design and maintenance. The process integration approach will also increase the efficiency and effectiveness of design and maintenance.

### 2.2.7 Integration for Building Industry

The integration of the building industry can be broken up into two categories as horizontal integration (or systems integration) and vertical integration (or process integration). Horizontal integration is an integration of building systems and services such as HVAC, electrical power/lighting system, fire system, security system, parking system, drainage system, etc.,. Vertical integration is an integration of building processes such as design, planning, construction, installation, financial, operation and maintenance, demolition, etc, (Council on Tall Building and Urban Habitat 1995). This research was specifically designed and attempted to explore this process integration issue.

#### 2.2.7.1 Systems Integration

Intelligent elevators, intelligent roofing materials, intelligent drinking fountains, intelligent wiring systems, intelligent refrigeration and intelligent HVAC control systems have been released and promoted through the media. Yet, is it really intelligent and enabling? (Hoffmann T. 2004) The foundation of these advanced technologies is in place and understood enough to be applied; however that answer might be conservative.
A successfully designed building has often been compared to an outstanding symphony. The parts of a building, like individual instruments in an orchestra, have the capacity to make up a whole that is greater than if they were played alone. The expectation on “intelligent” is often relies on the effective integration of the related factors and components. Fully integrating architecture is a framework which enables total building systems integration offering solutions and value to the end user. It combines the expected ability to tie all of the subsystems in a building together into an interconnected network that appears homogeneous to a user but maintains independence and the separation of subsystem powers.

Systems integration involves developing an integrating architecture which is a collection of products, tools, software and hardware, and communication instruments; in order to assure connectivity, interoperability and usability, they work together as different pieces of a single building management system. The key features and benefits of system integrating are (CIBSE 2000; Hoffmann T. 2004):

1. Features:
   - Integrating devices and subsystems using multiple communications with proprietary and standard protocols.
   - Providing a single user interface and a common interaction method for the different products and subsystems.
   - Adopting and promoting by an informed base of manufacturers, suppliers and end users.

2. Benefits:
   - Savings in installation costs.
   - Greater choices for the designer.
   - Simpler building operation.
   - Integrated operation

Effective integration requires partnerships and an experience base between key parties. Enabling technology does exist in the areas of computer hardware, software, networks and standard protocols to ensure the success of integration. However, the
substantial issues are raising the consensus-awareness and understanding, the need to take effective action.

2.2.7.2 Process Integration

The building industry constitutes a variety of processes from planning, design, procurement, construction, commissioning, operation, maintenance to demolition. Their entities and attributes are different and independent and are traditionally isolated. Their professional expertises rarely take into account work of others. This results in the ignoring the cost of the rest and a lack of communication with others with different expertise, thus making it impossible to enhance the effectiveness for the whole building progress taking a life time view.

The efforts of implementing the horizontal integration by the building system manufacturers, has rapidly increased the efficiency of the respective systems, along with the advanced technologies, especially in information technologies and telecommunication. However, it also produced redundancy and overlaps. On the other hand, the vertical process integration might be used to achieve a greater advantage than the horizontal integration for the systems. Accordingly, the vertical integration should be promoted for the real enhancement of the building performance and energy conservation in the life cycle of the building industry as in Figure 2-4 (a), (b), and (c):

Figure 2-4 (a): Conceptual Integration of Building Industry
This figure is not available online. Please consult the hardcopy thesis available from the QUT Library.
2.2.8 Current Trends of Integration

The intense activities and excitement of the late 1960s to produce integrated computer systems for buildings appear to have peaked in the 1970s. Since the middle 1980s the computer hardware and graphics software technology has significantly advanced, and efforts were also made to utilise this within the building industry, in spite of the professional and intellectual fragmentation. The interchange of the information developed by each profession to achieve optimum solutions continues to take place orally at frequent meetings between representatives from the various professions through the specific symposiums and conferences (Christiansson, p. 2000).

Database and systems integration must be extended beyond design to all phases of the high rise building development and operating cycles. An integrated building system that can operate the high rise building as a whole, and that can react automatically, correctly, and appropriately to the frequent changes that occur during building development, can reduce some of the problems of the past that were due to poor and ineffective communication (CIBSE 2000). The last decade produced computer imitations of a manual system reflecting the technology innovation. The next decade should produce a redefinition of the industry structure and a reprogramming of the high rise building processes through integrated efforts that will result in a more efficient use of the computer and support software development.

There are two features inherent in ongoing computer systems development that will produce changes in the organizational alignment of the building industry, and also impact on the process of developing and operating a tall building. The first is the continuous expansion of the scope of existing software applications and the continuous increase in the number of new applications to replace manual procedures that never before used the computer. The second is the cumulative effect of software development on the industry in the integration between different professional phases (Council on Tall Building and Urban Habitat 1995).

The building works are created and constructed in accordance with the requirements of owners or architects. Normally that could be categorised into two classes, one
technical, and the other art. The IT computer development can help to speed processing and duplicating. However the building projects usually are distinguished by unique identities which normally are different in case by case.

Therefore in the future the computer will continue to support the enhancement of building innovation, but the radical progress of the integration of interdisciplinary process would need architectural designers involving inherent creative and artistic expressions to pay more attention on such drastic changes. The architectural designer's role is therefore expected to bear more responsibilities in the future, in addition to their professional design tasks; they will be expected to extend the after-delivery service across the whole building life (Council on Tall Building and Urban Habitat 1995).

Consequently, the promotion of whole building performance and energy conservation would not only rely on the building system integration by the vendors or system suppliers, which have been reorganized and widely accepted the need for technical action to increase the effectiveness of the systems. But to actually improve the life cycle efficiency also needs the building process integration to be properly executed and accomplished by the virtual integrated teams including the designers and the associated professionals such as facilities managers through the adequate support tools. To accomplish these integration attempts, the diverse information and supports are needed. It highlights the fact that the integration will require extensive decision making and support.
2.3 Decision Support

2.3.1 Decision Support System

Decision Support Systems (DSS) was first articulated by Scott-Morton in the early 1970s, and defined such system as "interactive computer-based systems, which help decision makers utilise data and models to solve unstructured problems" (Scott-Morton 1971). Another classic definition of DSS is as follows (Keen and Scott Morton 1978):

"Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision makers who deal with semi-structured problems."

The system must aid a decision maker in solving unprogrammed, unstructured or semi-structured problems; the system must possess an interactive query facility, with a query language that is easy to learn and use (Bonczek, Holsapple & Whinston, 1981): DSS help managers/decision makers use and manipulate data; apply checklists and heuristics; and build and use mathematical models.

Decision support systems are not only providing information, but also providing a tool for learning and exploration (Olson 1998). According to Turban, E. et al. (2001), “a DSS supports complex decision making and increases its effectiveness”, the major DSS characteristics and capabilities will be the following:

- Semi-structured programs for managers at different levels—for groups and individuals
- Interdependent or sequential decisions
- Support intelligence, design, choice in a variety of decision styles and process.
- Adaptability and flexibility
- Interactive ease of use and construction
- Effectiveness, not efficiency for humans control the machine
- Modeling and analysis for data access
- Integration and web connection

The DSS has been broadly employed in the various areas, in the Matti’s islands of automation, continuing growth of the different entities such as design and maintenance, but the gaps between them would need a bridging tool to remove the
barriers. In brief, the DSS with the data store, retrieval, and integration functions can be applied in the construction and building industry.

2.3.2 The Need for Decision Support System

The environment today is changing very rapidly, is more complex than ever before, and the trend is toward increasing complexity; decision making today is more complicated than it was in the past, and is more difficult to make decisions for several reasons such as: the number of available information is larger; the cost of making errors can be very large; continuous changes creates more uncertainty; and requires quick decision-making. As a result, it is very difficult to rely on a trial-and-error approach to management, and managers must learn how to use new techniques such as DSS to support effective decision making, specially computerised decision support systems may be required for various reasons: speedy computations, increased productivity, technical support, quality support, competitive edge and overcoming cognitive limits in processing and storage (Turban, et al. 2001). Computerised systems enable people to quickly access and process vast amounts of stored information; computers can also improve coordination and communication for group work as the building project progresses.

2.3.3 Decision Support and Integration in Building Construction Industry

In order to identify desired features of the new approach in this research, it is appropriate to pay attention to the construction industry’s intensified research for practical decision support systems (Riley et al., 1994; Miresco, et al., 1995; Tang 1996). The intention is to make effective use of the knowledge and information on the operations required for various types of building processes (Syal, et al., 1991; Yamazaki 1994). The text that follows summarizes existing research efforts and applications in construction decision support systems.

Reviews of the generic research in construction decision support, during the last decade, shows computer technology has been going through rapid changes and advancement. The late eighties saw building researchers focusing on the use of computers to develop automated construction systems. With the inception of the
Artificial Intelligence (AI) technology, a number of these researchers attempted to employ the AI expert system to develop a range of applications from welding robots to building-defect analysis systems (Syal, et.al., 1991; Yamazaki 1994). This has provided potential tools for designers and clients to effectively use related knowledge during the practical construction processes.

Some researchers and construction software vendors began to study the integrated approach for many construction problems (Thabet 1994; Ito 1995; Dharwadkar 1995; Goncalves, et al., 1996; Scott 1997). The new generations of computer software are becoming compatible with each other and have extended their user friendliness. Computer Aided Design (CAD) has advanced from 2D drafting software (automated drafting system) to 3D based software which has the function of simulation. There are research projects to incorporate time measures into 3D based design information (Paulson 1995).

Currently, the advanced integration of current well-developed software is being developed for design and construction, including CAD, Estimation and Scheduling, has been moved from 3D to 4D, the integration of 3D CAD with the progress of the construction, i.e. three Dimension plus time (Paulson 1995).

One of the inadequacies of these technologies however, is that they do not address the processing need for qualitative information which is generated during the building process and will be used for making management decisions (Miresco, 1995; Yang, 2001). In fact, there is lack of support for problem solving and decision making during all stages of project development. In the light of this, decision support systems are needed to be developed and introduced into the building process.

A review of the relevant literature has identified two major types of decision support development: one is stand-alone applications for supporting the specific building phase such as design or planning and the integration approach across the different phases such as linking design and planning.

In the aspect of stand-alone applications as:

- Design support to computer aided design and drafting (Goettel 1994).
• Project planning: estimating, scheduling (Miresco 1995; Thabet 1994; Fischer 1996).
• Project control: Quality Control, Simulation of operations (Syal et al., 1991).
• Construction management: supplier selection (Chau et al., 2003; Onesime et al., 2004)
• Maintenance: selection of maintenance organisation and maintenance system (Emblemsvag et al., 2003; Fernandes et al., 2003)

o In the aspect of the integration applications as:
  • Project Management tasks linking with quality assurance (QA) (Riley, 1994).
  • Design linking with cost planning (Drogemuller, 1994).
  • Design linking with Project Control (Syal et al., 1991).
  • Design linking with scheduling and cost estimating (Yau 1991; Greste 1997).

These research efforts have explored the possibilities of using multiple packages for the processing of different project management tasks. However, little has been done in providing a readily useable linkage between these tasks, especially knowledge based decision support between design and planning (Miresco 1995; Ito 1995), and maintenance as well.

In the relevant research into the integration of different parities, the literature review has also identified research with a certain degree of relevance to the research project. Examples of these include the integration interface and framework as summaries below:

• Morad, et.al. (1989) presented an interface concept between Computer-Aided Design (CAD) and Construction Planning System (CPM). They point out that the benefits obtained from the integration of CAD and CPM is far greater than those realised from their separate application.

• A computer-integrated design drawings and construction project plans system was designed by Parfitt, et al., (1993) as a true two-way multi-application framework with shared-resource database. However, the lack of a universally
accepted data model for representing this information has limited further
development and implementation. Major improvement to this system is
needed to include a shared database module for hot-linking common data
between all programs within the system.

- A Collaborative Knowledge-Integration System was developed by El-Bibany
et al. (1994) to present a unified constraint-based representation and inference
methodology as a tool for AEC design, management, and coordination. This
system differentiates and formalises the relationship between knowledge and
data, which provides robust tools for decision support. However, the research
did not go on to generate applicable systems because of the lack of
cooperation between all parties of the AEC industry.

The previous research efforts have employed a variety of methods to improve the
integration among different tasks and stages of project. Their efforts can be classified
into two categories, one is to integrate and make better use of conventional computer
software, and the other is to explore the advanced information technology such as
Artificial Intelligence (AI) technologies to bridge gaps between isolated PM tasks.

A variety of techniques and methods are used. They range from the explorations of
Object Linking and Embedding (OLE) and Dynamic Data Exchange (DDE) to the
orchestrated application of spreadsheet, word processing and graphical presentations
(Paulson 1995). The linking of commercial related packages such as estimation,
scheduling, cost control and CAD, have been studied by many in a hope of providing
immediate interfaces for data transfer. Object oriented technology, hypertext, and
case based reasoning methods have been applied to develop decision support
systems.
2.3.4 Limitation of Decision Support and Integration

Despite the pilot exploration and a few earlier applications, the previous related researches were hindered by several common limitations. They can be summarised as follows:

1. The concept and method of integration between architectural design and planning, or construction and operation/Maintenance is still at an exploration stage. They do not provide immediate reference to practical operations during these stages that reflect consistency, accuracy and promptness (Miresco 1995).

2. Large volumes of information generated at various design stages are still difficult to be applied accurately and quickly at subsequent construction stages. This information is seldom used for forward process (Yang, 1995, Fischer et al., 1996).

3. There is a lack of sufficient integration approach to the various stages of the project development and transfer, which may have sequential impact on the use of design information (Parfitt, et al., 1993).

4. Effective and coordinated computer tools are still not available which can translate design information and update it automatically for other process application. Commercial packages and systems developed from earlier research do not communicate with each other in practical terms (Fischer et al., 1996).

The limitations described above indicate that much more work needs to be done in the process integration. Reviews of related research attempts emphasised the feasibility of developing a new integrated approach to eliminate the gaps, reduce the errors and optimise the operations between different processes such as design and maintenance. The problems existing in the construction and building industry with the limitations of different approaches should be explored for practical methods to overcome them.
2.4 Design and Maintenance for Office Building

2.4.1 Status of Design and Maintenance in Building Industry

Design and maintenance are two core activities in the building development process that directly contribute to the quality of construction and performance. Located at opposite ends of the construction sequence they are traditionally treated as separate entities (Chanter, B. et al., 1996). The priorities considered in design frequently rank maintenance as the lowest need and the lessons learned through remedial measures rarely influence design procedures. In few other industries is design so consistently divorced from construction, and construction so alienated from maintenance that they are divided by time and undertaken by various professionals having minimal knowledge or respect for each other's problems.

Design and maintenance are normally undertaken by different professionals and personnel, and operated through conflicting criteria and objectives. These processes are often counterproductive and fail to achieve an acceptable quality of building performance. Unfortunately, many factors relating to design and maintenance create contrasting and contradictory objectives and in accommodating certain design needs, maintenance requirements may be adversely affected. Conversely, the attempt to produce maintenance free buildings may impose completely impractical and certainly uneconomic design provisions. Consequently, there is a need to compromise and balance the opposing criteria to improve overall building performance.

In the light of the life cycle costing, the existing buildings that are the major part of the building stocks normally lack thorough documentation to reveal the real costs during the life of the building. Conventionally we may focus on the beginning cost of building i.e. built cost, but not really take care about the subsequent costs such as the maintenance costs.

Only in recent years, the expertise of maintainers and property managers has been recognised as an important contributor to the design process (Lueprasert, K. et al. 2000, and Wood 2003). The monitoring of buildings in use and feedback mechanisms is now recognised as regular activities. Feedback digests and reports on
condition surveys of buildings are prepared but are they being effectively communicated to designers?

Some effort has been attempted to facilitate improved communication and management to create a better balance of design and maintenance. One approach to this is for a single group to coordinate design, construction and maintenance activities. Another alternative is to forcefully involve greater participation by assigning legal responsibilities.

However, attempts to facilitate effective communication are burdened by conflicting objectives, professional prejudices, and inappropriate management structures. If design and maintenance issues are to be balanced, it is essential for one group to coordinate design, construction and maintenance activities.

For this reason, Singapore’s planning requirement for developers regulates to retain a 30% share in the building for ten years after completion (Clive, B. 1990); and Taiwan’s construction rules for the developers require to hand-over a maintenance budget to the building management control board during the building delivery process. These compulsory requirements will actively assist in increasing maintenance assessment but improved design and construction techniques are also important to achieve good quality buildings. These highlighted the on-going responsibilities of developers on buildings after project delivery. Furthermore, the impact on design and maintenance in different project delivery needs to be considered. For example, the design construct project delivery can effectively complete a building project as designed in house, but will do little for the on-going operation and maintenance due to the lack of interaction with direct benefits for the developers. In the Build, Operation and Transfer (BOT) project delivery system, the transition and technology transfer during the process can perform effectively, however this system is only applicable in larger projects with adequate financial backing and total considerations on cultural, political as well as economical and technical issues (Hampson, K. et al. 2001; CSI 2005).

Why do architects spend five or more years addressing design issues and practically no time on building maintenance? In practice, there is still only a limited degree of association and relation between maintainers and designers. Designers continue to
create many buildings which fail to achieve satisfactory long-term performance and maintainers still have little evident influence or impact on design. Design and maintenance issues require a practical approach, a problem solving orientation and a learning from experience exercise to produce a comprehensive approach to problem solving for improving the building performance and reducing lifecycle cost.

Building maintenance works can be classified as periodic inspection, cleaning, restoration and repair of the main building fabric, internal finishes, communication systems and engineering services (eg. electrical and gas services; heating, ventilation and air-conditioning; lifts, escalators & mechanical equipment; fire precautions; security installations; special equipment). Under legislation the building owners may be liable for any accident resulting from negligence in maintenance.

Over the typical lifespan of 50-100 years of office buildings, the design-build stage represents only 10% or less of this period; the rest, including operation and maintenance, makes up 90% (Yang & Peng 2001). The actual service life is dependent upon several factors such as quality of design; quality of construction; durability of construction materials and component systems; incorporated technology; location and local climate; use and intensity of use; type of operation and maintenance methods used; and damage caused by natural disasters and human error (NRC, 1998). Most facilities are designed to provide a minimum acceptable level of service of 30 years; facilities with proper maintenance and management may perform adequately for 100 years or longer (FFC 2001). However, recent studies revealed a decreasing lifespan of office-buildings with an average around 60 years (Amato, A.A & Eaton, K. J. 1998; Fletcher, S.L. et, al., 2003). What does it implicate?

2.4.2 The Relationship between Design and Maintenance

There is little explicit relationship between maintenance and the design process such as in the following description: 'Maintenance and design are frequently treated as if the two activities were unconnected ... Maintenance sections often appear to be self contained ... [leading to] ... risk of undesirable divorce from other related functions. The status of the section and its personnel may be such that there is a lack of influence at policy and strategic levels' (LAMSAC 1981). This view compels consideration of the design/maintenance relationship from a wider perspective.
In ideal circumstances, a design would represent a perfect model of the proposed facility which, as well as being of relevance to the detailed design and construction, will be of value to the maintenance related agents. This will be necessary, not only for design purposes, but also be useful later for all those concerned with the effective maintenance of the building.

The relationship between design and maintenance, characterised by design’s rapidly diminishing influence upon maintenance over time, is shown as in Figure 2-5:

**Figure 2-5: Relationship between Design and Maintenance**

Literature studies have identified a range of issues relevant to the nature, influence, characteristics, and information support and communication needs between design and maintenance for office buildings as follows:

◊ **Life-time cost consideration**: High maintenance costs are resulting in poor design detailing and ignoring the ease maintenance. Designers are responsible for minimizing future maintenance. (Lomas, L.C. et. al., 1970; Roger et. al., 1998). Designer’s involvement in building is gradually decreasing along with the building life.

◊ **Collaboration effectiveness**: Collaboration between architects and other members of the building team can militate against poor design (Benroy, E. 1971). The maintenance manager is able to assist the designer with providing a building which is easily managed and thereby less costly to the owner (James, D.B. 1972).
Design-maintenance influence: The role of the design team should be carefully considered for maintenance and operation (Arditi, D. et al 1999). Particular attention is needed on correct specification of materials (Thompson, E. 1975). Typical maintenance problems are often associated with inadequate design (Norman, C. 1977).

It should be noted that many of these findings were made between the 70’s and 80’s. More recent research efforts had been scarce. The overall situation of maintenance problems in the building industry is alarming which seem to coincide with the observed decrease of office building lifespan over the recent few decades. What may be the cause? In addition to climate changes and other environmental impacts on these buildings, are there any influence from poorly coordinated design, or lack of good maintenance?

2.4.3 The conflicts Between Design and Maintenance

Determining the requirement of a building in practice will set a decision making process which will inevitably affect the maintenance requirements of the building. Even if low maintenance is not directly on the agenda, a less than accurate definition of the requirements of the building may lead to inappropriate planning. It means the specification of design will relate to the whole following activities including maintenance in their performance and cost, and choice of components, materials, systems etc., any of which will lead to poor building performance, with the implications this has for its maintenance.

Many deficiencies as accuracy of the equipments, shutdown of the specific system, should be classified as defects to be accepted as normal maintenance work, or their rectification as an improvement (Lee 1987). It may also lead to the development of a perception amongst building owners, about the nature of their buildings that is decidedly unhelpful to a maintenance team. Action to remedy many of these may also be classified as improvements, in reality a substantial proportion should be considered to be design defects.

During the early 1970s the Building Research Advisory Service made detailed studies of samples of buildings and their analyses revealed that the majority of faults resulted from making wrong choices about materials or components for a particular
situation in the building. The poor decision making leading to this may have occurred at the detailed design stage.

A key issue is that maintenance must be fully considered at the design stage. The maintenance determinants are measured that could be normal or abnormal, when classified on experiences and current expectations, and each of the following was influential (Lee 1987; Chanter & Swallow 1996):

- The adequacy of the design and the suitability of the materials specified
- The standard of workmanship in the initial construction and subsequent maintenance
- The extent to which the designer has allowed for present and anticipated future needs
- A major issue, during detailed design, is the selection of materials and components, and choice is becoming increasingly difficult.

Additionally, designers are subjected to a great deal of lobbying to use one product rather than another, and are bombarded with an overabundance of publicity material. This can have two severe consequences (Chanter & Swallow 1996):

1. It may influence the designer to using a new component, which has not been sufficiently proved in practice, with a consequential failure to meet requirements.
2. Conversely there may be the opposite reaction, resulting in the designer using a component or material with which he is familiar, whether or not it is the right choice in the circumstances.

The major short-coming in detailed design appeared to be a failure to make use of the authoritative guidance that was available. This might be a simple failure to use codes and standards properly, or attributable to the sheer volume of advice. Thus, the design should be beyond the codes which would be only served as the basic requirements to meet the extensive client oriented requirements.

No matter how sustainable a building may have been in its design and construction, it can only be remained on an optimum condition so if it is operated responsibly and maintained properly (Goger 1998). The use of inappropriate systems can cause ineffective functionalities or overspending money; failure to test sensor control
points can affect energy efficiency and comfort; and poor training can lead to system failures and inadequate maintenance will result in higher operation and maintenance costs. Therefore, buildings must be operated and maintained with the security, safety, health, comfort, and productivity of their occupants, and with an understanding of the needs and technology developments.

2.4.4 Design and Maintenance in Building Automation System (BAS)

Today's Building Automation Systems (BAS) are more complex. The owner pays for an automation control system and will expect to get one with all available controls and automation capabilities. To meet these expectations, the technical support is often needed, especially during the initial design and installation stages. Therefore, BAS application engineers should be part of the design team. Their contributions could reduce the HVAC system cost and result in better overall design (Boed, V. 1996).

The following tables summarise the main issues of BAS design, their features, and frequently experienced problems during the maintenance stage as listed in Table 2-3 and 2-4. These BAS design and maintenance characteristics will help learn their interaction during the process.

Table 2-3: Attributes of Maintenance in Office Building Automation Systems (Arditi & Messiha 1996)
This figure is not available online. Please consult the hardcopy thesis available from the QUT Library.
BAS has become a powerful and effective tool for facility management in office buildings. It helps resolve problems quickly, reduces energy use, improves system performance, increases occupant comfort and safety, and helps manage maintenance costs. Savings produced by the systems can pay for their installation in as little as three to five years (James 2002). The development of BAS also allows previously independent building systems such as lighting, HVAC, fire safety, security and management to be seamlessly integrated into a single, comprehensive building system. In spite of the advantages and capabilities offered by BAS today, generally, many systems imperfectly performed never achieve their full potential with designed capabilities, or become unused after installation. Sometimes the needed functions were never installed. As a result, the building may fail to perform properly and projected cost savings never fully become visible (Arditi, D. et al 1999).
2.4.5 Security/ Fire System Design and Maintenance

The security for the office building encompasses several aspects, ranging from the tangible building to the intangible data information, and also how affects the human beings and is related to the fire, therefore it should be necessary to provide guidelines for protecting the building, the occupants and data to ensure their safety and availability during the conception design stage. Threats from natural-accidents and disasters are the potential direct causes of the building being damaged and humans being injured and fatalities. The data loss would affect the business benefits; hence it is an essential subject in addition to improving the performance and energy conservation, and the expectation of the comfort.

The application and installation of BAS can serve and improve the dual functions of security and safety by means of the intrusion detection, smoke and fire detection systems, alarm and communication systems that warn occupants of an event and guide evacuation and safety actions. However how to ensure the designated functionalities can be as effective as possible should be considered at the outset of the design, and balanced with maintenance needs in the future. There are no cookbook solutions for incorporating security into office building design. Each design must be tailored to project functional requirements on a case-by-case basis.

2.4.6 The Problems and Limitations of the Building Design and Maintenance Performance

The quality and performance of buildings is dependant on the effectiveness of the design and sustained maintenance (Arditi, D. et al 1999). However, traditionally, these tasks are treated as separate entities. This intrinsic separation causes several problems such as:

◊ Lack of feedback and support: Design and maintenance professionals often have minimal knowledge or respect for each other's problems (LAMSAC 1981; Lee 1987; Chanter & Swallow 1996). The priorities considered in design frequently rank maintenance as the lowest need and the lessons learned through remedial measures rarely influence design procedures.
◊ Lack of knowledge and understanding among design professionals: Due to the inherent separation and under the pressure of time/budget, design consultants often do not have sufficient understanding and knowledge on maintenance issues during office building design stage. As a result, there are limited considerations for service, upgrade and maintenance during the life span of the building (Eyke, M. 1988; Chanter & Swallow 1996; Kua 2002).

◊ Lack of data on operational requirement: There is a lack of historical data concerning the operational requirements and maintenance performance of existing buildings. As a result, designers have to work with insufficient and within the limited times, even inappropriate information (Eyke, M. 1988).

◊ Difficulties in forecasting future condition and changes: Increasing global warming may have a significantly important effect on the climate conditions for buildings to withstand. Without necessary support, designers are unable to predict such changes for remedial measures for building servicing and maintenance (Chanter & Swallow 1996; Arditi & Messiha 1996; Wood, B. 2000).

◊ The “First cost” mentality: Influenced by owners and developers, designers often focus on the initial cost of building, i.e. built cost, without sufficient consideration for subsequent costs such as that incurred in building maintenance. Capital cost is only 20% of the operation cost of a building over its lifespan (Edward, D. M. 1980; Chanter & Swallow 1996; Wood, B. 2000; Howard M. 2002). How buildings will perform or what they will cost to run, in 20, 50, and 80 years time is currently not a key issue considered by developers.

These problems and limitations are particularly evident in buildings built before the 80’s, which make up a large part of the existing building stock in many countries including Australia. Documentation is a matter of discipline, which, unfortunately, many maintenance systems do not have (Mostia, B. 2002), hence, the buildings’ operation and maintenance activities are normally insufficiently documented to reveal the true costs incurred during their life. Increased expenditure on routine maintenance and refurbishment are a burden for owners and occupants, who are only
now beginning seek strategic solutions. These problems also caused overall poor performance of buildings, with excessive energy use and high upgrading costs.

**2.4.7 Findings in Relation to Design and Maintenance**

Consideration of maintenance implications at the design stage is not a new idea (Seeley, I. H. 1976). However, success in this area has been moderate, maintenance and renewal consideration in the early project stages has been impeded for a variety of reasons, the most critical including time pressures, unaware decision-makers and ill-informed designers (McGeorge, D. et. al., 2002).

Previous research has identified several findings that demonstrated some concepts and principles on design and maintenance, and their recommendations towards maintenance issues in the design stage were like as design for maintainability. The maintenance concept has to be understood fully right from the start and features promoting the ease of maintenance have to be planned as part of the design as in (Chanter et al. 1996, Mostia, B. 2002, Neubeck, K. 2004):

1. Minimise maintenance from the beginning and get customer maintenance people involved whenever possible.
2. Suitable materials, finishes and components should be chosen and specified by the architects, which are long-lasting and robust in use, easily maintainable or readily and economically replaced.
3. Good design and detailing should become the first line of protection to avoid weathering or to reduce wear and tear.
4. Consideration of "buildability" and "maintainability" should be proposed to build a good standard of work.
5. Accessibility, ease and safety would be considered and facilitated for undertaking the inspection or the replacement of components in the future maintenance process avoiding long shutdown periods.

The relationship between design and maintenance and their roles can be amplified from an old belief among maintenance personnel that "The designers and engineers have it for a year, but maintenance has to live with it for 20 years." (Mostia, B. 2002).
Short term design activities could have impact significant on the long term maintenance. In general, maintenance tasks can generally be divided into those that are performed in-house on a regular basis, and those that are more specialised and require some disassembly. By identifying potential major maintenance problems, a strategic approach can be worked out, either to avoid these by specifying components and materials that are easy to maintain or replace when they become damaged or decayed, or by providing the best conditions to carry out unavoidable repairs. Such moves should become an instinctive part of the design process, and not seen as hindering design or being an additional financial burden to the client.

The maintainability concept is very important since reliability and maintainability overlap in many areas (Neubeck, K. 2004). The concept of design for maintainability is an integral and worthwhile part of creating a building. In the long run, the building maintenance, whether routine, repair or replacement, places a responsibility on the architect to make adequate prerequisite allowance to either reduce or facilitate this by good design. From the design aspect, good provision for future maintenance need not restrict the designer's creativity, but may actually help to shape the building. Rethinking of maintainability may provide hints to more efficient design.

Maintenance has become a big issue in the world of property and building. In a world of increasing costs, and at a time when clients are becoming more aware of the implications of budgeting for asset management, a greater degree of responsibility falls on the shoulders of the architect to make all possible effort to reduce this burden. An awareness of maintenance is the architect's responsibility, but to a good designer this should be neither a new concept nor a hindrance, but rather regarded as a positive motivation to allow this particular design factor, amongst all the others, to help him to 'shape' the building.

The designer must firstly identify the nature of the task of reducing, or minimising maintenance (Mostia, B. 2002). In building practice, during the construction market booming periods, there is only a short time for the developer and the designer to carry out a sophisticated plan in the preliminary design stages, or to do the detailed design work. This situation is partly caused by a client's ignorance of the information needs and procedures that must be undergone. Additionally, the financing of buildings, both in the public and private sectors, is subjected to pressures that do not
encourage proper consideration of the building's long term performance. Consequently the conclusion will be as (Bowyer, J.T. 1985):

"... The Architect is caught between the two forces of limited time for his professional work and the problem of designing a sound and suitable building within unrealistic cost limits."

Therefore, under the designer's duty to produce design works that can be safely built, the most important consideration will be access, not only during construction but also for cleaning, servicing, maintenance and repair. The client must reasonably receive a health and safety file at hand-over, warning of any potential risks, and the designer is responsible for providing relevant information and suggestions.
2.5 BAS for Office Building

2.5.1 What is Building Automation and Building Management?

The building automation is an approach designed for automatic operation on building systems by being equipped with sensors and controllers which are integrated in various ways to form a Building Automation System (BAS) for the specified functions and building services. It is being increasingly recognised, particularly in new construction projects, that a BAS is the most cost-effective way of managing the buildings.

BAS, which is the automatic operation of building systems by sensors and controllers, is normally used to perform the following tasks in office building (Eyke, M. 1988):

- To optimise the start-up and performance and control/monitor systems.
- To reduce the risk of breakdown of building services.
- To increase the interaction of mechanical subsystems within a building
- To prevent deterioration of the internal environment provide by building services.
- To increase reliability of system and services
- To decrease energy, time and operating costs.

BAS plays an essential role in building management. It not only helps personnel to execute the operation and maintenance tasks, but also facilitate the high performance of building, reduces the energy consumption and enhances the occupant’s comfort. A modern BAS is capable of fire detection and fire suppression which includes responsibility for personal safety, therefore their operations and maintenance must be given the highest priority.

2.5.2 Current Building Automation Systems (BAS)

A Building Automation System (BAS) is a system comprising microprocessor controllers (Direct Digital Controller (DDC)), personnel computers, printers, modems and controlled devices used to control and monitor subsystems such as Heating, Ventilation and Air Conditioning systems (HVAC) and other building
services such as lighting, fire protection, lifts, security etc. It is used extensively in HVAC to control temperature, humidity, pressure and other parameters to optimise the start-up and performance of the equipment and alarm systems. A typical system is shown as in Figure 2.6.

![Figure 2-6: A Typical BAS](http://global.daikin.com/global/our_product/sp_Inverter/3_techno.html#daikin8)

### 2.5.2.1 Functionalities of the BAS

The necessity of an automated control system is designed to eliminate the need for manual adjustment, maximise comfort by maintaining the required temperature, conserve energy and reduce operating costs by preventing over-heating or over-cooling as shown in Figure 2-7.

![Figure 2-7: Environment Control](http://global.daikin.com/global/our_product/sp_Inverter/3_techno.html#daikin8)

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library.
Modern BAS have greatly increased the interaction of mechanical subsystems within a building, improved occupant comfort, reduced heating, ventilation, and cooling costs through improved sub-system management, reduced the time required to monitor and manage building operations, and allow support and diagnostics from remote locations. Computer-based monitoring has been used to coordinate, organize and integrate building control sub-systems such as security, fire/life safety, elevators, etc. Common BAS applications include: equipment scheduling; optimum start/stop; operator adjustment; monitoring; alarm reporting (Eyke 1988). The structure of Office Building Automation System (BAS) is illustrated as the Figure 2-8:

Figure 2.8: Structure of Office Building Automation System (BAS)

Along with the development of advanced information and communication technologies, lifestyle patterns have significantly changed over the last two decades. For buildings, the orientation is shifting from the simple adoption of new materials and technologies to a balanced approach focused on user comfort, convenience, health and safety considerations and long term performance issues such as efficiency, market values and energy conservation (Harrison, A. et al. 1998; Ellis, M.W. et al. 2002) Automated and intelligent buildings, which can better perform and facilitate the prospective intentions of stakeholders, are becoming a major stream or ideal model of building development. These new trends will inevitably depend on more advanced building automation systems for flexibility, adaptability and energy conservation.
Besides affecting the physical and emotional well-being of the office building occupants, a building's interior lighting system is both a dominant consumer of electrical energy and a major source of internal heat. In the United States about one-quarter of the electricity budget is spent on lighting or more than $37 billion annually. In commercial buildings it normally accounts for more than 30% of the total electrical energy consumed. Yet much of this expense can be avoided. (Nelson, D. 2004).

Specifying a high quality energy efficient lighting system that utilizes both natural and electric sources as well as lighting controls can provide a comfortable yet visually interesting environment for the occupants of a space. To achieve a quality lighting environment, carefully choose lighting equipment and controls to satisfy both performance and aesthetics needs. Lighting equipment selection should be based on a balance between the requirements of the design and an effort to limit the number of fixture types and lamp types in order to have reasonable maintenance inventories. They are applied as part of a high quality energy efficient lighting system that integrates daylight and electric light sources to provide a comfortable and visually interesting environment for the occupants of a space and incorporated with day-lighting to provide flexibility, energy savings, and ecological benefits in office building (Nelson, D. 2004).

Electric lighting controls are used in lighting design projects to achieve a high quality energy efficient lighting system through specifying a layered, daylight-integrated lighting and control system to give the occupants control of the lighting.

When electric lighting controls are used properly, energy will be saved and the life of bulbs and ballasts can be extended. Moreover, they can provide a comfortable environment in office building as well as improve productivity and security by the various sensors.
2.5.2.2 Components of a BAS

Modern control systems have three key necessary elements: sensors, controllers, and the controlled devices as in Table 2-5:

Table 2-5: Elements of Control System

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td>There is an increasing variety and level of sophistication of sensors available for use with modern control systems. Some of the more common include: temperature, humidity, pressure, flow rate, and power. Sensors that track indoor air quality, lighting level, and fire or smoke are becoming more common.</td>
</tr>
<tr>
<td>Controllers</td>
<td>The function of the controller is to compare a signal received from the sensor to a desired setpoint, and then send out a corresponding signal to the controlled device for action. Controllers may be very simple, such as a thermostat where the sensor and controller are usually co-located, to very sophisticated microprocessor based systems capable of powerful analysis routines.</td>
</tr>
<tr>
<td>Controlled devices</td>
<td>The controlled device is the terminal device receiving the signal from the controller. Amongst others, typical controlled devices include: air dampers, mixing boxes, control valves, and in some cases, fans, pumps, and motors.</td>
</tr>
</tbody>
</table>

Building Automation System (BAS) is the building’s brain. It can normally include 5 major components (UNESCO, 1984; Boed, V. 1996).

- Sensors and Actuators
- Data Gathering Panel
- Central Processing Unit
- Transmission System
- Person-machine Interface

**Sensors and Actuators**: Sensors can be classified into two types, such as analog and digital. Analog sensors are used for measuring temperature, pressure, humidity, voltage etc.; on the other hand digital sensors are suitable for application as alarm sensors and as operating status indicators. Actuators can be in the form of digital and analog types. Digital signals are used for command such as start / stop, open / close, or secure / access, whereas analog signals are for positioning of dampers, modulating cooling coil valve, or resets control set point. In order to provide input information and to receive output signals, both sensors and actuators are connected to a data...
gathering panel, which is adjacent to the relevant area, usually the plant rooms for monitoring and controlling.

**Data gathering panel (DGP):** collects data from the central processing unit (CPU) and transforms them into practical signals or actions. In other words, DGP provides the interface between the input signals from the sensors to the CPU and the output signals from CPU to the actuators to perform output functions. This is also where signals conversion is performed to be compatible from sensors to CPU and then out to actuators.

**Transmission system:** provides a communication link between the DGP and CPU. The central processing unit (CPU) is the most critical element of BAS, which consists of the transmission interface, the computer and the database. The software typically comprises base operating software, application software and energy management software. Upon command or request from the software, the computer processes data and then communicates through the transmission interface board.

**Person-machine Interface:** is where the operator can access information, feedback or update data from the system, give commands to plants being controlled, modify on software programs from the keyboard or request printout records from the printer.

The type of sensor, control system and control actions and the functions of BAS are summarised as in Table 2-6 and 2-7 (Source: UNESCO, 1984; Boed, V. 1996):

**Table 2-6: Types of Sensors**

<table>
<thead>
<tr>
<th>Types</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>• Can be sensed by the movement of a bimetallic strip that directly operates a switch giving an on/off electrical signal as in a thermostat.</td>
</tr>
<tr>
<td></td>
<td>• Other devices include thermostats, thermocouples, resistance elements etc that give a varying voltage or current signal representing temperature as their resistance varies with temperature.</td>
</tr>
<tr>
<td></td>
<td>• Thermostats are the most common due to their large resistance change with temperature.</td>
</tr>
<tr>
<td>Humidity</td>
<td>Can be sensed by the change in length of a hygroscopic material (traditionally human hair) or the change in electrical resistance or capacitance of a hygroscopic material.</td>
</tr>
<tr>
<td>Pressure</td>
<td>Can be sensed by the movement of a bellows or diaphragm and the movement converted into a digital or analogue signal by a switch or variable resistor.</td>
</tr>
</tbody>
</table>
Table 2-7: Functions of BAS in addition to Controlling

<table>
<thead>
<tr>
<th>Functions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator Control</td>
<td>The building services engineer or manager can make changes to the operation of the building services via a PC. Changes could include adjusting temperatures, operating times, alarm settings, etc or change the type of control of a plant item.</td>
</tr>
<tr>
<td>Graphics</td>
<td>Diagrams of the services can be shown on the PC screen complete with actual temperatures, plant on/off status, and fault indication.</td>
</tr>
<tr>
<td>Logging</td>
<td>Operating data can be collected (logged) for later print-out and/or graphed in real time on the screen.</td>
</tr>
<tr>
<td>Reporting</td>
<td>Maintenance schedules, fault history, energy consumption etc can be viewed or printed out.</td>
</tr>
<tr>
<td>Maintenance call-out</td>
<td>Service technicians can be automatically called when a fault occurs by means of an auto-dialer or modem and beeper system.</td>
</tr>
<tr>
<td>Remote control</td>
<td>A building services engineer can dial in to the system by means of a home or portable PC and modem. This allows remote monitoring or system adjustments.</td>
</tr>
</tbody>
</table>

2.5.2.3 Building Automation system (BAS) and Intelligent/green Building

In an office building, the building automation system (BAS) can help minimise energy consumption and maximise indoor comfort, making it a valuable tool for any intelligent and sustainable design. It also can help ensure that a building remains intelligent long after it is built. When properly integrated into a facility, a BAS can help to optimise energy, operations and indoor comfort over the entire lifetime of the building. Besides minimising the building's environmental impact, such benefits can also minimise operational and maintenance costs while increasing employee retention and productivity, making a BAS a valuable investment. A truly intelligent building is a green building.

In a green building, a BAS works with already specified high-efficiency equipment, like variable air volume (VAV) HVAC systems, to fully maximise their potential for energy savings. It increases energy efficiency in two ways - by controlling the amount of energy used, and by monitoring energy use to ensure that building systems are operating as designed.

Today's advanced BAS can often further optimise a building's performance by ensuring that all systems are working together to achieve maximum efficiency, monitoring a building's energy use to ensure that all systems are operating as
intended. A BAS can track the daily consumption of electricity and alert the operator if consumption is outside the normal range.

In addition to providing increased energy efficiency, a BAS can help ensure the comfort and health of a building's occupants by automatically monitoring the amount of heat and fresh air that enters a space. More sophisticated BAS systems can also track the occupancy status of each zone, and adjust the temperature and fresh airflow accordingly to minimize energy use.

Intelligent/green buildings must be built with intelligent and sustainable design methods and materials. Nevertheless, the process does not stop when the building is complete - steps should also be taken to ensure that the building remains intelligent and sustainable throughout its lifetime. To comply with these requirements a BAS plays a key role in supporting an intelligent/green design by reducing energy and improving indoor environmental quality from design to commissioning and through the full optimisation of the facility in the building.

2.5.2.4 The Benefits of a BAS

When deciding on the appropriate type of control system to specify for a building, it is necessary to remember that the benefits of a modern control system are satisfied by the different groups of users involved with the building. Table 2-8 (CIBSE 2000; WWWBAS) lists some of the benefits to be achieved with an effective modern BAS.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building owner</td>
<td>Higher rental value and reduced maintenance costs</td>
</tr>
<tr>
<td></td>
<td>Flexibility on change of building use</td>
</tr>
<tr>
<td></td>
<td>Individual tenant billing for services</td>
</tr>
<tr>
<td>Building tenant</td>
<td>Reduced energy consumption</td>
</tr>
<tr>
<td></td>
<td>Effective monitoring and energy conservation</td>
</tr>
<tr>
<td></td>
<td>Good control of internal comfort conditions</td>
</tr>
<tr>
<td></td>
<td>Increased staff productivity</td>
</tr>
<tr>
<td></td>
<td>Improved plant reliability and life</td>
</tr>
<tr>
<td>Occupants</td>
<td>Better comfort and lighting</td>
</tr>
<tr>
<td></td>
<td>Possibility of individual room control</td>
</tr>
<tr>
<td></td>
<td>Effective response to HVAC-related complaints</td>
</tr>
<tr>
<td>Facilities manager</td>
<td>Control from central supervisor</td>
</tr>
<tr>
<td></td>
<td>Remote monitoring possible</td>
</tr>
<tr>
<td></td>
<td>Rapid alarm indication and fault diagnosis</td>
</tr>
<tr>
<td></td>
<td>Reduced maintenance training</td>
</tr>
<tr>
<td></td>
<td>Good plant schematics and documentation</td>
</tr>
</tbody>
</table>
As the above benefits of BAS, it has capabilities to meet the expectations and requirements of different parties. However these benefits will only be obtained if the BAS and associated building systems are properly specified, installed, commissioned, operated and maintained.

Effective control of the heating, ventilating and air conditioning systems in a building is essential to provide a productive, healthy and safe working environment for the occupants. Without a properly functioning BAS the activities carried out in the building will be disadvantaged.

Along with good building design and efficient HVAC plant, the BAS plays a vital role in the prevention of energy waste and reducing the environmental impact of the building. The scale and complexity of the control system should be appropriate to the building and its operation; highly effective and reliable control may be achieved with relatively simple control systems. Furthermore, when considering the life cycle cost effectiveness of a BAS, all of the benefits that result from a well-managed facility should be taken into account including energy conservation, reductions in staffing cost, improvement of the maintenance scheduling and the benefits of system integration with other building facilities.

2.5.2.5 Current Situation and Limitation of BAS

In BAS there is not a lot of history on the new integration and communication protocols, but the success of the building automation industry is now 20 years old and has made conventional building controls obsolete and expensive (Eyke1988). To fully perform the BAS capabilities, reviews of the BAS current applications expose several limitations and challenges in relation to the economical consideration, design and managerial process. These can be summarised as (Eyke 1988; CIBSE 2000):

**Economical factors:** The BAS application is still limited on the cost of building control systems, quantity and complexity of sub-systems.

**Needs of BAS:** The need to integrate building sub-systems should be investigated and new functionality discussed and understood to ensure successful implementation of BAS in new building designs.
System coordination: During the system design stage it is important to co-ordinate the functions of computer hardware and software. Without this emphasis on the co-ordination of system components, a BAS may not achieve its intended purpose.

Management arrangement: How the building will be operated and by whom should be identified early in the process.

Early involvement: The Building Automation System designer should be involved early in the building design process to identify the potential benefits of BAS could be fully reached.

Integration: Identification of ownership and required interaction between building sub-systems must be done to ensure successful integration. Both design presentation and construction management should be an active part of this integration.

Quality concerns: Selection of good quality BAS and quality maintenance is equally important.

Historical support: BAS design should get enough information such as examples and references and the maintenance limitations or problems during the life of building for the right decision making.

2.5.3 The Future of the Office Building Automation

Over viewing the history of the technology development, technical advancements over the past two decades have dramatically affected and altered the way of living and business and industry as well. Similar technical advancements and changes also occurred in building industry during those years, particularly in office buildings supported with new work environment, electrical and air-conditioning systems. One of the most significant consequences to come out of these changes was the development and use of building automation systems (BAS). These systems were designed to electronically control, monitor, and regulate all building functions such as HVAC, electrical, personal safety, or security.

The energy conservation and technological innovations drove building system design in the 70s and 80s. In the 90s, there were some major factors that could have potentially impacted on building system design such as air quality, optimum
comfort levels, fire and personal-security, building services design, emphasis on quality, energy options, environmental solutions, and cost-effective considerations. Beyond the year 2000, a variety of technologies involving artificial intelligence will be applied to modern building systems, where the occupants of sophisticated office buildings will be able to control the HVAC, electrical, mechanical, security and life safety systems of their immediate areas, while secured areas will be programmed to turn on lights and air conditioning units in selected office zones. It is foreseeable that technologies will be developed rapidly in the new decade and successful implementations of them will ensure effective, reliable, robust and energy efficient building systems (Akihiko, et. al. 1993; So and Chen 1999).

Several advances in related areas, including the central data management, linkage to the information superhighway, distributed intelligence, the concept of open system, human comfort based control, home automation and multi-media user interface. In effect, there will be greater integration between electronic technology and building systems. In this integration era we must be prepared to meet these new challenges and new opportunities. (Norman and Kurtz 1991; So and Chen 1999)

Technologies for furthering the progress in building automation systems will lead to advanced integration in some or there will be a partial combination and integration of the systems such as in (Akihiko, et. al. 1993; So and Chen 1999; WWWHC):

- Integrated Facility Management system
- Emergency measures control systems
- Fault warning /diagnosis systems
- Standardisation of transmission methods
- Multi-vendor systems
- Open protocol/object oriented technology
- Predicted Mean Vote (PMV) control
- Long-range radio alarm/surveillance systems
- Facial recognition systems
- Intelligent sensors

The systems integration for different purposes will reflect the special diversities and relevant functions while consideration must be given to budgets and individual applications to reach the requirements of response and to cope with the demand of...
the occupants' expectations. In the new decade, the advanced technology is going to be pursuing 'CHIM': Computer Human Integrated Manufacturing. A dominant message is that it represents a challenge to develop and exploit people's skills in parallel with advancing automation as shown in Figure 2-9 (Willmott 2002).

Advancing automation and the development of technology implies that the activities of Operations and Maintenance (O&M) have to keep pace fulfilling the system design intentions. On the other hand, making predictions is very difficult but whatever the future developments are it is difficult to imagine them not including ways of making the systems easier to use (Eyke, M. 1988). Notwithstanding, in anticipation the future changes, backed by the advanced technologies, BAS development will move forward to be more simpler in the unit and to be more sophisticated in the whole system to become intelligent and smarter. However, how to keep BAS smart and sustainable for the building maintenance to meet with the building occupant’s expectations in building performance, energy conservation and comfort? These are critical and still a challenge. The solution would not only rely on the building systems and BAS integration to ensure the systems are smart, but also on the process integration in commissioning the diverse needs of the different parties and quality management of process to sustain the maintenance effectiveness during the life cycle process.
2.6 Other Relevant Literatures

2.6.1 Energy Conservation and High Performance Office Building

Energy conservation in buildings has been regarded as an important issue of sustainability all over the world. Building energy consumption accounts for 1/4 of total primary energy consumption in China, and will inevitably increase (Maio 2004). Statistically, in commercial buildings, heating is the largest single end use of energy at 33% of total energy use in 1990 in Australia (ABS 2003) as in Figure 2-10. Energy consumption in buildings accounts typically for over 30-40% of the national total annual energy consumption in UK (Hensen 1996). Heating, Ventilating, and Air-Conditioning (HVAC) systems are major energy users in buildings. HVAC systems account for 40%-60% of the energy used in commercial and residential buildings in the United States (DOE 2004). According to Ian & Graham (2004), the use of high performance HVAC equipment can result in considerable energy, emissions, and cost savings (10%-40%); in addition, high-performance HVAC can provide increased user thermal comfort, and contribute to improved indoor air quality (IAQ). This represents an opportunity to realise significant savings by improving its control of HVAC operations and improving the efficiency of the system.

![Figure 2-10: Commercial Building Energy use](source: ABS 2003)
The optimised control mechanisms can ensure occupant comfort, provide safe operation of the equipment, and in a modern HVAC control system enable sensible use of energy resources. The system’s efficiency in making energy savings as well as in the utilisation of adequate methods to reach the savings expectation would require a totally ideal performance of HVAC. The benefits of high performance, energy-efficient HVAC systems are universally recognised. Therefore, the office building could be installed with high performance HVAC systems to improve the efficiency and meet the occupant’s expectation.

Hence, with respect to environmental impact and economics, the choice and design of HVAC systems are of the utmost importance (Hensen 1996). In addition, employing high-performance HVAC equipment in conjunction with adequate design can result in significant energy savings and offer comfort. However, the energy-efficient design utilizing high-performance HVAC equipment often requires more effort and more collaboration from the design team than a conventional, sequential approach. To reach the energy conservation and high performance in office buildings, in addition to the high performance HVAC application, effective alternatives should be adopted. Several alternatives such as Total Quality Management (TQM), Total Building Commission (TBC), and Life Cycle Costing (LCC) have been effectively practiced in the construction fields (Barrie, et. al. 1996; McGeorge & Palmer 2002; DOE 2004), which would impact on design and maintenance processes during the building’s lifetime.
2.6.2 Total Quality Management (TQM)

Total Quality Management (TQM) is relevant with a broader philosophy than the traditional techniques of quality control which has been widely applied in the manufacturing industries. TQM is the integration of all functions and processes, customer focus and the continuous improvement of the quality of goods and services (Vinceent & Joel 1995; McGeorge & Palmer 2002). Japanese construction companies began instituting TQM during the 1970s. An indication of their success is that since the mid-1970s, three Japanese contractors have won Japan’s coveted Deming Prize, which recognises quality improvement in industry (Deming, W. E. 1986).

TQM is an effective, comprehensive management technique that has proven successful both in the United States and overseas in manufacturing, service and construction (CII 1990). The effectiveness and benefits of TQM in quality of product, integration process and user satisfaction can be realised from a definition as “A people focused management system that aims at continual increase in customer satisfaction at continually lower real cost. TQM is a total system approach (not a separate area or program), and integral part of high level strategy. It works horizontally across function and department, involving all employees, top to bottom, and extends backwards and forwards to include the supply chain and the customer chain.” (Rampsey & Roberts 1992). Therefore, TQM is accomplished through an integrated effort among personnel at all levels to increase customer satisfaction by continuously improving performance (Arditi & Gunaydin 1997; McGeorge & Palmer 2002). TQM focusing on the process integration as well as on the product and service quality will impact and facilitate the whole process quality of the whole process.

The approach to Total Quality Management and the use of checklists is an effective management tool, which can be utilised through the whole building process: design, construction/ installation, operation/ maintenance to ensure the quality is presented as designed. For BAS design and maintenance processes, progressive inspection by the O&M personnel has experienced: familiarisation themselves with the location of individual components for speed in responding to emergency or routine maintenance calls, and a feeling of "ownership" of the building even before completion of the job.
Over the years we have experienced a high level of acceptance of jobs by the O&M personnel when they had a chance to participate in field inspections and/or in custom development of graphical DDC screens, alarm definitions and other job-related activities as the follows (Boed, V. 1996):

- Comply with site standards, specifications, codes and job documentation.
- Transfer of information from one trade to another.
- Quality assurance by inspecting the job site by trade supervisors and construction managers.
- Progressive inspection and review of the installed systems by the owners O&M personnel.

To reach the occupants expectations, the quality is vital whether it be in ‘the quality in fact’ or quality in perception’. The providers of services or goods that meet specifications achieve quality in fact. A service or product that meets the customer’s expectations achieves quality in perception (Culp 1993). In other words, a product can be of high quality and yet it may not meet customer’s needs and vice versa. An example of not meeting customer needs is the high rise office building that was built using cutting edge technology in a high-cost building process. However, few occupants want to rent the building, because of the high rent. This building failed to meet the tenants’ expectations of operation/maintenance costs.

In office building industry, quality can be defined as meeting the requirements of the designer, constructor and regulatory agencies as well as the owner. The quality of the process may cause the quality product to be acceptable or not (Nagasaku & Oda 1965). ‘Product quality’ in the BAS may refer to achieving quality in the equipment and systems such as sensors and thermostats, whereas ‘process quality’ may refer to achieving quality in the way the project is organised and managed in the three phases of planning and design, construction/installation, and operation and maintenance.

Traditionally building construction organizations have been separated into several parties that carry out a set function, such as design, construction and maintenance. The hierarchical segmentation leads to some of the problems such a different perception of values, conflicting priorities, different expectations and rigid structures (Choppin 1991). One of the main drivers of TQM, integration aims to break down the compartmentalization of organizations and move towards more integrated
structures (McGeorge & Palmer 2002).

TQM is a process that requires overall involvement in the building construction processes such as planning/design, construction, and operation/maintenance to be successful. Juran’s triple role concept: supplier (input), processor (process), and customer (output) (Juran 1992, 1999) applied to construction can be shown as in Figure 2-11. Quality in each construction process is affected by the quality in the preceding phases. Quality is important for the overall quality performance of the process.

In addition, in TQM activities, some of inspection and review tasks may often be omitted from the process unless there is an owner's appointed commissioning agent or inspector for the job. These are important to ensure the quality of the installation and for the operation of the installed systems. Many deficiencies become invisible since the components are hidden behind walls, ceilings and in other building cavities which are closed in as the job is nearing completion. They usually show up later as maintenance items after the job is turned-over to the owner. The cost for "fixing" these problems is then much higher than it would have been if discovered during installation. Also, the costs associated with these problems burden the O&M department, which usually do not have related costs in their budget. Most importantly, the building occupants, who expected to move into a new comfortable and trouble-free building, are inconvenienced by problems originating from systems.
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installation (or design). Therefore, this needs a balanced approach as with Building Commissioning (BC) to fill the gap to ensure sustainable quality during the building process.

2.6.3 Building Commissioning (BC)

Building Commissioning (BC) is the systematic process of ensuring and documenting that all building systems are carried out in accordance with specification and design intent, consistent with the owner's operational needs to improve the building delivery process; to provide a safe and healthy facility; to improve energy performance; to reduce operating costs; to provide O&M staff orientation and training; and to improve systems documentation (DOE 2004; Prowler 2004).

Most complaints from building occupants are related to the operation of environmental control systems, which are the building systems as HVAC and HVAC controls and automation systems. According to the published survey of the Architecture Institute of America, 90% of complaints are due to occupancy comfort, or rather; discomfort (Boed, V. 1996). As building systems have become more complete and contractors more specialized, the traditional methods for building start-up and final acceptance have proven inadequate. Building Commissioning fills this gap by applying a comprehensive written plan of testing, approvals and acceptances that begins with the basis of design preparation and extends throughout the design and construction process. Correctly implemented, it provides fewer requests for change, smoother building turnover, improved energy performance, increased systems reliability, enhance occupancy comfort and reduced expenditure for operations & maintenance (O&M). The benefits of commissioning to the building participants were disclosed by Tamblyn et al (1994) as:

◊ To the owners:
  o There is lower overall cost when considering first cost and operating costs.
  o There is a smooth hand-off from the design team and contractors to the operations staff because of the O&M’s involvement in the design process from the beginning.
  o The smooth start-up permits the educational staff to perform their
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Responsibilities.

◊ To the designers:
  - Commissioning provides improved integration between design disciplines.
  - The design team can extend their devices by offering commissioning activities.
  - The gap of knowledge between designers and field staff (construction and O&M staffs) is narrowed.
  - Contractor-designer conflicts are reduced and start-ups are smoother.
  - The clients are handed a functioning building.

◊ To contractors:
  - The inclusion of performance testing and commissioning responsibilities in tender documents gives clearly documented expectation of the contractor’s performance.
  - The performance reports give a documented account of the contractor’s performance.
  - Less time is spent in conflict resolution.
  - The contractor also has a satisfied client.

Commissioning provided these benefits can facilitate the overall quality of building systems and satisfy the clients’ expectations. While building commissioning is becoming more common, there is still no absolute consensus of what constitutes the most appropriate scope of building commissioning activities. Building Commissioning is a relatively new field and standard procedures are still not being defined. Overall, the Building Commissioning process is intended to facilitate the building turnover process, realize energy savings; assure indoor air quality (IAQ); improve system function, operation and maintenance (O&M); and increase thermal comfort. The key elements of a comprehensive Building Commissioning Plan include (Prowler 2004):

- Thorough documentation of system design intent and operating sequences;
- Verification of system performance based on documented functional testing and measurement;
• Preparing and submitting O&M manuals (and increasing videos) and the training of building operations staff on system operations and maintenance procedures;
• Ongoing monitoring of system performance.

The use of commissioning must be tailored to suit the building owners. For the owners, commissioning may help resolve major communication problems. If the original building design does not accurately reflect the client's needs and requirements, then regardless of the proper implementation of a commissioning process, the building will not achieve the efficiency, comfort and performance desired (Boed, V. 1996). Therefore Building Commissioning is not a substitute for good architecture and engineering.

Experience in office building construction and management has validated that starting the commissioning process as early as possible in a project leads to the best results. In a survey (Larsson 1994), it reflected that usually occupancy and construction phases are the time when commissioning activities begin. Commissioning is a complex task which should confirm (GSA/FEMP):

- The installed systems meet design parameters,
- They are properly installed and set up,
- They operate properly under various operating conditions,
- They interact and are interoperable with other systems,
- Provide the owner with a set of start-up operating values - a very valuable information for future system maintenance
- Provide instructions to O&M personnel on how to operate the building.

The owner’s O&M personnel should be fully involved in this stage of the project. They should be part of setting up a commissioning plan, witness functional and performance testing, and the validation and verification of systems operating parameters. They should be instructed in the operation of the installed systems under normal and emergency conditions, during shut-downs, start-ups, etc. They should receive operator training documentation prior to final acceptance. They should be involved in post-acceptance systems performance verification for a one-year (four-season) systems performance warranty. The commissioning documentation
should be part of the acceptance documentation package and should aid the owners O&M personnel in future maintenance and systems calibration.

Therefore, Building Commissioning (BC) should be an alternative to balance and fill gaps between different building phases to sustain the quality throughout the whole building process. BC should be seen as a sub-set of quality assurance process (Larsson 1994). The contractors quality control and commissioning program are combined into an effective management tool that saves money not only for the contractor, but for the building owner and design consultants as well (Tseng 1994). TQM and BC offer a solution which, if properly applied, will enhance quality design and system implementation, and provide a bridge between design/ implementation and operation/ maintenance (O/M) (Boed, V. 1996), therefore, the quality of either BAS products or building processes such as design and maintenance can be assured. In addition, the costs through the whole building life also need to be taken into consideration to balance the “First Cost mentality”. The multiple levels of savings, which all are energy-related, that occur when building systems are properly commissioned are tied into the long term revenue of the buildings (Benner/ Bjornskov 1994).

2.6.4 LCC for Building Development

Before improving the total performance of life cycle in office building, it would be necessary to evaluate and compare the present status of the conventional building with the intelligent office building. The Life Cycle Cost (LCC) analysis is a method used to assess design alternatives considering all the significant costs of ownership. The critical objective of LCC is the determination of optimum design decisions following the evaluation of all feasible design alternatives to assure the total performance related to the maintenance activities. The LCC process can be applied to a total building or to any building components such as the Building Automation System (BAS).

It is generally accepted that life cycle costing techniques are a valuable tool for considering options of new developments, refurbishment works and even maintenance strategies because they focus the owner's attention on the need to take account of future maintenance liabilities as well as present capital costs. The basic
information on life spans, maintenance costs and discount rates needs to be obtained and whilst there are always elements of risk in any forecasting methods there is still a case for an improved refinement in LCC to be of benefit. Various techniques have been developed to assist in the analysis of a building's total costs over its life span.

### 2.6.4.1 Life Cycle Cost

The cost of building service systems in a modern high-rise building can be over one-third of the building's total first cost, and over two-thirds of its 25-year total life-cycle cost (Council on Tall Buildings and Urban Habit 1995). The Life Cycle Cost (LCC) of an asset is defined as the present value of the total cost of that asset over its operating life, including initial capital cost, occupation costs, operating costs and the cost or benefit deriving from disposal of the asset at the end of its life.

An essential element in using LCC is defining the life cycle period, or 'building life', and within this, the expected life of the components and/or elements. The application of LCC must always be carried out in a proper context, as considerations of a life cycle may differ somewhat from notions of the life of a building or a component as normally perceived (Barrie, et. al. 1996).

\[
\text{Life cycle cost} = \text{Capital cost} + \text{cost-in-use} - \text{Net residual value}
\]

Exhaustive lists of life cycle costs are difficult, but the following will typically need to be counted:

- Maintenance, including redecoration
- Energy consumption
- Cleaning
- Rates
- Insurance
- Estate management or management overheads
- Finance costs

Single building systems apply those LCC components related to capital cost, maintenance cost, operating cost and demolition cost.
2.6.4.2 Life Cycle Cost Analysis (LCCA)

Application of a BAS would measure their lifetime cost before a start was made on design, installation and operation to ensure the system’s continuum in the building life. Although the predictions of the life cycle cost of utilities and services are often difficult at the outset of projects, since there are difficulties in determining long-term economic conditions, along with other factors, such as unforeseen budget constraints, making future cost predictions difficult. However, the accuracy of such cost predictions can be increased significantly by analysing the total ownership cost of facilities, especially the operating and maintenance costs, and identifying the factors that govern them. Some of the factors that affect these costs are facility location, facility type and purpose, facility size, facility design, quality of facility construction material, price indices for utilities and services (inflationary effect) (Christain and Pandeya 1997). Examining those factors is important in relation to the design and maintenance activities; therefore, this examination would be cost effective. On the other hand, that anticipating technologies and knowledge will increase during the service life, could see the difficulties decrease, and above all that the BAS innovation also will reduce the risks of the application, consequently, the LCC consideration would be a strategy for problem solving.

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of facility ownership. It takes into account all costs of acquiring, owning, and disposing of a building or building system. LCCA is especially useful when project alternatives that fulfil the same performance requirements, but differ with their initial costs and operating costs, have to be compared in order to select the one that maximizes net savings. For example, LCCA will help determine whether the incorporation of a high-performance HVAC or glazing system, which may increase initial cost but result in dramatically reduced operating and maintenance costs, is cost-effective or not. LCCA is not useful for budget allocation. Lowest life-cycle cost is the most straightforward and easy-to-interpret measure of economic evaluation. The LCCA should be performed early in the design process while there is still a chance to refine the design to ensure a reduction in life-cycle costs. There are numerous costs associated with acquiring, operating, maintaining, and disposing of a building or building system. Building-related costs usually fall into the following categories:
◊ Initial Costs (Purchase, Acquisition, Construction Costs, Fuel Costs),

◊ Operation, Maintenance,

◊ Repair Costs, Replacement Costs, Residual Values (Resale or Salvage Values or Disposal Costs),

◊ Finance Charges (Loan Interest Payments, Non-Monetary Benefits or Costs).

The vast majority of costs associated with engineering and construction relate to operation and maintenance as shown in Figure 2-12. There are three pillars of typical Life-Cycle Cost with cost elements as design and construction costs, operating and maintenance costs, and acquisition, and disposal costs (Christian and Pandeya 1997; ASHRAE 2003; WWW2.6.4.2). In Figure 2-12, the cost of operation and maintenance (O/M) is 60-85% of the life cycle costs of a facility. However, O/M cost is not scrutinised as extensively as the first costs (Council on Tall Buildings and Urban Habit 1995; FCC 2001), this would impact on the building costs decision making in the planning and design stage, especially selection of the BAS and building systems for easy maintenance and energy conservation.
Figure 2-12: Comparison of Cost in Building Process
(Three Pillars of Typical Life-Cycle Cost Elements: 30 year Period)
2.6.5 Practice with Smart and Sustainable Design Incorporating Maintenance

In spite of the fact that the definition of what constitutes smart and sustainable building design is constantly changing, there are several fundamental principles that nearly everyone agrees on: minimising energy consumption, protecting and conserving water, using environmentally preferable products, enhancing indoor environment, optimising the operational and maintenance practices.

In order to achieve quality, high performance buildings, optimisation of the operational and maintenance (O/M) practices has been considered by incorporating operating and maintenance into the design of a facility and BAS which will greatly contribute to improved working environments, higher productivity, and reduced energy and resource costs (James 2002). Since the building design, construction and O/M have an enormous direct and indirect impact on the environment; appropriate building construction and maintenance will increase thermal comfort, lower costs and reduce the overall environmental impact (ABS 2003). The buildings impact environment during construction, operation and maintenance, and demolition stages in various aspects such as energy use, atmospheric emissions and raw material usages (Roodman and Lenseen 1995; Vittori 2002). The extent of environment impacts comes from buildings is illustrated as in the Figure 2-13 (WBDGEIB 2004).

![Environmental Impact of Buildings](image)

Figure 2-13: Environment Impact of Buildings
(Sources: World watch Institute and U.S. EPA)

The building impacts on the environment start from the design decisions and material choices that may relate to the energy use and solid waste generation to the whole life
cycle of building phases. These direct and indirect influences may not only affect construction of the building for about five years, but also have an effect on building operation, maintenance for about 50 years or more in Life Costing estimates (Vittori 2002).

On the other hand, minimisation of energy consumption is also the main objective in the office building, and this relies on conservation and passive design considerations for its operation by meeting or exceeding applicable energy performance standards. In an energy conservation studies, designs of energy improvement indicate that more than 20% of energy use for HVAC is likely to be the result of improper equipment operation, poor installation (Donahue 2001; Roth et al 2002). These studies in the technology options for energy saving potential, encompassing building component, equipment and system (such as Airfoil Fan Blades, Triple-Effect Absorption Chillers, Microenvironments), and controls, operations and maintenance (O/M) (such as Complete Commissioning, Building Automation Systems), indicate that the system choices and O/M consideration in design stage have an effect on the energy conservation (Roth et al 2002).

In addition, comfort and health are an expected necessity for the office buildings. To ensure and enhance the impact on occupant’s health, comfort, and productivity, maximising day lighting, installing appropriate ventilation and moisture control have also to be taken into consideration. Hence designers are encouraged to specify systems that simplify and reduce maintenance requirements; are cost-effective and reduce life-cycle costs to meet the occupant’s expectations (WBDGEIB 2004).

This "smart and sustainable" approach supports an increased commitment to environmental management and conservation, and results in an optimal balance of cost, environmental, societal, and human benefits while meeting the mission and function of the intended facility or infrastructure to avoid waste in the resources of energy, water, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are habitable, comfortable, safe and productive (UNEP 2003).

Sustainable development may include more recycled materials, require less energy or water usage, reduce construction waste, increase natural lighting, or include other
opportunities that contribute to an optimal facility (FCC 2001). Using more effective alternatives such as life cycle costing (LCC), total quality management (TQM), and building commissioning (BC) in design and maintenance can promote to balance environmental performance with product reliability, safety, and functionality. When all alternatives are utilised equally, sustainable development technology and integration can then be fully evaluated for performance in the whole process.
2.7 Summary

Being smart and sustainable office buildings are evolving characteristics of building products pursued by many practitioners and researchers around the world today. Design and maintenance, as two interrelated phases at the opposite ends of the building development cycle, can have substantial implications on the long-term performance of office buildings, therefore are highly relevant to both smart features and sustainable outcomes. Smart building design, should actively consider potential service and maintenance issues associated with building structure, components and systems. Sustainable maintenance of office-buildings should be carried out to truly reflect designated intended use of components and systems, aided by a full knowledge of design decisions and a total appreciation of the characteristics and behaviours of these systems. This will require the deployment of new strategies such as decision support based integration.

In brief, the findings of the literature study can be categorised into four aspects such as general status of the office building industry, potential approach, required information and strategies development as in Figure 2-14:
1. General status:
   - Intelligent building and building automation in the office building industry
   - Building designers and maintainers are normally working independently with less communication and support during the life time of buildings.
   - In the life cycle process, collaboration between design and maintenance can help improve their relationship.

2. Potential approach:
   - Process integration between different parties can help improve the effectiveness and efficiency; it is a potential approach.
   - Decision support tools have potentials for filling the gaps and limitations in practice.
   - Total Quality management (TQM) and Building Commissioning (BC) and Life Cycle Costing (LCC) might have potentials for the improvement of the quality of product and process, and balance the environmental impact.

3. Required information:
   - Current status of the office building automation
   - Barriers and limitations existing in office building practices
   - Information in relation to design and maintenance

4. Strategies development:
   - Raising awareness and understanding to facilitate communication between design and maintenance
   - Guide to enhance the design and maintenance of office building automation
   - Exploration of the computerised decision support
CHAPTER 3
RESEARCH METHODOLOGIES AND DEVELOPMENT PROCESSES

3.1 Introduction
3.2 Key Methodologies
   3.2.1 Justification of Literature Study
   3.2.2 General Research Approaches
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3.3 Research Design and Development
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3.4 Summary
3.1 Introduction

The objectives of the research have been disclosed in chapter 1 as:

◇ To identify barriers and limitations of BAS between design and maintenance

◇ To establish guidelines for the improvement of design and maintenance of office building automation

◇ To develop a prototype decision support system to demonstrate the potential of integrating design and maintenance tasks of office building automation

In order to achieve the research objectives, the research methodology should firstly be considered and adopted. By examining the literature findings, it was revealed that the current situation of BAS in office building design and maintenance should be collected for advanced data analysis to extract the useful knowledge to justify the potential issues. An in-depth study of office building relating the BAS issues is also essential for further guideline generation and decision support development.

3.2 Key Methodologies

Key methodologies proposed in the research project include:

- Literature study
- General research approaches
- Industry surveys
- Case study
- Knowledge acquisition
- System design and development
3.2.1 Justification of Literature Study

The purpose of the literature review is to ensure that the required materials that have in the past been found to have had an impact on the problem. Based on the issues of research and the factors identified during the research process, a literature review needs to be done. Generally, literature reviews have to go through three steps. The first step involves identifying the various issues in published and unpublished materials. The second step is gathering the relevant information either by going through the necessary material in a library or by getting access to online sources. The third step is writing up the literature review. In this research, after the literature review detailed in Chapter 2, the research was able to narrow down the problem from its original broad integration issues and define the issues of concern in the process integration more clearly. The relevant literatures has been surveyed as detailed in the previous chapter which has demonstrated and verified the possible direction for providing a solution to the proposition of the research: “Could possible alternatives be created to help overcome the problems which exist between design and maintenance for office building automation during the life time of the buildings?”

The literature study has reviewed several contexts encompassing building integration in the building industry, the decision support approach for improving the practice, design and maintenance of office buildings, BAS status and other literatures in relation to the building assessment such as Life- Cycle Costing (LCC) and quality assurance in Building Commissioning (BC) and Total Quality Management (TQM).

It has demonstrated the needs and feasibilities for this subject, and has also highlighted the possible alternatives to accomplish the objectives which can be achieved from the integration approach and decision support development. However, the literature survey is potentially an endless task. In order to accomplish the designated objectives to prove the theories, in addition to the on-going literature reviews, the feasible and effective methodologies should be selected, justified and deployed.
3.2.2 General Research Approaches

Integration

The importance of integration can be highlighted from the literature reviews, because the building development process is a dynamic one involving many stages of work such as design, construction, operation, maintenance, retrofitting and upgrading. There is a clear need for interaction between these stages among all participants including designers and the maintenance team. Information related to maintenance should be supplied to the designer as the assumptions of what will be required for inspection, maintenance and replacement, sufficient details of relevant technical considerations that apply, and especially, the unexpected deviations in performance that have occurred in service.

The degree to which the design of a building embraces maintenance consideration has a major impact on the performance of a building. Maintenance related problems that occur during the lifetime of a building can be minimised by making future decisions in the design stage of the project. The integration between design and maintenance will at least achieve the following goals (Arditi, D. 1999):

◊ Enhance their inherent relationship and prevent mistakes from the lack of understanding and communication,

◊ Facilitate effective consideration of maintenance in the design stage, and

◊ Fulfil design intentions through service and maintenance processes by taking the right procedures for the specific problems encountered.
Decision support

As the complicate and fragmental characteristics of building industry, management and improvement are still challenge for the changing environment. Dealing with the rapid alteration and quick response of decision making, appropriate decision supports are required. Especially, across the two building phase- design and maintenance, the bridge will relate more interdependent expertises and knowledge. To reach the integration objective of the research, an approach as decision support might be appropriate and effective way. The decision support approach can make available trial-and error attempts, knowledge support and experience accumulation for speedy response and process. It might not only support the sophisticate manual information, but also can supply quick interactive response through the computer-based decision support development. The computer-based decision support for quick access and process vast amounts of stored information would improve coordination and communication for building group work. The research objectives will accomplish through this decision support development to integrate design and maintenance.

Increasing client expectations on building performance, energy conservation and comfort, and continuing report of maintenance problems prompt researchers and practitioners to search for solutions. Despite the integration approach, the development of decision support is also an alternative. DSS can provide data store, retrieval, and integration functions to help decision makers utilise these data and models to solve unstructured problems. In this project, the integration will facilitate the sharing of information and decision support between design and maintenance utilising a knowledge-based system. Decision support methods have proved their worthiness in the field of qualitative analysis of construction problems (Yang & Peng 2001).

A DSS is composed by three basic elements: the database and its management, the model base and its management, and the dialog sub-system as in Figure 3-1:

- Data management: includes databases, which contains relevant data, performs functions as data retrieval, capture, and integration.
- Model management: provides analytical capabilities and management.
- Communication (dialog subsystem): provides user interface to input and output
In inductive and deductive methods, one of the research methods such as inductive and deductive methods can be used to form the concepts and build the knowledge base. Valid concepts are derived from observed reality. Concepts are formed through the process such as observation, classification, similarities, identification, combination and differentiation. Thus concept-formation is basically an inductive process. Knowledge must be consistent without contradiction. Deduction is how to achieve this. Concepts are generated inductively and tested and refined deductively. Deduction gives concepts their predictive usefulness. Hence knowledge generation is mostly a deductive process. If exceptions in the nature of concepts and reality occur, the deduction again comes in, in refining the concepts. All forms of deductive logic are some form of If $A$ then necessarily $B$, whose converse is If not $B$ then necessarily not $A$. The first deduce the nature of particular instances of existing concepts. The second refines the concepts. In brief, induction is deriving the general from the particular; deduction is deriving the particular from the general (Saunders et al 2000; Kruger and Welman 2002; Collis...
The induction has to do with building theory and collection of qualitative data. The deduction seeks to test hypotheses in terms of the data obtained. The process of induction and deduction is illustrated in Figure 3-2.

According to Figure 3-2, the facts and observations can be induced to make a theoretical statement that explains the observations and facts. Through deduction, such a theory is determined whether it is a reliable in reality. The validity of the hypothesis is then determined in terms of the contradiction and suitability by collecting new data.
3.2.3 Industry Survey

To reach the first objective, information in relation to BAS design and maintenance in the office building industry must be collected to identify the current status. The literature findings have demonstrated that the lack of the effective ways to bridge design and maintenance as well as the insufficient acknowledge between different building phases. The needs and overall situation of the management in building practice would rely on the realistic survey. In spite of the rare literatures relating to the research context, the survey of industry practice would be essential to reply and develop effective approach. The survey can provide both information as facts of the practice and opinions from the professional experience. The information can base the initial source for the further knowledge base formulation along with the decision support development to achieve the goals in this research. To get an understanding the current status of the BAS design and maintenance of office building, the industry professionals including design and maintenance personnel have been the major subjects. The industry survey will be carried out in the major capital cities of Australia.

3.2.3.1 Information Required

Useful, timely, accurate, reliable, and valid data are needed. When this data from the replies are evaluated, analysed, and synthesised, useful information becomes available to help decision making (Sekaran, U. 2003). Information includes the facts and opinions, from the surveys respondent’s opinions, their criticisms or description and the responses of the current situation of industry. Data may be regarded as ‘raw facts’, information is facts which are expressed in forms suitable to assist a decision maker; information directly supports decisions (Fellows and Liu 2003).

In this research the required information may come in the forms of:

◊ Opinions
◊ Current design and maintenance practice
◊ Design and maintenance information
◊ Manual

The research concentration on the integration (system or process) and decision support approach related to the research context is also required. All of this
information should be obtained by means of accepted suitable methods.

### 3.2.3.2 Selection of Data Collection Method

Data collection methods include interviews, questionnaires or instrument administration, observation of documents and a variety of other motivational techniques such as projective tests (Robson, 2002; Sekaran, U. 2003; Sproull, 1995). Taking into consideration the necessities of research and justified by literature reviews on research methodology, two distinctive approaches for data collection have been selected. They are questionnaire surveys and case studies. The questionnaire is specifically designed to reach the first objective of collecting first hand data; while the case study is for supplementing any deficiencies in the data collection and will indirectly reach the second objective.

Justification of the selected data collection methods should be undertaken on the basis of understanding their advantages and disadvantages (Sekaran 2003; Fellows and Liu 2003; Saunders, et. al. 2003), and then to select the appropriate choices. Reviewing the research findings, one of the approaches used for data collection are mail questionnaires which have several benefits as in Table 3-1.

Table 3-1: Advantages and Disadvantages of the Mail Questionnaires

<table>
<thead>
<tr>
<th>Data Collection</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mail Questionnaires</td>
<td>◊ Anonymity is high.</td>
<td>◊ Response rate is almost always low.</td>
</tr>
<tr>
<td></td>
<td>◊ Wide geographic regions can be reached.</td>
<td>◊ A 30% response rate is reasonable and quite acceptable or 25%-35% useable response rates.</td>
</tr>
<tr>
<td></td>
<td>◊ Token gifts can be enclosed to seek compliance.</td>
<td>◊ Cannot clarify questions.</td>
</tr>
<tr>
<td></td>
<td>◊ Respondent can take more time to respond at convenience.</td>
<td>◊ Follow-up procedures for non-responses are necessary.</td>
</tr>
<tr>
<td></td>
<td>◊ Can be administered electronically, if desired.</td>
<td></td>
</tr>
</tbody>
</table>

The mailed questionnaire survey is best suited (and perhaps the only alternative open to the researchers) when information is to be obtained on a substantial scale through structured questions, at a reasonable cost, from a sample that is widely dispersed geographically (Sekaran, U. 2003). The advantages of the mail questionnaires comply with the needs of the research in seeking for a wide geographic coverage of current practices and wide-ranging responses because there are no time constraints on the respondents and it is a convenient form of communication. Nevertheless, the
disadvantages of the low response rate could be solved by using of the electronic tools and strategic follow-up methods. On the other hand, it might also be verified by the second approach—case study to overcome this shortcoming.

### 3.2.3.3 Mail Questionnaire Survey

A questionnaire is a pre-formulated written set of questions used to obtain information from respondents, it can be administered personally, mailed to the respondents, or electronically distributed is an efficient data collection instrument when the researcher knows exactly what is required and how to measure the variables (Sekaran, U. 2003). Questionnaire surveys can be carrying out in a variety of ways, commonly including: mail questionnaires, personally administered questionnaires, telephone and internet questionnaires. The choice of questionnaire communication methods may depend on personal preference, cost, time constraints, potential response rates or many other criterions. Table 3-2 compares and summarises these approaches by Frazer & Lawley (2000):

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Mail questionnaire</th>
<th>Personally administered questionnaire</th>
<th>Telephone questionnaire</th>
<th>Internet questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>Very low</td>
</tr>
<tr>
<td>Speed</td>
<td>Slow</td>
<td>Immediate</td>
<td>Immediate</td>
<td>Fast</td>
</tr>
<tr>
<td>Geographical dispersing</td>
<td>High</td>
<td>Very low</td>
<td>Medium</td>
<td>Very high</td>
</tr>
<tr>
<td>Length of questionnaire</td>
<td>Long (30-60 minutes)</td>
<td>Long (10-30 minutes)</td>
<td>Long (4-12 pages)</td>
<td></td>
</tr>
<tr>
<td>Question complexity</td>
<td>Moderate</td>
<td>Simple to complex</td>
<td>Simple only</td>
<td>Simple to moderate</td>
</tr>
<tr>
<td>Recall data</td>
<td>Good</td>
<td>Poor</td>
<td>Moderate</td>
<td>Good</td>
</tr>
<tr>
<td>Respondent anonymity</td>
<td>Possible</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Rapport with respondents</td>
<td>None</td>
<td>High</td>
<td>Moderate</td>
<td>None</td>
</tr>
<tr>
<td>Interviewer bias</td>
<td>None</td>
<td>High</td>
<td>Medium</td>
<td>None</td>
</tr>
<tr>
<td>Need for interviewer supervision</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Response rate</td>
<td>Low</td>
<td>Very high</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Reviewing the above features of the various methods, the mail questionnaire was chosen to achieve the first research objective which was to identify potential problems and limitations of BAS between design and maintenance in the building industry. The proposed respondents were spread geographically around the major capital cities of Australia and were invited to participate in this research. Personally administering of survey and telephone questionnaires were not options. In addition, the cost of these is much higher than of mail questionnaires. The Internet method is
similar to the mail approach, however it currently needs extra support by the web server and internet access which is related to either respondents’ preference or their computer literacy; thus this method will not be suitable until Internet access is as common as telephone access.

Amongst other advantages, the mail questionnaire allows the author to review the obtained data, provides a good length of questionnaire, allows respondent anonymity and is unbiased. All of those features directly contribute to obtaining good data and affect the response rate. Nonetheless, the slow speed of response and prospectively low response rate will need to strategically improve as allocating sufficient response time and utilising effective communication techniques with prior contact by letter or telephone; using visual aids to increase respondent interest and improve recall; and instigating follow-ups to raise response rates (Kervin, J.1992). In this research, a questionnaire-based industry survey has targeted both design consultants and facility managers of existing buildings to identify practical issues and concerns.
3.2.4 Case Study Method

The case study is one of the many research methods which can provide an intensive examination of a single instance of a phenomenon of interest. In such process, the researcher can explore in depth a program, an event, an activity, a process, or one or more individuals to examine a research problem in the exploratory stages (Kervin 1992; Creswell 2003). The use of the case study for research purposes is becoming increasingly widespread in management research. A wide range of information gathering techniques can be used in case studies including available documents, observation, presence, participation, or even intervention in the actual process (Gummesson, E. 1991; Kervin, J.1992; Welman, Jc. & Kruger, Sj. 2001).

Research in the social science and management spheres usually involves asking and obtaining answers to questions through conducting surveys of people by using questionnaires, interviews and case studies; while there is a finite amount of resources available for carrying out the field work, a choice of research method is necessary. The choice is between a broad but shallow study at one extreme and a narrow and deep study at the other, or an intermediate position which can be illustrated as in Figure 3-3 (Fellows and Liu, 2003).

The case study method in this research is expected to produce findings extracted from the history and experience of the selected office building. It will not only facilitate the exploration of the research focus and enhance the deficiency of the

![Figure 3-3: Breadth v. Depth in ‘Question-based’ Studies](image-url)
industry survey, but also learn from their experience and introduce the building integration practice. The case study method can be used (Gummesson 1991):

- To derive general conclusions from a limited number of cases with high reliability thus can be replicated by others.
- To arrive at specific conclusions regarding a single case because this “case history” is of particular interest.
- A case research is a useful strategy for studying processes and also for explanatory purposes.
- Provide an opportunity for holistic view of a process to further generate theory for initiating change.
- Apply as an emergency approach to serve as a basis for fruitful theoretical developments and also provide guidelines for salutary advice.

Thus, case study method as in Figure 3-3 can be used for in-depth investigation into the research focus and for verifying the reliability of the surveys.

### 3.2.5 Data Analysis

The purpose of analysing the data is to provide information about variables and, usually, relationships between them. Data may be regarded as ‘raw facts and figures’ which information is facts and figures which are expressed in forms suitable to assist a decision maker. Information directly supports decisions. Accordingly, the purpose of data analysis is to provide evidence of relationships and to aid understanding to support decision making (Fellows and Liu 2003).

After data are obtained through questionnaires and observation, they need to be edited and analysed in a flow of processes as shown in Figure 3-4.
Data analysis can be manually done, but is now routinely done with some software programs such as SPSS and MS Excel to generate information (Sekaran, U. 2003) such as:

- **SPSS**: can be used to create surveys (questionnaire design) through the SPSS Data Entry Builder to analyse the data collected. It can turn data into relevant results and transforms the data into information. It offers analytic applications, data mining and text mining, and comprehensive statistical analysis software that support the decision making processes. Generally, it displays in text, chart, table and graph forms that is suitable for the analysis of the facts and compares the relevant factors.

- **MS Excel**: can be used to analyse the statistical analysis to display data and analysis in the forms of charts and graphs. Data analysis and probability are some of the most important functionalities in this software package. It is a member of the spreadsheet family of software. It can be used to store information in columns and rows which can then be organized and/or processed. Spreadsheets can help organise information, or reordering records according to a numeric field. However, it is more often used for calculating, to calculate some statistical measures from a list of numbers.
During the research development process there were three fields of data that needed to be gathered. They were the data from literature, data from the professional survey, and findings from the case study.

In accordance with these research findings and survey results, analysis and knowledge extractions will be used to format and create a support for the design and maintenance decision-making to form guidelines which could provide support during the building’s life-cycle. The collated survey data will be analysed through the utilization of the statistical analysis software SPSS (V11.5 & 12.0) and supplemented by Microsoft Excel to generate the graphic results for advanced analysis and application.

### 3.2.6 Knowledge Acquisition

Knowledge Acquisition is the extraction and formulation of knowledge derived from existing sources, especially from experts. The process of acquiring knowledge involves:

(1) identification of knowledge requirements, and

(2) selection of the most appropriate acquisition techniques such as knowledge elicitation and knowledge acquisition techniques.

However, there are no definite techniques for expert knowledge acquisition which can guarantee complete success (Brandon et al 1988). Generally, data and information collected should be analysed (selected, differentiated, dissected, broken up) and synthesised (integrated, combined, recasted, formulated, reorganised) to gain knowledge pertaining the definition, classification, description, application, recognition, awareness, understanding and problem solving of the subject area (Hart 1998). The process of knowledge elicitation is often difficult and time consuming for the following reasons (Brandon et al 1988):

◊ Human knowledge is very complex and can be messy and ill-formulated.

◊ Humans find it very difficult to articulate what knowledge they have and how they use it to solve problems.

◊ The more expert someone becomes at a task, the more ‘unconscious’ his knowledge becomes.

◊ An expert’s verbal comments or actions need careful interpretation to extract what underlying knowledge may be inferred from them.
◊ The existing knowledge acquisition techniques are often of limited applicability. To apply decision support, sufficient information and relevant knowledge are needed. Particularly, in the office building context, design and maintenance integration shares design information as well as maintenance experience and procedure based practice. These require extensive information and routing following consultation patterns. During the decision support process, the interactive communication between the users and the knowledge engineers or computer based system relies on sufficient knowledge to support and provide inference reaction as suggestions and guidelines. The required knowledge encompasses:

◊ The facts including the needs and expectations of the building participants.
◊ Information in relation to the explanations of the design and maintenance phenomena.
◊ Possible strategies or approach to the research issues.

The knowledge which can be utilised for problem solving and provided for decision making needs to be extracted by following a logical sequence during the process. The relevant knowledge which can be systematically acquired needs to be collated. Based on the industry survey and case study, the results can provide the base for these knowledge acquisitions. Furthermore, knowledge extraction in relation to the current BAS issues in the research context might be through the strategic methods detailed in the previous sections to collect and analyse. Then the extracted knowledge will be used to formulate a knowledge database and generate the guidelines for the decision making support.

According to Turban et al (2001), the methods of knowledge acquisition can be classified in three categories: manual, semi-automatic, and automatic:

◊ Manual methods are basically structured around some kind of interview which include interviewing (structured, semi structured, unstructured), tracking the reasoning process, and observing; the knowledge is elicited from the expert or other sources and then coded it in the knowledge base.

◊ Semiautomatic methods are divided into two categories: to support the experts by allowing them to build knowledge bases with little or no help from knowledge engineers, and to help knowledge engineers by allowing them to execute the necessary tasks.
In automatic methods, the roles of both the expert and the knowledge engineers are minimised or even eliminated.

Generally, knowledge can be elicited either from the existed documentation and current experts’ experience or observation from the practice by manual or computer aided. In this research, the knowledge required might be through the integrated approach as in Figure 3-5 to achieve.

![Integrated Knowledge Acquisition Diagram](image)

**Figure 3-5: Integrated Knowledge Acquisition**

Utilising the induction and deduction methods knowledge extraction from the research findings, information of practice, survey results and case studies can be used to formulate the design guidelines and checklist for design and maintenance to form a database to include:

- Knowledge from research findings: this is collected from the desk research that will include know-how from experts, published findings and others.
- Knowledge from survey results: this is obtained and analyzed through the activities of professional surveys and analysis.
- Knowledge from practice: this can be extracted from the candidate’s experience and case studies, and also can be added to later by the users to keep the knowledge up to date.
3.2.7 System Development

Because of the different types and categories of DSS, there is no single best approach to DSS development. Development is a very deliberate and orderly approach to making a system a reality and a methodology is needed to provide the structure for the system development (Turban et al 2001). All system developments follow essentially the same fundamental process, called the system developmental life cycle (SDLC), and there are many “traditional” SDLCs for information systems, including DSS. A traditional SDLC consists of four fundamental phases- planning, analysis, design, and implementation- which lead to a deployed system as in Figure 3-6:

A methodology is a formalised approach to implement the SDLC (i.e., it is a list of steps and deliverables). There are many different systems development methodologies each one of which is unique with its specific emphasis including: “Structured design methodologies such as waterfall and parallel development to produce a solid, well-thought-out system, “Rapid Application Development (RAD) methodologies such as phased and prototype (Prototyping, Throwaway Prototyping) development to speed up easier development, and a new emerging “Agile development methodologies” such as Extreme programming (XP), scrum, and the dynamic systems development method (DSDM) to emphasise simple, iterative application development. The choice of methodology is influenced by the criteria in Table 3-3 by the user requirements, familiarity with the base technology, system
complexity, and the need for system reliability, time pressures, and the need to see progress on the time schedule:

Table 3-3: Criteria for Selecting a Methodology (Dennis and Wixom, 2003)

Dennis and Wixom further comment these methodologies:

◊ Structured design methodologies: adopt a formal step-by-step approach to the SDLC that moves logically from one phase to the next.

◊ Rapid application development (RAD): is a newer approach to systems development that emerged in the 1990s, most RAD methodologies recommend that analysts use special techniques and computer tools to speed up the analysis, design, and implementation phases, such as CASE (computer-aided software engineering) tools, JAD (joint application design) sessions, fourth-generation/visual programming languages that simplify and speed up programming (e.g., Visual Basic), and code generators.

◊ Agile Development: is still emerging today, and it is typically used in conjunction with object-oriented methodologies. XP requires a great deal of discipline; otherwise projects may become unfocused and chaotic.

In this research the attempt to explore the process integration is often faced with unclear user requirements. It needs quick short time responses and interactions. Thus the prototype methodology must comply with the necessities of performing the analysis, design, and implementation phases concurrently so that all three phases are performed repeatedly in a cycle until the system is completed as illustrated in Figure 3-7. The key advantage of prototyping is that it can very quickly provide a system for the users to interact with, even if it is not ready for widespread use at first. This helps
with more quick refinement of real requirements.

![Figure 3-7: The Prototyping Methodology](image1)

The developmental prototyping methodology is based on iterative refinement of a prototype. Its structure is shown as in Figure 3-8, and this refinement process usually results in faster system development than a conventional development methodology under some or all conditions as: some portion of the requirements cannot be fully specified independently of architectural or detailed design, or technical feasibility for some unknown or uncertain system functions. Prototype development tools are powerful enough to create a fully functional system (Satzinger et al. 2002).

![Figure 3-8: The Developmental Prototyping Methodology](image2)
Several key methodologies as above which could be utilised in this research, where their advantageous features would comply with the objective necessities during the research process, and their disadvantages will also have little affect on the results. The Developmental Prototyping Methodology can be employed to iteratively develop a prototype system until it becomes the final system. However, successful prototyping tools employ a highly interactive application development, which requires system developers to employ tools with power, flexibility, and developmental efficiency. Many of the modern “*visual programming tools such as Microsoft Visual Basic and PowerBuilder, they make it Functional, make it Pretty, and make it Fast- FPF principle*” satisfy these requirements (Satzinger et al 2002).

Compromising the strengths and weakness of the methodologies, in addition to the deployment of the effective techniques and approaches, the comprehensive design of the research could be the alternative and could guide the research to achieve its aims. The next chapter has detailed the process of the research design and development.
3.3 Research Design and Development

3.3.1 Schedule Planning for the Research

There are three essential tasks in research design and development:

Firstly, on-going literature reviews in the office building automation context, relevant information and research findings of the design and maintenance are essential. The study encompasses the exploration of design and maintenance integration, possible alternatives to improve their interaction, the examination of the decision making process in design, and its implementation in the maintenance stage. The strategies of the maintenance practice to facilitate design effectiveness and improve the reliability of maintenance are also included.

Secondly, survey of the industry professionals and the practical operations, and case study of office building project will be essential for data collection. Data analysis and knowledge extraction provide for knowledge base formulation.

Thirdly, a pilot system and prototype model will be developed to demonstrate the integration concept and the potential of a computerised support application. It will be developed as a design and maintenance decision-making tool, which will allow the users to update the information as they gain experiences and have access to more literature.
3.3.2 Overview of Each Research Stage

This research intends to demonstrate the potential of computer based system development and provide a new concept and approach for the building industry and academic studies as well. The research process can be broken down into six stages:

**Stage1. Literature review**

Literature review of the research has demonstrated what is needed in practice and the status of industry. On-going literature study focusing on the evaluation and exploration of existing research findings in office building automation practices, as well as the problems and limitations are the central issues in this stage. The relevant approaches to facilitate the integration between design and maintenance should be broadly investigated.

**Stage2. Survey and case study**

Based on the findings of the literature review, the barriers and limitations in the context of design and maintenance should be identified by the use a survey of industry professionals and case studies. Understanding the current state of the office building automation based on the literature reviews and professional surveys would be the critical tasks for the development of this research. The survey sample size should be over a hundred with an expectation of a minimum of 32 usable responses and an expected response rate of 30% for a mail questionnaire to provide sufficient data. Some effective techniques can be employed for improving the rates of response such as sending follow-up letters, providing the respondent with self-addressed stamped return envelopes, and notification in advance about the forthcoming survey.

Two kinds of professionals were selected under certain benchmarks to be surveyed. These benchmarks include the author’s experience of at least 15 years in the field of specialization, substantial practical contributions to a related field, and comprehensive understanding of the interdisciplinary relationships in the related fields. The information and knowledge collections in the design and maintenance areas were considered while selecting potential experts.

In this stage a single case of an office building will be selected and studied to collect
information for validating the BAS status and integration practice. The sample office building to be selected should have been completed over ten years and built in the Intelligent Building (IB) with BAS application to support the required information.

Stage 3. Data collection, analysis, knowledge extraction and guideline development

Using the collected information from the industry surveys and case study, the major step will be the data analysis and knowledge extraction to complete an knowledge database; then guidelines will be generated to support decision making. Knowledge extraction through the inductive and deductive approach in the research context can raise the awareness and understanding of the concept of integration and provide operational strategies and guidance for the research focus.

Stage 4. Prototype decision support system design and programming

This stage specifies the technical requirements for the design of a prototype decision support system to facilitate the generation of practical decision support. Initially, a pilot system has been explored and tested. Once the pilot system has been examined, the redefined and improved procedures will become the basis for a prototype system development.

Using a relational database and object-oriented programming tools, programming work must be done at this stage to facilitate the system development. The programming is necessary to provide three essential elements for the system as:

- The basic function of decision support will be established.
- The guidelines of decision support for the design and maintenance of building automation system will be applied in the prototype system.
- The resource flexibility in accepting updated information would be a special feature in the system, which will have the facility for users to add new information from their experience and practical examples.

Stage 5. System test and debugging

The prototype system of the project must be checked for operation of capability and potential “bugs”. Final testing and modifications would be very essential work for
this task. The analysis of the system will include the examination of overall performance, the limitations and potentials for the further development. How to validate the outcome of research is a critical issue of this project. Validation of the prototype system operation will be advantageous for the system development that could be a potential tool for the practice.

Stage 6. Presentation of Results

This stage involves the compilation of the final report over-viewing the methodology and findings of the various stages. The prototype decision support system and the dissertation and its presentation will be done.

The overall research design and development process can be illustrated as in Figure 3-9.
### CHAPTER 3: RESEARCH METHODOLOGIES AND RESEARCH PROCESSES DEVELOPMENT

#### Figure 3.9: Research Design and Development

<table>
<thead>
<tr>
<th>Plans</th>
<th>Implementation</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Research Preliminary Planning</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research Design and Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Literature Study</td>
<td>Overview</td>
<td>Design and Maintenance</td>
</tr>
<tr>
<td>Establish Areas and Objectives</td>
<td>Identify BAS Problems and Limitations</td>
<td>Establish a guide for improvement</td>
</tr>
<tr>
<td>Research Methodology</td>
<td>Desk Research</td>
<td>Questionnaires</td>
</tr>
<tr>
<td>Industry Survey and Case Study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case Study</td>
<td>Case Study</td>
<td>Building Information Collection</td>
</tr>
<tr>
<td>Knowledge Extraction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge Extraction</td>
<td>Intelligent Buildings</td>
<td>Building Automation</td>
</tr>
<tr>
<td>Prototype DSS Design and Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software Review</td>
<td>Knowledge Database</td>
<td></td>
</tr>
<tr>
<td>Thesis Writing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Publications and Seminars</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seminars</td>
<td>Integration DSS Seminar</td>
<td>Confirmation Seminar</td>
</tr>
<tr>
<td>Publications</td>
<td>Integration Design and Plan</td>
<td>Integration Design and Maintenance</td>
</tr>
</tbody>
</table>

**Further Research**
- Industry DSS Survey Findings - Journal Article
- Decision Support Approach - Implementation - Journal Article
- Prototype DSS Development - Web Application

**Research Problems**
- Verification from Questionnaires
- Verification from Case Study

**Outcomes/Contributions**
3.3.3 Prototype System Design and Development

In this research, the developmental prototyping methodology will be adopted to develop the prototype decision support system. In the research context, the integration would facilitate the sharing of information between design and maintenance utilising a computerised knowledge-based decision support system. A conceptual model of knowledge integration is illustrated as in Figure 3-10.

![Figure 3-10: Conceptual Model of Knowledge Integration](image)
This model will help make decisions which ensure design effectiveness, and eventually improve the reliability of maintenance for the building’s automation. The intention of the project is to develop a new integrated approach providing the knowledge support with guidelines for the design of building automation, and to improve maintainability during the practical implementation processes, with an eventual goal of building performance improvement.

Once the results of enquiries were input into the proposed system, it was interactively analysed by means of the human-machine interface to generate solutions associated with the design/maintenance aspect. Through the interaction/dialog between users and the proposed system, solutions can be generated. Data flows and managing procedures are outlined as in Figure 3-11:

A knowledge-based prototype system provides both functions of supporting and updating. Therefore this research intends not only to provide computer-based guidelines for design and maintenance practice, but also to provide knowledge support together with updating from practical experience.
3.3.4 Hardware and Software Specification

During the process of designing the decision support system and its development, in addition to the planning phase detailed in the previous sections, the design phase is also the time to begin selecting and acquiring the hardware and software that will be needed for future development. The hardware and software specification needed to support the system development is detailed in Table 3-4:

Table 3-4: Hardware and Software Specification

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation System</td>
<td>Windows Internet Explorer</td>
<td>Windows</td>
<td>Windows</td>
<td>Windows</td>
</tr>
<tr>
<td>Hardware</td>
<td>20-gig disk drive,</td>
<td>40-gig disk drive</td>
<td>40-gig disk drive</td>
<td>200-gig disk drive</td>
</tr>
<tr>
<td></td>
<td>Pentium 3 above 17-inch Monitor</td>
<td>Pentium 4</td>
<td>Pentium 4</td>
<td>Quad Pentium</td>
</tr>
<tr>
<td>Network</td>
<td>Always-on Broadband preferred</td>
<td>Dual 100 Mbps Ethernet</td>
<td>Dual 100 Mbps Ethernet</td>
<td>Dual 100 Mbps Ethernet</td>
</tr>
<tr>
<td></td>
<td>Dial-up at 56kbps possible with some performance loss</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.3.5 Programming

Programming works for the implementation and development of the system used Microsoft Based software such as Windows XP as the Windows operation system, MS Access as the knowledge based database and MS Visual Basic, Visual Studio.NET as the programming tool for creating the inference engines and knowledge based decision support and visual interactive interface.
3.3.6 Validation and Verification

Generally, once a system has been developed or knowledge has been extracted, they will have to be evaluated (Hopkin 1993). There are several methods has been utilised such as validation and verification (Usama et al 1996). Validation is a process of testing whether the outcomes satisfy the expected requirements. Verification is a process of confronting a hypothesis against evidence in order to decide its truth value. Deutsch (1982) defined both validation and verification. “Validation” is “An activity that ensures that the software end product contains the features and performance attributes prescribed by its requirements specification”. “Verification” is “An activity that ensures that the results of successive steps in the software development cycle correctly enhance the intentions of the previous step”. In practice, this definition will probably have to be extended beyond theory or a hypotheses to include conclusions, recommendations, practices, and procedures (Carroll & Campbell 1989). According to turban et al (2001), verification is to ensure that the system works or subsantiating that the system is functioning according to its specifications; validation deals with the performance of the system (e.g. how it compares with the expert knowledge), that is, substantiating that the system performs with an acceptable level of accuracy. Simply stated, validation is building the right system. Verification is building the system right. In software quality assurance, validation is the assurance of customer acceptance; verification is the assurance of technical correctness (smith et al 1993).

There are several sources of data that might support verification and validation processes compiled by Hopkin (1993) such as: comparing domains (relate data gathered in one domain to data gathered in another), interdisciplinary comparisons (verify and validate findings by using data from another discipline as criteria), plans and their realisation (compare plans and their realisation), prediction (depends on explicit and implicit predictions), expert opinion (either the expert opinion is compared with other data, or the opinions of several experts are compared to ascertain the extent of agreement between them), user acceptance (measures of user acceptability and attitudes), case histories (obtain case histories of actual incidents and accounts of practical experience with the system), standards (standards, guidelines, data in handbooks), human and machine comparisons, errors and failures.
Therefore, once the prototype system has been created, it was to be verified and tested to determine its effectiveness and validate its performance before instigating further development of the overall integration decision support system. The range of verification and testing will include the logic managing sequence and debugging of the computer program. The validation will compare the outcomes with the case study and professional knowledge to confirm its accuracy.
3.4 Summary

In this chapter, the research development processes have been outlined and discussed to justify its feasibility for the research objectives. With the assistance of appropriate research methodology, research objectives can be met by means of phased methods to collate data, analyse, extract, induce/ deduce knowledge, generate guidelines and develop a computer-based prototype decision system. The whole structure of research design and development is illustrated in Figure 3-12:

![Diagram of Research Design and Development]

Figure 3-12: Overview of the Research Design and Development
CHAPTER 4
SURVEY, DATA ANALYSIS AND CASE STUDY

4.1 Introduction
4.2 The Questionnaire Survey
   4.2.1 Total Survey Response
   4.2.2 Composition of Respondents
   4.2.3 BAS Design Questionnaire Response Analysis
      4.2.3.1 The Needs
      4.2.3.2 Products
      4.2.3.3 Design Issues
      4.2.3.4 Assessment
   4.2.4 BAS Maintenance Questionnaire Response Analysis
      4.2.4.1 Overall Status
      4.2.4.2 Management
      4.2.4.3 Technical Issues
      4.2.4.4 Assessment
   4.2.5 Summary of the Survey Results and Suggestions
4.3 Survey Results in relation to Literature Study
4.4 The Case study
   4.4.1 Outline of the Case Study
   4.4.2 Building Automation System in the "Asia Business Centre" Office Building
   4.4.3 Progress of the Design-built, Operation and Maintenance
   4.4.4 Example of Process Integration
   4.4.5 Demonstrated case study in relation to Design and Maintenance
   4.4.6 Lessons from the Case Study
   4.4.7 Findings from the Case Study
4.5 Comparison of the Literatures, Surveys and Case Study
4.6 Summary
   4.6.1 Implication from the Literature, survey and Case Study
   4.6.2 Recommendations, for the Better Design and Maintenance
4.1 Introduction

Chapter 2 discussed some of the facts and factors impacting current office buildings and predicted potential trends for future practice. In order to verify these findings to produce first hand data as the basis of the knowledge bank, this research has adopted questionnaire surveys and case study to identify key design and maintenance (D&M) characteristics of Office Building Automation Systems (BAS).

The questionnaire survey questions encompass two main aspects: BAS design for the designers/ design consultants, and BAS maintenance for the building developers/ owners and facilities managers. Survey questions in the design category consist of four main parts: “The Need”, “The Products”, “Design issues”, and “Assessment”. For maintenance, they include four main subjects of “Overall status”, “Management”, “Technical issues”, and “Assessment” which are outlined as in Figure 4-0.

The raw data for the survey has been collated and analysed and key findings summarized in the following sections. In addition, the case study has been carried out using an office building which has been operating for more than ten years. Its integration examples and discovered limitations during the process have demonstrated a typical situation during the boom of high rise office building construction in Asia in the nineties. This will provide valuable lessons for the assessment of the current status of office building.
4.2 The Questionnaire Survey

This section reports on the data collected from respondents who completed and returned the questionnaires through the mailed survey. Data obtained were then edited and coded accordingly to ensure that it was valid, applicable and easily scored. Not Applicable (N/A) responses or missing values were excluded from the analysis. Only data relevant to the research objectives were tabulated and analysed using SPSS (Version 11.5 and 12.1) and Microsoft word, Excel (2003).

4.2.1 Total Survey Response

This part of analysed results provides a general view of the survey. It includes total survey response rates and the composition of participants.

Table 4-1: Survey Response Rate

<table>
<thead>
<tr>
<th>Type</th>
<th>Sent Out</th>
<th>Return useable</th>
<th>Return Unclaimed</th>
<th>Not Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designers/ design consultants</td>
<td>55</td>
<td>26 (47.3%)</td>
<td>3 (3%)</td>
<td>26 (47%)</td>
</tr>
<tr>
<td>Builders/ Developer/ Facilities managers</td>
<td>50</td>
<td>16 (32%)</td>
<td>2 (2%)</td>
<td>32 (64%)</td>
</tr>
<tr>
<td>Total (%)</td>
<td>105</td>
<td>42 (40%)</td>
<td>5 (5%)</td>
<td>58 (55%)</td>
</tr>
</tbody>
</table>

Figure 4-1: Survey Response Rate

As shown in Table 4-1 and Figure 4-1, 105 questionnaires were sent out through the mail to a relatively equal spread over two different categories of respondent, namely Designers/ design consultants and Builders/Developer/ Facilities managers. Over a period of three months, a total of 47 questionnaires were returned, representing a 45% response rate; 5 questionnaires were marked “unclaimed”, representing 5%; the
useable rate was 40%; meanwhile 58 questionnaires were not returned (55%). The questionnaire response rate and usable response rate can be calculated as the follows:

1) Total Responsive Rate
\[
\text{Total Responsive Rate} = \frac{\text{Total Questionnaires Return}}{\text{Total Questionnaires Sent Out}} \times 100\%
\]
\[
= \frac{47}{105} \times 100\% 
\]
\[
= 45\% 
\]

2) Total Usable Questionnaires
\[
\text{Total Usable Questionnaires} = \text{Total of questionnaires return} - \text{Return unclaimed} 
\]
\[
= 47 - 5 
\]
\[
= 42 
\]

3) Total Usable Response Rate
\[
\text{Total Usable Response Rate} = \frac{\text{Total Usable Questionnaires}}{\text{Total Questionnaires Sent Out}} \times 100\%
\]
\[
= \frac{42}{105} \times 100\% 
\]
\[
= 40\% 
\]

4.2.2 Composition of Respondents

Designers and design consultants had the highest response rate with a total of 47.3% (or 26 responses) out of 55. This is followed by responses from Builders/Developer/Facilities managers with 32% (or 16 responses) out of 50 as in Table 4-1. Unfortunately, non-respondents’ views were unable to be examined. This might infer that they were less interested in the topic, or felt that they could not respond meaningfully nor had association with the BAS. In addition, these non-respondents, unclaimed and not applicable responses, and missing values were removed, using SPSS and MS Excel, the cleaned-up data has been analysed in accordance with the categorised design and maintenance professionals respectively as in the following sections.
4.2.3 BAS Design Questionnaire Response Analysis

In the aspect of BAS design, the questionnaire primarily focused on the four specific subjects as “The Need”, “Products”, “Design issues”, and “Assessment” detailed in Appendix A to verify and extract the design views, practical experience and knowledge from the designers and design consultants. The results of the design professional survey can be analysed with the code system as in Figure 4-2:

Figure 4-2: Outline of the Design Questionnaire Survey
4.2.3.1 The Needs

From results of this survey, the ranking of the importance of office building automation systems (BAS) in relation to the clients, building owners and developers is different. It revealed that the clients and owners of buildings are more interested in BAS than building developers. Generally, the developers were more focused on first costs and sale profits, rather than on the BAS life cycle benefits for the building operation and maintenance as in Table 4-2 (Appendix D: Code DA01).

Table 4-2: Importance of BAS Preference

<table>
<thead>
<tr>
<th>Importance</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clients</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>Building Owners</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Building Developers</td>
<td>4</td>
<td>10</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

The designers can mostly relate to the benefits of BAS in office building and are aware of the BAS responsibilities for building maintenance during the design stage as in Figure 4-3 (Appendix D: Code DA02). The awareness and understanding of benefits and tasks of BAS will create a good design as well as easy maintenance.

Figure 4-3: Benefits and Responsibility of BAS
They believe that the BAS is relevant to the performance and cost of the building, especially in relation to the building life-cycle cost. Their major considerations with BAS during the design stage include four aspects: easy operation/maintenance, meeting regulation, performance of systems and meeting client requirements. Conversely, designers were not very interested in the reliability and price or cost of the system during the design stage is shown in Table 4-3 (Appendix D: Code DA03). These considerations will affect the BAS design quality.

Table 4-3: Major Consideration of BAS Preference

<table>
<thead>
<tr>
<th>Main considerations</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy operation and maintenance</td>
<td>18</td>
<td>27.3</td>
</tr>
<tr>
<td>Meet regulation</td>
<td>14</td>
<td>21.2</td>
</tr>
<tr>
<td>Meet client requirement</td>
<td>14</td>
<td>21.2</td>
</tr>
<tr>
<td>Performance of systems</td>
<td>12</td>
<td>18.2</td>
</tr>
<tr>
<td>Price/cost</td>
<td>6</td>
<td>9.1</td>
</tr>
<tr>
<td>Reliability</td>
<td>2</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>66</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Designers consider BAS highly relevant to the performance of building, especially in association with the life-cycle cost as in Table 4-4 (Appendix D: Code DA04). It implies that BAS design, taking into consideration of the life-cycle cost as well as the performance of building, will contribute to maintenance costs reduction.

Table 4-4: BAS in relation to Building Performance and the Life Cycle Cost

<table>
<thead>
<tr>
<th>BAS</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building performance</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Building life cycle cost</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>16</td>
<td>2</td>
</tr>
</tbody>
</table>

In practice, the designers obtained the requirements and specifications of the BAS product mainly from the product manufacturer. Alternatively, they accessed from the feedback of previous users, client discussions, consultants’ or sub-contractor’s recommendations and statistical information as in Table 4-5 and Figure 4-4 (Appendix D: Code DA05). The BAS specifications should not only rely on the provision of information from the product manufacturers, but also needs refer to other sources to learn and compare the real status of the application to allow for adequate decision making.
The current building regulations and BAS product specifications have had the greatest impact on the BAS design as shown in Figure 4-5 (Appendix D: Code DA06). It implies that updated building regulation and product specification would be needed to assure the quality of design. The sources of the regulation and specification should be abundant and updated.
4.2.3.2 Products

BAS products selection relies on having sufficient information. In practice, the information of BAS products and relevant performance information is readily available and will be provided by the vendors during the design stage. The designers can easily access new or current information in relation to the product pros/cons and applications, however the historical records in practical usages are likely to be insufficient for the designers as shown in Figure 4-6 (Appendix D: Code DB01, DB02). It shows that historical records are not easily kept and updated, and that there is a need for an effective method to collation and storage.

Figure 4-6: Availabilities of the Products, Information and Records
The BAS design is critically affected by several factors including the feedback from previous users, availability of up-to-date information, communication with building owners and the facility managers as shown in Figure 4-7 (Appendix D: Code DB03). From the designer’s responses, it reflects that the BAS design requires effective information including relevant information and feedback, and communication with the practical maintenance personnel to collect information.

According to the responses, it is not compulsorily to request the designers to deliver information or manuals of BAS operation and service to the facility managers or management agency of the building as shown in Figure 4-8 (Appendix D: Code DB04). The provision of the information and service support impacts on the practical maintenance after building delivery, hence it is necessary to build a systematic system or approach to provide support and service.
Moreover, the feedback from the facilities managers in relation to the current status does not become a necessary procedure in the operation and maintenance process as shown in Figure 4-9 (Appendix D: Code DB05), so historical records can not be effectively utilised. Meanwhile, the timely support and service may also not be available and is reflected in the new design and application. Therefore, both sides-design and maintenance would need a strategy to bridge and compensate this shortcoming.

**Figure 4-8: Designer providing Information to the Facilities Manager**

**Figure 4-9: Feedback from the Facilities Manager**

### 4.2.3.3 Design Issues

The building systems such as HVAC, electrical power/ lighting system Fire/ security systems and lifts/escalator are both independent and interrelated. These are more complicated and important than the parking equipment/ parking systems and water
supply/ drainage system in the office building as shown in Table 4-6 (Appendix D: Code DC01). All of the systems need to be adequately designed and maintained to ensure overall building performance and a comfortable environment to meet the occupants’ expectations during the life of the building.

Table 4-6: Importance of the Building Systems (Designer views)

<table>
<thead>
<tr>
<th>Importance</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC/energy management</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Electrical power/ Lighting system</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Fire/ Security systems</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Lifts/ Escalator</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Parking equipment / Parking system</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Water supply/ Drainage</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

The application of the parking equipment /parking systems, water supply/drainage systems are normally more troublesome than the other building systems. However HVAC system presents the more critical problems during the service than the others as shown in Table 4-7 (Appendix D: Code DC02). Problems such as shutdown and malfunction will result in the uncomfortable of occupants and complaints. Therefore, in addition to adequate design, maintenance should be scheduled in conjunction with the execution of the appropriate maintenance strategies.

Table 4-7: Troubles in the Building Systems

<table>
<thead>
<tr>
<th>Troublesome</th>
<th>Critical Trouble</th>
<th>More Trouble</th>
<th>Troublesome</th>
<th>Few Trouble</th>
<th>Trouble Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC/energy management</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Electrical power/ Lighting system</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Fire/ Security systems</td>
<td>1</td>
<td>1</td>
<td>14</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Lifts/ Escalator</td>
<td>1</td>
<td>3</td>
<td>12</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Parking equipment / Parking system</td>
<td>1</td>
<td>3</td>
<td>18</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Water supply/ Drainage</td>
<td>1</td>
<td>5</td>
<td>16</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
The requirement of decision support tools for BAS design has gained a high ranking in the level of necessity as well as in the computer aided design (CAD) utilisation in practice as shown in Figure 4-10 (Appendix D: Code DC03). Hence, the development of decision support tools to compare with what CAD has done to ease design decision making.

The integration between different building systems has several benefits such as increasing their effectiveness, decreasing energy consumption, increasing comfort, etc. In the survey, the HVAC, electrical power/lighting systems, security system, and lifts/escalator have been shown as being more suitable than fire and parking systems for the integration in BAS as shown in Figure 4-11 (Appendix D: Code DC04). It implies that system integration, if adequate and effective, will facilitate energy conservation, security and safety, and comfort. It also relates to the need for adequate coverage of these aspects in design and maintenance practice.
In spite of the variation of the integration requirements, generally, there are several general functionalities such as performance, effectiveness, efficiency, energy conservation, and comfort/health. In this survey, these are as important as the free maintenance or easy management during the integration process in office buildings as shown in Table 4-8 (Appendix D: Code DC05).

Table 4-8: Functionalities of the Integration

<table>
<thead>
<tr>
<th>Functionalities of Integration</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance/ Effectiveness/Efficiency</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Energy conservation</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Comfort/ Healthy</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Free maintenance/ Easy management</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

Among the various types of sensors, the major control applications are temperature, smoke/air and light sensor, the second preference is for humidity sensors, and pressure sensors, as shown in Figure 4-12 (Appendix D: Code DC06). It becomes obvious that the major controls are the HVAC, fire safety and lighting systems for energy conservation, safety and comfort.
The designers and building developers have different concerns about cost and performance. There is little consistency aspects of cost, or technical support in relation to performance as shown in Table 4-9 (Appendix D: Code DC07). Generally, the designers are more focussed on performance and the developers are focussed on the costs.

Table 4-9: Concerns of the Cost and Performance

<table>
<thead>
<tr>
<th>Cost and Performance</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency between designers/developers</td>
<td>2</td>
<td>8</td>
<td>8</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Technical support</td>
<td>2</td>
<td>4</td>
<td>14</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

4.2.3.4 Assessment

Evaluating the BAS design practice, it was found that the requirements of clients are mostly met either in the performance/efficiency after delivery or in the instruction manuals during the delivery stage, as well as the balance of BAS cost between design requirements and client’s budget. However, concerning the availability of evaluation tools, designers are dissatisfied with the current status for assessing the BAS as
shown in Table 4-10 (Appendix D: Code DD01). Thus the applicability of BAS might not effectively reflect the real situation.

Table 4-10: Assessment of the BAS Design

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAS meeting requirement</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Performance/ efficiency</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Instruction/ manual</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Balance of BAS cost between design requirements and client’s budget</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Evaluation tools for BAS</td>
<td>1</td>
<td>3</td>
<td>12</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

The major reasons causing poor BAS performance, include: lack of instruction, inappropriate operation, improper maintenance, and a design deficiency/ shortage. Nonetheless, owing to insufficient historical data, it is physically difficult to assess the situation in relation to unsuitable materials, elements and systems application as shown in Table 4-11: (Appendix D: Code DD02). It implies that historical records are needed for effective assessment and management during the building process. In addition, to sustain high performance in building systems, design is as important as maintenance.

Table 4-11: Reasons of the Poor BAS Performance (Design Views)

<table>
<thead>
<tr>
<th>Reasons of poor performance</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of instruction</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Inappropriate operation</td>
<td>2</td>
<td>3</td>
<td>9</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Improper maintenance</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Design deficiency/ shortage</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Unsuitable material/elements/systems</td>
<td>2</td>
<td>4</td>
<td>16</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The provision of up-to-date instructions on the use of BAS from the vendors or manufactures is not very satisfactory to the designers. They passively provide
maintenance suggestions or guidelines to the facility managers of buildings or provide a consulting service. It reflects that the longitudinal integration between such diverse professionals as designers, products providers and facility managers in building industry is not sufficient to provide support and communication during the operation and maintenance processes as shown in Figure 4-13 (Appendix D: Code DD03). So the process integration across the different phases such as design and maintenance has the potential to facilitate the communication and support which will improve BAS applications.

Adequate operation and maintenance are commonly recognised along with environmentally friendly design as being able to improve energy conservation. In addition to factors such as the selection of the applicable BAS, suitable BAS integration is also crucially in minimising energy consumption as shown in Table 4-12 (Appendix D: Code DD04). Energy conservation is an overall result of the energy saving attempts, and relies on the process integration such as design with maintenance, and system integration such as BAS with building systems to enhance the integral efficiencies.

Table 4-12: Factors Affecting to Energy Conservation

<table>
<thead>
<tr>
<th>Affection to energy conservation</th>
<th>Least</th>
<th>Less</th>
<th>Fair</th>
<th>More</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy conservation design</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Selection of applicable BAS</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>BAS integration</td>
<td>1</td>
<td>3</td>
<td>12</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Adequate operation and maintenance</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 4-13: Communication between Different Parties
The communication between different parties in the building process affects the effectiveness of the building service. In practice, from the survey, it was found that the designers normally meet with the building facility managers during the design and delivery stages, or as problems occur, but rarely provides life-cycle service after building delivery as per Figure 4-14 and Table 4-13 (Appendix D: Code DD05).

![Figure 4-14: Communication between Designer and Facilities Manager](image)

Table 4-13: Communication between Designer and Facilities Manager

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design stage</td>
<td>18 (33%)</td>
</tr>
<tr>
<td>Delivery stage</td>
<td>12 (22%)</td>
</tr>
<tr>
<td>After delivery</td>
<td>6 (11%)</td>
</tr>
<tr>
<td>Problems happening</td>
<td>16 (30%)</td>
</tr>
<tr>
<td>Never</td>
<td>2 (4%)</td>
</tr>
</tbody>
</table>

In this case, the lack of support after building delivery would logically result in asking for support as problem occurs. It also revealed that the demand for an enhancement in communication, not only during the design stage, but also after delivery throughout the whole building process. Primarily, the support and feedback is needed during the operation and maintenance stages to prevent and reduce the failure and damage of systems, and breakdown losses.

Consequently, with respect to the integration of design and maintenance, the enhancement of communication is a critical step. Sufficient communication can help
overcome some of inherent challenges such as fragmented entities, and the life-time duration of the building process. It also can build a bridge between the two, effectively connecting them into one composite team.

4.2.4 BAS Maintenance Questionnaire Response Analysis

The BAS maintenance survey mainly includes four aspects as the “Overall status”, “Management”, “Technical issues”, “Assessment” detailed as Appendix B for the office building maintenance professionals. The results of the maintenance professional survey can be analysed as shown in Figure 4-15:

Figure 4-15: Outline of the Maintenance Questionnaire Survey
4.2.4.1 Overall Status

Building maintainers generally are satisfied with ‘smart/ intelligent’ features of the Building Automation System (BAS) and a comfortable/ healthy work environment, as well as with the BAS maintenance; but are unlikely to be satisfied with the energy conservation required to comply with the occupant’s expectations as per Figure 4-16 and Table 4-14 (Appendix E: Code MA01). It implies that BAS functions can improve the comfort and ease of undertaking the maintenance tasks. However, energy conservation is still a challenge.

![Figure 4-16: BAS Features and Functions](image)

Table 4-14: BAS Features and Functions

<table>
<thead>
<tr>
<th>BAS Function</th>
<th>Dissatisfied</th>
<th>Somewhat Satisfied</th>
<th>Satisfied</th>
<th>Fairly Satisfied</th>
<th>Very Satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Smart/ intelligent' features</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Comfortable/ healthy</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>BAS maintenance</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>
The problems of building systems can be categorised into three classes as electrical, mechanical and control/monitoring problems including individual electrical systems out of order/malfunctioning, individual mechanical systems out of order/malfunctioning, and automatic operation/monitoring systems downtime. The result of surveys associated with the less dissatisfaction with the BAS maintenance as shown in Figure 4-14 might reflect having good maintenance and could also reflect the lack of historical data to reveal the real maintenance situation such as the problems record as shown in Table 4-15 (Appendix E: Code MA01, MA02) which mostly held less problem records.

<table>
<thead>
<tr>
<th>Problems/Troubles</th>
<th>Least</th>
<th>Less</th>
<th>Fairly</th>
<th>More</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical systems</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mechanical systems</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Automatic operation/monitoring systems</td>
<td>4</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

In practice, it has generally been recognised that the reasons for poor BAS performance mainly include inappropriate operation, improper maintenance, lack of instruction, design deficiency/shortage and unsuitable systems, but the last reason would have less affect than the previous four reasons as shown in Table 4-16 (Appendix E: Code MA03). This result is similar with the results from the design view as shown in Table 4-11 (Appendix D: Code DD02). Operation and maintenance (O/M) requires on-going support and service during the building life. In addition to design deficiencies, inappropriate O/M as well as the lack of support primarily affects the BAS performance.

<table>
<thead>
<tr>
<th>Reasons of poor performance</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of instruction</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Inappropriate operation</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Improper maintenance</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Design deficiency/shortage</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Unsuitable material/elements/systems</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
Basically, the building regulations/codes and product specification directly influence the BAS operation and maintenance tasks. In the survey, it is confirmed that these instructions are effective for the O/M process as per Figure 4-17 and Table 4-17 (Appendix E: Code MA04). However, to meet with the increasing expectations of occupants, the O/M of BAS needs more information on current product application, pros/cons, and historical data to work effectively.

![Figure 4-17: Effects of the Building Regulation and Product Specification](image)

Table 4-17: Affects of the Building Regulation and Product Specification

<table>
<thead>
<tr>
<th>Affection</th>
<th>Ineffective</th>
<th>Somewhat Effective</th>
<th>Average</th>
<th>Effective</th>
<th>Very Effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building regulation/ codes</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Product specification</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Additionally, Standard Operation Procedures (SOPs) of O/M are essential. With these, the regular O/M tasks can be executed consistently and effectively. SOPs can be generated as the need arises in accordance with the requirements. In practice, SOPs are mainly designed/ provided by design consultants and maintenance consultants. On the other hand, some of SOPs are prepared by facility managers and design-construction mechanical contractors as shown in Figure 4-18 (Appendix E: Code MA05).
The survey revealed a fact that operation/maintenance SOPs in practice are mostly formulated by designers and maintenance consultants. This causes implications for the effectiveness and performance of building systems relying on support from professionals associated with the design and maintenance in the practical implementation. Especially under the rapidly changing environments and the increasing expectations of clients, the occupants are highly demanding of the building functions and performance as well as energy conservation and comfort, which is shown as per Figure 4-19 and Table 4-18 (Appendix E: Code MA06):

<table>
<thead>
<tr>
<th>Expectations</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility/ Adaptable/ Accessibility</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Friendliness/ Comfort/ Convenience</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Minimisation of energy consumption</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Performance/ Effectiveness/ Responsiveness</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>
The needs and expectations of the occupants will drive the design and maintenance more effectively and bring about highly efficient building services via adequate management.

### 4.2.4.2 Management

Generally, after building delivery, the responsibilities of BAS can be divided into three parts: operation, maintenance and developing/reconfiguring. The BAS operation relies on in-house qualified staff. The maintenance and developing/reconfiguring tasks mostly rely on the contract services, and partly on management professionals as per Figure 4-20 and Table 4-19 (Appendix E: Code MB01).

![Figure 4-20: Responsibilities of BAS O/M Process](image)

**Table 4-19: Responsibilities of BAS O/M Process**

<table>
<thead>
<tr>
<th>Responsibilities</th>
<th>In-house qualified staff</th>
<th>Contract services</th>
<th>Management professional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>12</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Maintenance</td>
<td>2</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Developing/ Reconfiguring</td>
<td>2</td>
<td>9</td>
<td>5</td>
</tr>
</tbody>
</table>

Evaluating current BAS management, the current O/M instruction/manual has been found sufficient. The existing integrated BAS is less adequate for building operation and maintenance, furthermore, the BAS integration strategy is not very supportive of BAS management as shown in Table 4-20 (Appendix E: Code MB02). It implies that the current systems integration is not adequately performing their functions and potential integration benefits.
Table 4-20: Evaluation of the BAS Management

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Not at all</th>
<th>Somewhat So</th>
<th>Fairly</th>
<th>More</th>
<th>Definitely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current instruction/ manual</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Existing integrated BAS</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>BAS integration strategy</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

In the office building maintenance stage, several indicators such as churn rate (number of times employee change work location per year) and maintenance rate are reflected in the maintenance costs. Those are mostly the concern of the building maintainers. Generally, the application of computers in facilities management is not very popular. In addition, the communications between building occupiers and design consultants are relative poor as per Figure 4-21 and Table 4-21 (Appendix E: Code MB03). It appears that the facilities maintenance and management did not get help from the computer application or support from the design consultants.

![Figure 4-21: Maintenance of the BAS](image)

Table 4-21: Maintenance of the BAS

<table>
<thead>
<tr>
<th>Importance</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Churn rate</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Maintenance rates</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Computer applications</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Communications between occupiers/design consultants</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Comparatively, if the building systems integration is adequate, it will facilitate the building performance and energy conservation. Among the building systems, to meet the design requirements and client expectations, the systems suitable for integration
include electrical power/ lighting, security system, lifts/escalator, fire system, and HVAC, there is less need for the parking system to be integrated as shown in Table 4-22 (Appendix E: Code MB04). Additionally, one of the factors in consideration of the system integration is focusing on the simpler operation to provide of ease maintenance. Hence, adequate integration design directly affects maintenance efficiency.

Table 4-22: Integration of the Building Systems

<table>
<thead>
<tr>
<th>System Integration</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical power/ Lighting</td>
<td>14</td>
</tr>
<tr>
<td>Security</td>
<td>12</td>
</tr>
<tr>
<td>Lifts</td>
<td>12</td>
</tr>
<tr>
<td>Fire</td>
<td>12</td>
</tr>
<tr>
<td>HVAC</td>
<td>10</td>
</tr>
<tr>
<td>Parking system</td>
<td>6</td>
</tr>
</tbody>
</table>

The surveys have shown that the building maintainers are mostly concerned with the effectiveness of problem solving procedures for dealing with the complaints of building occupants, and tracking/ solving problems of BAS as per Figure 4-22 and Table 4-23 (Appendix E: Code MB05). It proves that most occupant complaints are due to discomfort, which can be the caused by ineffective problem solving, tracking and dealing with complaints. Thus, customer orientation is important as well as sustainable maintenance.

Table 4-22: Problem Solving of the BAS

<table>
<thead>
<tr>
<th>Problem Solving</th>
<th>Least</th>
<th>Less</th>
<th>Fairly</th>
<th>More</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving procedures</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Dealing complaints</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Tracking solving problems</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>
The building maintainers have obtained the applicable instructions from the designers, vendors or manufactures, as well as feedback of the problems/complaints from building occupants as well. Conversely they did not relatively deliver problems in relation to BAS operation and maintenance to the designers as in Table 4-24 (Appendix E: Code MB06).

Table 4-24: Communication between Design and O/M

<table>
<thead>
<tr>
<th>Communication</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deliver problems to designers</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Applicable instruction</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Problems/complaints feedback from occupants</td>
<td>13</td>
<td>3</td>
</tr>
</tbody>
</table>

These facts imply that the maintainers did not expect to gain support from the designers, either because of the lack of communication or good relationships between them. Hence, the close communication between design and maintenance is necessary.
4.2.4.3 Technical Issues

In practice, office buildings occupants biggest concerns are the fan coil units equipped with individual controllers and humidity control in their space. Especially, they regard energy conservation as a critical consideration in relation to HVAC operation as shown in Figure 4-23 and Table 4-25 (Appendix E: Code MC01). The expectation of comfort is also important for the occupants. It is important at the same time to reduce energy consumption. Accordingly, the design and maintenance needs to balance and optimise the both expectations.

![Figure 4-23: Importance of the HVAC Controls](image)

Table 4-25: Importance of the HVAC Controls

<table>
<thead>
<tr>
<th>Importance</th>
<th>Least</th>
<th>Less</th>
<th>Fairly</th>
<th>More</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan coil control</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Humidity Control</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

Most occupants of the office buildings are concerned about inadequate temperature/humidity control, lack of individual control and air quality, likewise the noise from HVAC system has not been a worry as per Figure 4-24 and Table 4-26 (Appendix E: Code MC02). It implies that the occupants expect to be able to control the working environment of their own occupied space to increase the comfort, and do not expect to have acoustic noise complaints.
With respect to the security and fire system, an overall security system is generally required and installed with a secure separate power supply for office buildings. In addition, the security system interface is also needed to integrate with the fire systems and building management systems. For instance they are all closed doors, automatically released in case of a fire alarm and outfitted the direct CCTV cameras as shown in Table 4-27 (Appendix E: Code MC03). This is a typical system integration, which integrates the security systems with fire systems to accomplish an automatic response and action.

Table 4-27: Integration Preference of the Security System

<table>
<thead>
<tr>
<th>Integration Preference</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Security system with separate power supply</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Security system interfaced with the fire systems</td>
<td>12</td>
<td>4</td>
</tr>
</tbody>
</table>
On the other hand, office buildings are normally accessed by using smart cards, key codes or manual ID cards and have CCTV presence detectors in the security systems as in Table 4-28 (Appendix E: Code MC04). Currently, this type of security system has been commonly applied to the office building. It will continue to be developed along with the advanced ICT technologies to enhance the security and ease the access management.

Table 4-28: Access Management of Office Building

<table>
<thead>
<tr>
<th>Utilities</th>
<th>Least</th>
<th>Less</th>
<th>Fairly</th>
<th>More</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access control smart cards/key code/ ID cards</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>CCTV presence detectors and archiving</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

The various sensor controls which are key elements of BAS, such as smoke and temperature sensors are more common in office building applications, which is similar with the designer’s views as in Figure 4-12. Other sensors as humidity, pressure, air and light sensors which are also equipped to increase the occupant’s comfort and decrease energy consumption. The preference of the sensor controls is shown as in Table 4-29 (Appendix E: Code MC05).

Table 4-29: Preference of the Sensor Controls

<table>
<thead>
<tr>
<th>Sensor Types</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>14</td>
</tr>
<tr>
<td>Smoke</td>
<td>10</td>
</tr>
<tr>
<td>Humidity</td>
<td>6</td>
</tr>
<tr>
<td>Pressure</td>
<td>6</td>
</tr>
<tr>
<td>Air</td>
<td>4</td>
</tr>
<tr>
<td>Light</td>
<td>3</td>
</tr>
</tbody>
</table>
4.2.4.4 Assessment

From the survey, the building maintainers are mostly satisfied with the support of new or up-to-date information, sufficient instruction/ manuals for BAS operation and maintenance, and historic records of BAS operations as well. The current maintenance support is shown as in Table 4-30 (Appendix E: Code MD01). It indicates that the support of maintenance is important as well as the historic records which rely on the maintainer and is gathered by computerised aids.

Table 4-30: Satisfaction of the Maintenance Support

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Insufficient</th>
<th>Somewhat Sufficient</th>
<th>Average</th>
<th>Sufficient</th>
<th>Very Sufficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information of maintenance</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Instruction/ manual</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Historic records</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

The maintainers are basically concerned with those factors which minimise energy consumption including the energy conservation design in BAS, applicable BAS, applicable BAS integration and adequate operation/ maintenance as shown in Table 4-31 (Appendix E: Code MD02), This is similar to the designer views as shown in Table 4-12. This indicates that the design and maintenance have the same consensus and responsibilities to achieve energy conservation.

Table 4-31: Factors Affecting to Energy Conservation

<table>
<thead>
<tr>
<th>Affection to energy conservation</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy conservation design</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Selection of applicable BAS</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>BAS integration</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Adequate operation and maintenance</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>
In practice, the evaluation of BAS is carried out over different durations categorised as monthly, seasonally, half-yearly, and yearly periods. Normally, it is often done by monthly or yearly as shown in Figure 4-25 (Appendix E: Code MD03). These periods are considered the necessary inspection and maintenance routines in order to sustain the functions of facilities. Normally, the evaluation of BAS should be scheduled to become the regular tasks.

![Figure 4-25: Preference of the Maintenance Duration](image)

The BAS evaluation is exclusively the responsibility of the facility manager, or alternatively by the design consultants as shown in Figure 4-26 (Appendix E: Code MD04). The BAS evaluation is the responsibility of the maintenance staff as well as the designers across the whole building process.

![Figure 4-26: Responsibility of the BAS Evaluation](image)

From the facility managers’ point of view, the building systems as HVAC/energy management systems, electrical power/ lighting systems, fire/ security systems, and lifts/escalator are more important than the parking equipment /parking systems and
water supply/drainage systems as shown in Table 4-32 (Appendix E: Code MD05). This is similar to the designer views as shown in Table 4-6. The results indicate that the awareness and understanding of the importance of the building systems can result in an integrated solution.

Table 4-32: Importance of the Building Systems (Maintenance views)

<table>
<thead>
<tr>
<th>Importance from maintenance view</th>
<th>Low</th>
<th>Below Average</th>
<th>Average</th>
<th>Above Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC/energy management</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Electrical power/ Lighting system</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Fire/ Security systems</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Lifts/ Escalator</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Parking equipment /Parking system</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Water supply/ Drainage</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

The maintainers consider that the following factors are very significant to the BAS application in the office building, such as applicable BAS which meet the requirement of clients, the performance/efficiency of BAS after delivery, the balance of BAS costs between the design requirements and the client’s budget, availability of the evaluation tools for BAS as shown in Table 4-33 (Appendix E: Code MD06). This is similar to the designer views as shown in Table 4-10.

Table 4-33: Assessment of the BAS Application

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Least</th>
<th>Less</th>
<th>Fairly</th>
<th>More</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAS meeting requirement</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Performance/efficiency</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Balance of BAS cost between design requirements and client’s budget</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Evaluation tools for BAS</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>
The Maintainers of the office building only closely communicated with designers during the design and delivery stages where problem occurred. However, they rarely kept contact with each other after delivery for support in the practical operation and maintenance as shown in Figure 4-27 (Appendix E: Code MD07). This is similar to the designer views as shown in Table 4-14.

![Figure 4-27: Supports between Design and Maintenance](image)

The lack of communication after building delivery is quite similar to the response from designers. The lack of support for design and maintenance are apparently caused by the lack of a systematic mechanism. The results intrinsically reflected that the design and maintenance professionals did not maintain a close communication for most periods of building life, only in the initial building stage. As a result, historical data and information in relation to practical BAS performance and application was not available. Generally the situation is that building industry is still staying close to the product manufacturing position, focusing more on the building production, instead of the customer orientation and life cycle considerations for facilitating BAS performance improvement and energy conservation.
4.2.5 Summary of the Survey Results and Suggestions

Summarising the survey results in the design and maintenance aspects, four aspects of findings can be outlined as the following:

- Industry status and awareness of the office building automation:
  - Lack of support after delivery
  - Demand relative communication and support
  - Feedback is insufficient

- Design and maintenance limitations:
  - Rare support from designers after building delivery except as the problems occurrence
  - Lack of the historical data and records
  - Expectations in energy conservation and comfort are still a challenge

- The needs of the guidelines and decision support tools:
  - Up-to-date instructions and guidelines are needed
  - Lack of the evaluation tools and computerised decision support tools
  - High response rates in asking support as problems occur

- Integration approach:
  - Integration approach is needed
  - System integration can help minimise the energy consumption
  - Process integration across the diverse professionals can gain help
From the open-ended question of the questionnaire survey, the design and maintenance professionals also provide their practical experience and suggestions in the facilitation of design/ maintenance relationships and efficiency improvement as the follows:

- **Industry status and awareness in office building automation:**
  - Thorough understanding of the system to be adapted (including documented feedback from other users).
  - BAS is an ongoing Operation expense and Capital expense (OPEX/CAPEX) balance, and where the building developers are going to on-sell quickly they are typically much more interested in reduced CAPEX than OPEX, therefore less inclined to install expensive BAS. The probable exception is A grade/ premium office space.
  - Make it cheaper. Developers look at cost and what they have done before, don’t want to change.

- **Design and maintenance limitations:**
  - Use clever sub-consultants.
  - By having simple robust systems- reliability and minimum needs for maintenance and avoiding total reliance on BAS, it must also be equipped with good back-up systems.

- **The needs of the guidelines and decision support tools:**
  - Develop designs with the use of all tools available and latest information.
  - Comprehensive maintenance manuals together with formal instruction from supplier would need to be provided for building managers/facilitators.
  - Good service is needed.
  - Needs more available post-occupancy data and benchmark data.

- **Integration approach:**
  - Direct contracts between building owners and BAS contractors.
  - Building owners need to have their maintenance staff attending during the design stage of their developments.
  - Close liaison among builders/ designers/ suppliers/ client is essential.
4.3 Survey Results in relation to Literature Study

In conclusion, the induction from this industry professional questionnaire survey, the results have verified the findings of the literature studies. Their comparison can be illustrated in four aspects as in Table 4-34:

- Industry status and awareness of the office building automation
- Design and maintenance limitations
- The needs of the guidelines and decision support tool
- Integration approach

Table 4-34: Comparison of the Induced Survey Results with Literature Findings

<table>
<thead>
<tr>
<th>Relevant subjects</th>
<th>Literature findings</th>
<th>Induced survey results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry status and awareness of the office building automation</td>
<td>◇ Building designers and maintainers are working independently with less communication and support during the building life. ◇ In life cycle cost considerations, collaboration between design and maintenance can help to improve the relationship.</td>
<td>◇ Lack of support after delivery ◇ Demand of enhancing the communication and support ◇ High response rates in asking for support as problems occur ◇ Feedback is insufficient</td>
</tr>
<tr>
<td>Design and maintenance limitations</td>
<td>◇ Designers should extend their service for minimizing future maintenance ◇ The maintenance manager is able to assist the designer with providing building maintenance experience</td>
<td>◇ Rare support from designers after building delivery excepting problems occurrence ◇ Lack of the historical data and records ◇ Satisfaction of the expectation in energy conservation and comfort are still a challenge</td>
</tr>
<tr>
<td>The needs of the guidelines and decision support tool</td>
<td>◇ The design should consider maintenance and operation by providing applicable specifications and instructions during early design stage.</td>
<td>◇ Up-to-date instructions and guidelines are needed ◇ Lack of the evaluation tools and computerised decision support tools</td>
</tr>
<tr>
<td>Integration approach</td>
<td>◇ Process integration between different parties can help to increase the effectiveness and efficiency; it would be a potential approach.</td>
<td>◇ System integration can help minimise the energy consumption ◇ Process integration across the diverse professionals can gain help</td>
</tr>
</tbody>
</table>
From the above comparisons, the industry professional surveys have verified the limitation and problems of the office building automation applications. These results are more valuable and can be further utilised for knowledge extraction, and demonstrates the potential integration approach, which should be explored and developed. All of these findings and results imply that the professional surveys could extend and expand their survey scopes for more advanced investigation. Even so, the above efforts still need a real case to demonstrate the key subjects in the context of design and maintenance. Thus, the following section will introduce and present a case study for in depth verification.
4.4 The Case study

Findings and results of the literature reviews and professional survey revealed that the building automation systems (BAS) has been popularly employed in office buildings as a major element. However, for the numerous high rise office buildings, does BAS realise the effective operation and performance? To really understanding the ramification, it needs to be done by reviewing a real case. This section will present a detailed case study analysis based on practical activities of the integration between design and maintenance.

A real office building case has been selected in accordance with the needs of research and information provided. That is the “Asia Business Centre” office building which is located in Kaohsiung, southern part of Taiwan R.O.C. It has presented a real practical example of the integrated building design and maintenance, and provided a comparison to verify the situation of building automation in a high-rise office building.

This case study could be used as a model of the conceptual design studies for other tall building projects, in which the process integration is given importance during the preliminary stages of design and the post-occupant concerns. Such early emphasis on whole building integration in the design and maintenance process could lead to the efficient design solutions and avoid expensive design modifications at a later stage. Especially, it can be utilised to assure and enhance the performance of building systems in the maintenance process.

4.4.1 Outline of the Case Study

The “Asia Business Center” is a modern high rise office building equipped with sophisticated infrastructure and a central distributed HVAC system, electrical power and lighting systems, and security/fire systems etc. It has been run for ten years with the high occupancy that was typical of the market. The office building profile and features are illustrated and shown as in Table 4-35 (Appendix C):
Table 4-35: Profile of the ‘Asia Business Centre’ Office Building
(Courtesy: the Great Country Construction Group)

<table>
<thead>
<tr>
<th>Category</th>
<th>Building Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Kaohsiung, Taiwan ROC</td>
</tr>
<tr>
<td>Floors</td>
<td>Above ground: 28 (Basement levels: 4)</td>
</tr>
<tr>
<td>Structure</td>
<td>SRC (partly SRC, RC)</td>
</tr>
<tr>
<td>Gross floor area</td>
<td>45,408m² (488,768sq.ft.)</td>
</tr>
<tr>
<td>Gross lettable area</td>
<td>34,056m² (366,576sq.ft.)</td>
</tr>
<tr>
<td>Parking spaces</td>
<td>169 (partly mechanical)</td>
</tr>
<tr>
<td>Elevators</td>
<td>5 passenger units; 1 emergency unit</td>
</tr>
<tr>
<td>Completion Date</td>
<td>July 1994</td>
</tr>
<tr>
<td>Lettable area per floor (standard floors)</td>
<td>1,419m² (15,274sq.ft.)</td>
</tr>
<tr>
<td>Ceiling height (standard floors)</td>
<td>3.60m</td>
</tr>
<tr>
<td>Under floor PVD Box</td>
<td>3 way under floor duct system</td>
</tr>
<tr>
<td>HVAC system</td>
<td>Interior: Floor-by-floor A/C; Perimeter: Air-cooled packaged A/C</td>
</tr>
</tbody>
</table>
Office utilisation and main tenants: This office building primarily provides office space. The main tenants encompass a variety of companies such as:

- Life insurance companies,
- Trading companies,
- International companies,
- Shipping cooperations,
- Engineering and construction companies,
- Property and real estate companies,
- Musical instrument companies,
- Interior decoration and furniture companies,
- Information technology companies and ISP,
- Marketing and advertising companies,
- Financial companies (bank, credit card service, consultants),
- Stock exchange companies,
- Seven-Eleven market, etc.

Independent management institution for the maintenance:

Before the building delivery, the developer, the Great Country Construction Group, instituted and set up an independent building management corporation to train staff for further management of the building and to carry out the commissioning tasks for quality assurance and warranty service after delivery. At the delivery stage, this helped the building owners in organising the future building management committee. At the same time, it initiated a contract with this committee to carry out the building management and maintenance works, and to provide building and hospitality services. The purpose of the authorised institution is mainly:

- to integrate the design-build and maintenance process during the design-construction-management stage,
- to coordinate and communicate the technical tasks between designer, facilities constructors and providers after building delivery,
- to manage the future maintenance tasks for the building life, and
- to train the management personnel and to plan and write up the standard operation procedures (SOP) for the building operation and maintenance from end of construction to O/M duration.
4.4.2 Building Automation System in the “Asia Business Centre” Office Building

The “Asia Business Centre” is representative office building during the boom of building automation in Asia region, and was designed and built from 1989 to 1994, equipped with building automation systems so-called 5A- Building Automations and building systems, features of which are illustrated in the following Table 4-36 (Appendix C):

Table 4-36: Features of the “Asia Business Centre” 5A-Building Automations

<table>
<thead>
<tr>
<th>Types</th>
<th>Features</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical power system</td>
<td>o Electrical power automatic control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Back up generator start testing regularly, operation monitoring and automatic recording</td>
<td></td>
</tr>
<tr>
<td>HVAC</td>
<td>o On/off sequence automatic control of cooling tower, chillers, and pump</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Optimised on/off duration control of chillers and coolers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o AC utilisation automatic counting of payment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Ventilation intake/ outtake regular O/F and energy saving operation control of the roof and parking area</td>
<td></td>
</tr>
<tr>
<td>Lighting system</td>
<td>o Regular O/F and energy saving operation and control in public zone lighting circuit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Lighting system regular control in the envelope of building, parking area and landscaping garden</td>
<td></td>
</tr>
<tr>
<td>Water/drainage system</td>
<td>o Water capacity monitoring and alerting of the water reservoirs and tank</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Water capacity monitoring and alerting of the waste water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Monitoring on the operation of pumps</td>
<td></td>
</tr>
<tr>
<td>Escalator equipment</td>
<td>o Regular O/F control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Emergency automatic control and treatment</td>
<td></td>
</tr>
<tr>
<td>Parking management</td>
<td>o Monitoring and control of parking</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Door security and automatic control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Traffic light automatic control</td>
<td></td>
</tr>
<tr>
<td>Fire system</td>
<td>o Fire alarm and monitoring</td>
<td></td>
</tr>
<tr>
<td>Building management</td>
<td>o Computerised integrated management system</td>
<td></td>
</tr>
</tbody>
</table>
Table 4-36: Features of the 'Asia Business Centre' ( Continued )

<table>
<thead>
<tr>
<th>Types</th>
<th>Features</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office Automation (OA)</td>
<td>〇 Security management system</td>
<td>〇 Door card security control</td>
</tr>
<tr>
<td></td>
<td>〇 Data network service system</td>
<td>〇 Pre-allocation space</td>
</tr>
<tr>
<td></td>
<td>〇 Mail management system</td>
<td>〇 Mailing automatic alerting</td>
</tr>
<tr>
<td></td>
<td>〇 Pre-allocation OA underfloor duct box</td>
<td>〇 Power, voice and data (PVD) box</td>
</tr>
<tr>
<td>Communication Automation (CA)</td>
<td>〇 Pre-allocation fibre communication channel</td>
<td>〇 the satellite communication receiving channel</td>
</tr>
<tr>
<td></td>
<td>〇 Pre-allocation information intelligence process data network</td>
<td>〇 Pre-allocation space</td>
</tr>
<tr>
<td></td>
<td>〇 Pre-allocation Telecommunication AV equipment zone</td>
<td>〇 Pre-allocation space</td>
</tr>
<tr>
<td>Security Automation (SA)</td>
<td>〇 Door management system</td>
<td>〇 Door card/ password</td>
</tr>
<tr>
<td></td>
<td>〇 CCTV monitoring system</td>
<td>〇 Installing in the public outlets and parking area</td>
</tr>
<tr>
<td></td>
<td>〇 Emergency broadcasting system</td>
<td>〇 Linking with fire and security systems</td>
</tr>
<tr>
<td></td>
<td>〇 Fire and Security protection system</td>
<td>〇 Automatic alarm system</td>
</tr>
<tr>
<td></td>
<td>〇 Mechanical monitoring system</td>
<td>〇 Fire alerting and extinguisher monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>〇 Intake air and smoke discharge regular start testing</td>
</tr>
<tr>
<td>Management Automation (MA)</td>
<td>〇 Computer control mechanical maintenance</td>
<td>〇 Fire system maintenance listing</td>
</tr>
<tr>
<td></td>
<td>〇 Computer control BAS maintenance</td>
<td>〇 Generator maintenance listing</td>
</tr>
<tr>
<td></td>
<td>〇 Computer control printing report such as cleaning and maintenance listing</td>
<td>〇 Escalator maintenance listing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>〇 Cooling tower cleaning listing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>〇 Water/ drainage pumps maintenance listing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>〇 Drinking water cleaning and filtering, and Water reservoir tank cleaning listing</td>
</tr>
<tr>
<td></td>
<td>〇 Computer management personnel information</td>
<td>〇 New staff and off staff door card password management</td>
</tr>
<tr>
<td></td>
<td>〇 Computer listing service payments and receipts</td>
<td>〇 Patrol monitoring</td>
</tr>
<tr>
<td></td>
<td>〇 Visiting I/O management</td>
<td>〇 AC expenditure and water/ electrical expenditure listing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>〇 Personnel visiting management</td>
</tr>
</tbody>
</table>
4.4.3 Practice of the Design-build, Operation and Maintenance

From 1989 to 1994, and 1998 to 2002, the author has experienced the complete progress of “Asia Business Centre” building development from the building design-build to the operation and maintenance process. The building was designed and built, and then it was managed and maintained after delivery by a building management company which was set up by the developer’s group as a sub-company.

The “Asia Business centre” office building project was designed and planned from the Spring of 1989. Construction started at the end of 1989, and was completed in July 1994, and the building was handed over to the various building owners. Among the four years the project there were numerous detailed design modifications until the end of the construction.

Facts pertaining the design and maintenance in this project can be summarised as follows:

◊ Requirements and specification designated: Since the building units of the project have been sold at the outset of the design stage, the construction had to be built in accordance with the contracts between developer and clients to meet the initial commitments and building specifications. The design was according to the best specification of products in that period which was likely popular by the clients, thus the sale rate of the building was 100% sold within the three months.

◊ Unpredictable change: however, the final delivery rate of the building units was decreased to 80%, as some clients’ retracted and there was an economic downturn. The other reason was the market for office space market also declined during that period.

◊ Quality control and management: during the construction period, the developer incorporated with the sub-constructor who constructed the building. Product quality control and management was carried out in accordance with the ISO 9000, step by step for each stage of the construction and system installation stage.
Building commissioning: with respect to the operation and maintenance (O/M), the office building was running and managed by the building management company set up by the developer from the Spring of 1993 which was running and pre-delivering the major facilities such as BAS, HVAC, Parking system, … etc,. The in-advance delivery and participative progress did help the further management of the building and made it possible to train the maintenance personnel.

Customer-orientation: the building was running and providing a variety of services. The services was likely compliance with the designated functions and the client expectations.

BAS benefits: the hospitality service and building system management did benefit from the BAS application.

Relationships: there were close relationships between designers and maintainers, building systems sub-contractors.

As a result, the management of the building in the initial occupied stage was very successful. The “Asia Business Centre” office building has a good reputation in the southern part of Taiwan. However, along with the rapid growth of business activities, as the occupancy of the units was increasing, the designated facilities were becoming inadequate to cope with the expectation of the occupants and exposed several deficiencies after the delivery. The situation has verified, but it is difficult to predict likely the future change and demand to meet the client’s expectation.

Nonetheless, the process of integration between building design and maintenance in this office building project was successful and is ideal to use as an integration example.
4.4.4 Example of Process Integration

This section will outline the features of integration in the case “the Asia Business Centre” office building including process integration and building system integration.

This case has practiced process integration between design and construction, then design and maintenance. It has resulted in a great effectiveness and good performance during the construction period, and the latter operation and maintenance process as:

**In the design stage:** the developer has close discussions with the designers and subcontractors to embed the future management and maintenance considerations into the design specifications and construction requirements.

**During the construction process:** the project team continued to review the building design including drawing and system specifications and to monitor the practical construction progress to find out potential or possible problems in the operation of building, and to optimise the detailed design. In the mean time the detailed design had also taken into account the subsystems compromising the building structure and facilities.

**Hand-over and after delivery:** in addition to the technical information and the building construction drawings, the developer produced a hand-over book to demonstrate the features and functionalities of building, and related services and supports such as the emergency contacts and the design and maintenance professional details, and key O/M operation and maintenance manual. After delivery, the building units were managed and maintained by the authorised management corporation to carry out maintenance tasks and provide hospitality service to support business activities including public functional utilities, gym equipment, entertainment, business club, post, business service centre, etc.

Consequently, the building has shaped and sustained a good work environment and effective building performance with which the building owners and occupants are
happy, since it has created several benefits such as high rental rates compared to the other similar office buildings.

The successful process integration of this project presents a good experience, instruction and guidance for the study. Additionally, the building also has several systems integration, for instance:

◊ The building facilities include mechanical, electrical, plumbing, fire protection and environmental systems.

◊ There was lighting control integrated with BAS, and BAS with the electronic variable air volume boxes, which provides the calculations of energy use for the chiller plant to facilitate the energy conservation.

◊ The information associated with a variety of operation and control systems, such as HVAC, electrical power systems, lighting systems, security systems, parking management systems, water drainage systems, which automatically report to the central building management system and interface with the fire safety system.

◊ Additionally, all major electrical and utility systems, as well as the back-up power supply, were designed to be monitored and metered.

◊ Although within the building it was possible to tie in the security network as well, the engineers chose to maintain it as a separate system.

In this case, the design template allows for even greater integration in the future as required. This case can be viewed as a model of the current trends in design for integrating automated systems and potential for process integration between design and maintenance.
4.4.5 Example of Design and Maintenance Interface

Reviewing the design and maintenance subjects in this case, several findings can be used to verify the literature study and industry survey for advanced knowledge extraction. Those findings were outlined and categorised into three aspects:

1. Responsibility distinction:

   Designer:
   - Provide specification for the selection of BAS equipments and systems
   - Guidelines and checklists of installation, operations and maintenance
   - Construction and installation monitoring and auditing
   - Commissioning
   - Operation and maintenance instruction
   - Preparations of the technical information and relevant guidelines
   - Technical supporting to maintainers

   Maintainer: facilities manager
   - Commissioning
   - Standard operation procedures (SOP) preparation and implementation
   - Checklists preparation and implementation
   - Feedback the operation/maintenance status, and problems
   - Consulting/meeting with designer

2. Implications of integration between design and maintenance:

   - Infrastructure: designer should take into consideration the public telecommunication infrastructure of the building site: broadband, fibre, and integrated with the development of the city urban project.
   - Intercom and information communication technology (ICT) equipment and systems installation space has to consider the future expansion.
   - Elevator installation, replacement and retrofit have to comply with the capacity of the building.
   - The layout/installation/maintenance of cooling tower and ventilation space should consider the requirements of easy cleaning and maintenance.
   - Backup generator installation space: consideration their easy installation, disassembly and maintenance
Fire and ventilation integration: smoke detector, fresh air regulator/damper and shut off should be appropriate.

Elevator operation time control and scheduling, stop and return design need to be optimized.

Elevator layout and capacity consideration and prediction for occupied growth.

Security management utilizing the door card and sensor are helpful for easy operation and maintenance.

Automatic sensor control in lighting system is advantageous for energy saving during the non-business hours.

Occupant interior/workspace design and intercom and telex-communication equipment/system installation management need to be considered during the design stage.

3. Limitations:

In this case, as there were no heating applications in HVAC, it therefore could not provide information on heating subjects.

Design: it was difficult to predict the future needs and changes in practice. For instance, escalator design did not meet the occupied growth which has caused crowds of people waiting for the lifts during the peak business time. BAS for the optimisation of lift stops has encountered a challenge to meet the occupant’s expectation.

Building system design specification was not easy to comply with the infrastructure of the building environment. For instance, the World Wide Web (WWW) has led to wide diffusion and application in recent years. It blocks the original closed BAS control and monitoring systems. It also affects the maintenance effectiveness.

Building internal ICT infrastructure could not comply with the occupant’s needs for the various business parities. For instance, stock exchange company uses a huge number communication channels which has challenged with the original design maximum of ICT infrastructure. It also has caused the difficulties in maintenance.
4.4.6 Lessons Learned

The case study has provided an actual case of the process integration activities in the design, construction and management to show how the work can be done through the integration mechanism and early comprehensive considerations and interaction as following:

- Maintainers participating in the building design stage as early as possible.
- Equipping with an applicable assessment and decision support tool to assist the regular operation and maintenance.
- Keeping historic records for the building management.
- Establishing a program for good relationships between design and maintenance including feedback and support mechanisms.
- Implementing the building commissioning.
- Renovating and improving the building systems to keep pace with the advanced technologies and the regulations.

The optimal management of office building relies on the close relationship between design and maintenance, thus the maintenance should integrate with design taking the responsibility of understanding the designated specifications and be able to perform the functionalities and capabilities of the building systems.

The trend of new technology innovation has emerged, but if the infrastructure on site can not cope with the ICT growth, the BAS design should be able to provide the allocation space or to retain the ducts for future installation and expansion. For example, in this case there was a pre-allocation of space for the communication and satellite system installation to allow for flexibilities and expansion.

The success of the office building management relies on the cooperation between design and maintenance, comprehensive planning and the facilities maintainers early participation during the design stage. These are critical key factors for the implementation of integration activities. Continuing development and renovation will be necessary for the building life time. Assessment and decision support tools are also needed for the building design and management including operation and maintenance.
4.4.7 Findings from the Case Study

Based on the efforts from BAS advanced development and neo-ICT tools, the office building performance could be further promoted through the process integration between traditionally fragmented sectors such as design and maintenance, which have respectively unique features. To support a working environment that includes fully integrated designs, lean construction, interoperability, sustainable infrastructure, coordinated construction and optimised operation and maintenance of facilities should be the essential theme for future activities in the building industry. Achieving these goals will require a series of attempts and explorations, especially focusing on the building process integration by means of the development of integrated decision support for knowledge incorporated applications to reduce the gaps. In addition, the interoperable strategies and guidance for the middle and high level decision making would also be necessary during the building life.

The integration adventure in this case study has scoped the following aspects:

◊ Integration between design and maintenance

◊ BAS design and maintenance decision making strategies

◊ BAS quality management and commissioning guidance

◊ Decision support application

The discussion of the above case study has provided a valuable view of the process integration between design, construction and maintenance to ensure that the relevant tasks can be implemented as was the design intention for the life of the building. Furthermore, the building developer could apply contract tools to undertake process quality control, commissioning and warranty service after delivery to ensure the quality of the building systems. In brief, the case study is a demonstrated example of the process integration between design and maintenance of office building automation.
### 4.5 Expanded Comparison of the Literatures, Surveys and Case study

Table 4-37: Expanded Comparison of Literature Study, Surveys and Case Study

<table>
<thead>
<tr>
<th>Relevant subjects</th>
<th>Literature Findings</th>
<th>Induced Survey Results</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry status and awareness of office building automation</td>
<td>◊ Building designers and maintainers are working independently with less communication and support during the building life. ◊ In life cycle cost consideration, collaboration between design and maintenance can help to improve the relationship.</td>
<td>◊ Lack of support after delivery ◊ Demand of enhancing the communication and support ◊ High response rate in asking support as problems occurrence ◊ Feedback is insufficient</td>
<td>◊ The evidence of integration mechanism provides a good experience for process integration. ◊ The benefits of integration also have been proved. Feedback and support are sufficient during the process.</td>
</tr>
<tr>
<td>Design and maintenance limitations</td>
<td>◊ Designers should extend their service for minimizing future maintenance ◊ The maintenance manager is able to assist the designer with providing building maintenance experience</td>
<td>◊ Rare support from designers after building delivery except when problems occur ◊ Lack of historical data and records ◊ Satisfaction of the expectations of energy conservation and comfort are still a challenge</td>
<td>◊ Support from the designers does not end after delivery, especially during the warranty period. ◊ Historical data has been recorded by means of the computerised management system. ◊ Satisfaction by the occupants was supported by the hospitality service program and maintenance management.</td>
</tr>
<tr>
<td>The needs of the guidelines and decision support tools</td>
<td>◊ The design should consider maintenance and operation by providing applicable specifications and instructions during early design stage.</td>
<td>◊ Up-to-date instruction and guidelines are needed ◊ Lack of evaluation tools and computerised decision support tools</td>
<td>◊ Intimate relationships between designers and developer and occupants are the major factors of success.</td>
</tr>
<tr>
<td>Integration approach</td>
<td>◊ Process integration between different parties can help to increase the effectiveness and efficiency; it would be a potential approach.</td>
<td>◊ System integration can help increase the building performance and minimise energy consumption. ◊ Process integration across the diverse professionals can gain help.</td>
<td>◊ Applicable system integration and building process integration can help energy conservation and maintenance staff.</td>
</tr>
</tbody>
</table>
Several findings in Table 4-37 have been disclosed from the literature reviews and confirmed with the results of industry survey in this research. These specific issues are also verified by the case study as in Figure 4-28. In brief, these include:

◊ the necessity of raising awareness and understanding of the importance of process integration between design and maintenance,

◊ the needs of applicable guidance and operational supports in practice in the office building automation context.

Figure: 4-28 Outlines of the Research Process
4.6 Summary

4.6.1 Implication from the Literature, survey and Case Study

The building occupant’s expectations for energy conservation and comfort are still a challenge, as well as the requirements of the building performance. BAS is the brain of the office building, and plays a key role in these critical issues. In addition to the system integration of BAS, the process integration across different phases has shown potential feasibilities to improve these issues. In the research context, there is a need to develop an approach for improvement during the BAS design and maintenance process.

4.6.2 Recommendations for the Better Design and Maintenance

Subsequently, this survey and case study have presented a number of valuable facts of the practice and validation of the literature study. They also suggest that in addition to the horizontal integration between different building services as HVAC, power/ lighting system, fire/ security system, etc., the vertical integration of process and support between diverse professionals such as design and maintenance would be a potential approach in the building automation in an attempt to optimise the performance of buildings and minimizing energy consumption.

It also has complied with the trend of development and research in the BAS field, especially while technologies has been promoted and provided various support tools for building design and maintenance services.

To reach better design and maintenance, several recommendations to enhance the effectiveness and efficiencies of design and maintenance in the office building automation are summarised as the follows:

- Balance the building initial costs with the developer’s budgets during the design stage for the life cycle building costs.
- Early cooperation and direct relationship/ close liaison during the BAS design stage, especially focusing on the long term communication between design and maintenance.
- Provide the adequate tools for decision making during the design and
maintenance periods.

- Develop an adequate support system to provide reference to the latest information, instruction related design and maintenance, documented feedback/post occupancy data and benchmark data collection.
- Understanding the quality of BAS product/system is important as well as the quality of process as design and maintenance.
- Reduce the need for maintenance by means of adequate strategies and employing experience during application and providing after-service.

In accordance with the survey results and analysis merged with above suggestions, alternatives and decisions for the improvement will rely on adequate information and knowledge, therefore knowledge extraction is necessary. However, it must be stressed that this research is an exploration. As such the knowledge extraction and guidance described in the following chapters intend to develop and pilot a way for contributing knowledge to the building automation field. This would not be a substitute for the statutory building regulations or act of government. Therefore, the following chapters (Ch. 5 & 6) will further extract knowledge and generate applicable guidelines. The survey results analysed using the code system has been introduced to make it to look up and search details in the Appendix D and E. The code system will also be used to instruct in the advanced knowledge induction/deduction, and guidance listing as well.
CHAPTER 5

KNOWLEDGE EXTRACTION

5.1 Introduction
5.2 Knowledge Extraction from Design Professionals
   5.2.1 Knowledge Extraction in "The Needs"
   5.2.2 Knowledge Extraction in "Products"
   5.2.3 Knowledge extraction in "Design issues"
   5.2.4 Knowledge extraction in "Assessment"
5.3 Knowledge Extraction from Maintenance Professionals
   5.3.1 Knowledge Extraction in "Overall Status"
   5.3.2 Knowledge Extraction in "Management"
   5.3.3 Knowledge Extraction in "Technical Issues"
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5.4 Decision Making Procedure
   5.4.1 Decision Making Process
   5.4.2 Decision Making Checklists
5.5 Summary of the Knowledge Extraction
CHAPTER 5 KNOWLEDGE EXTRACTION

5.1 Introduction

In this chapter, the data and facts, collected and analysed from the industry surveys detailed in Chapter 4, will further be extracted by the inductive and deductive methods. In the research context, the knowledge has been extracted, primarily deduced with codes from the induced results of the surveys relating to design and maintenance, then induced relevant knowledge rules to formulate a knowledge base for decision support applications. The inductive and deductive methods will drive the knowledge extraction through the process. In order to describe the knowledge extraction process, an example relating to the data how to generate knowledge has been illustrated in Figure 5-1. From this example, the inductive and deductive knowledge can be expanded to extract the rest of issues with respect to design and maintenance, which has been illustrated in the following sections and collated in the Appendix D and E.

Figure 5-1: Example of the Inductive and Deductive Process
An outline of the knowledge extraction and deductive and inductive process starting from the survey results has been illustrated in Figure 5-2:

Figure 5-2: Outline of the Knowledge Extraction
5.2 Knowledge Extraction from Design Professionals

With respect to BAS design issues, four specific subjects as “The Need”, “Products”, “Design issues”, and “Assessment” have been discussed and shown in Chapter 5 which detailed the data analysis of the surveys. This section will discuss the process that further extract knowledge and induce knowledge rules to formulate a knowledge base for decision support applications as illustrated in Figure 5-3.

Figure 5-3: Outline of the Design Knowledge Extraction
5.2.1 Knowledge Extraction in “The Needs”

The induction results of “The Needs” as DAR01-DAR06 are illustrated as in Figure 5-4:

- Importance of BAS to people (DA01)
- Role/ awareness of BAS (DA02)
- Main considerations in design stage (DA03)
- Major factors of consideration (DA04)
- Realisation requirement/ specification (DA05)
- Regulation and specification (DA06)

<table>
<thead>
<tr>
<th>DAR01</th>
<th>DAR02</th>
<th>DAR03</th>
<th>DAR04</th>
<th>DAR05</th>
<th>DAR06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance of BAS to people (DA01)</td>
<td>Client (occupants), Building owner, Building developer</td>
<td>Awareness/ benefits, Responsibility</td>
<td>Meet regulation/ Easy operation and maintenance/ Performance of systems/ Meet client requirement</td>
<td>Building performance, Building life-cycle cost</td>
<td>From statistical information/ product manufacturer/ Feedback from previous use</td>
</tr>
</tbody>
</table>

Figure 5-4: Induction Results of “The Needs” from the Design Issues

Based on these induction results of the data analysis, the knowledge extraction can be undertaken from the design point of view to explore the current client’s needs and expectations, and reflect the situation of office building industry. Through the inductive/ deductive methods, the findings eventually can be concluded (as in Figure 5-5) into four major headings:

- What is BAS?
- What is Intelligent Building?
- Strategies for high performance and life cycle cost considerations
- Need to specify the applicable and constructible BAS specification
What is BAS?
Raising the awareness of BAS benefits for the whole building participants (KDA0101, KDA0201)

Some of the participants in the building process are not really recognising what BAS is?

What is Intelligent Building?
Rapidly advanced technology and high expectation of the end users have formed the requirements of building.

Strategies for high performance and life cycle cost considerations
BAS performance focuses and embeds the life-cycle cost consideration into design (KDA0401)

In the building life cycle, the building performance and costs are equally essential.

Need to specify the applicable/constructible BAS specification
The sources of BAS requirements and specifications (KDA0501)

The advanced technology and high expectation of the end users have asked the rapid response of the building requirements.

The regulations and specifications are the qualified and standard requirements of the building process and products.

BAS regulations and product specifications need to be complied and become a basic requirement (KDA0601)

Figure 5-5: Deduction of “The Needs” from the Design Issues
The knowledge rules induced from “The Needs” of BAS design are listed as in Table 5-1:

Table 5-1: Induced Knowledge Rules in relation to “The Needs”

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R01DA01</td>
<td>Developers are less focusing on BAS</td>
<td>They will need to learn the BAS benefits</td>
</tr>
<tr>
<td>R02DA02</td>
<td>Designers mostly realise the BAS benefits and BAS responsibilities for the building maintenance</td>
<td>They will facilitate good BAS designs</td>
</tr>
<tr>
<td>R03DA03</td>
<td>Designers are not very interested in the reliability and price or cost of the BAS.</td>
<td>They will affect the BAS design quality and need to learn the life-cycle cost of the BAS.</td>
</tr>
<tr>
<td>R04DA03</td>
<td>BAS design quality is low</td>
<td>BAS reliability is low</td>
</tr>
<tr>
<td>R05DA03</td>
<td>BAS design quality is high</td>
<td>BAS reliability is high</td>
</tr>
<tr>
<td>R06DA03</td>
<td>Designers consider the BAS meeting with the regulation and easy operation and maintenance, performance of the systems, and the client requirements.</td>
<td>They will facilitate good BAS designs</td>
</tr>
<tr>
<td>R07DA04</td>
<td>BAS designs take into consideration of the life-cycle cost and performance of the building</td>
<td>They will contribute to the maintenance costs reduction</td>
</tr>
<tr>
<td>R08DA05</td>
<td>BAS design requirements and product specifications are provided by the product manufacturers.</td>
<td>These will provide the current BAS product for design application.</td>
</tr>
<tr>
<td>R09DA05</td>
<td>BAS design requirements and product specifications are obtained from the feedback of the previous user, client discussion, and sub-contractor's recommendation and statistical information</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R10DA06</td>
<td>BAS designs are in accordance with the building regulation and product specification</td>
<td>These will assure the quality of the BAS designs</td>
</tr>
</tbody>
</table>
5.2.2 Knowledge Extraction in “Products”

The induction results of “Products” as DBR01-DBR05 are illustrated as in Figure 5-6:

Based on these induction results in the aspect of the products, the knowledge extraction can be deduced and concluded as in Figure 5-7 under two major headings:

- Select and ensure appropriate, reliable and applicable BAS products.
- Building process integration.
Communication with the product vendors is needed during the design stage. (KDB0102)

Updated product information and application historic records are needed during the design stage (KDB0101), (KDB0201), (KDB0301)

Relationship enhancement between designers and building participants are helpful to the building service and application (KDB0302)

The BAS design directly affect the future building operation and management.

The basic regulations and codes are the base of the practice. Beyond them can dominate to meet the needs of end users.

Close relationships can facilitate enhancements and learning between the different parties.

The integration has been recognised as the potential strategies either in the systems integration or in the building process integration.

Select and ensure appropriate, reliable and applicable BAS products.

Integration of building process is a possible alternative for the building management. (KDB0501)

The BAS design and maintenance beyond the basic regulations and codes can optimise the building performance and service. (KDB0401)

Keep the information updated will ensure the design can be sustainable for the needs.

Updated product information and application historic records are needed during the design stage (KDB0101), (KDB0201), (KDB0301)

Close relationships can facilitate enhancements and learning between the different parties.

The integration has been recognised as the potential strategies either in the systems integration or in the building process integration.

Select and ensure appropriate, reliable and applicable BAS products.

Building process integration

Figure 5-7: Deduced Results of “Products” from the Design Issues
The knowledge rules induced from the “Products” of BAS design are listed as in Table 5-2:

Table 5-2: Induced Knowledge Rules in relation to “Products” of BAS Design

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R11DB01</td>
<td>BAS designs support by the update product information and the historical records.</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R12DB01</td>
<td>BAS designers communicate with the product vendors.</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R13DB02</td>
<td>BAS designs support by the information of the product pros/cons</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R14DB03</td>
<td>BAS designers communicate with the building owners and the facilities managers.</td>
<td>They will support the building maintenance.</td>
</tr>
<tr>
<td>R15DB03</td>
<td>BAS designs gain information from the previous use.</td>
<td>These will help the new building designs.</td>
</tr>
<tr>
<td>R16DB04</td>
<td>Designers deliver the information and manual of BAS operation and maintenance to facilities managers.</td>
<td>They will support the building maintenance.</td>
</tr>
<tr>
<td>R17DB05</td>
<td>Responses and feedbacks provide by the facilities managers.</td>
<td>These will help the new building designs.</td>
</tr>
<tr>
<td>R18DB05</td>
<td>Responses and feedbacks provided by the facilities managers.</td>
<td>These will facilitate the building process integration.</td>
</tr>
</tbody>
</table>
5.2.3 Knowledge extraction in “Design issues”

The induction results of “Design issues” as DCR01-DCR07 are illustrated as in Figure 5-8:

From this induction result (DCR01-DCR07), the results in the aspect of design issues can be deduced and concluded under seven major headings shown as in Figure 5-9:

- Intelligent Buildings with BAS, and their benefits.
- Strategies for sustainable maintenance
- ICT and DSS applications
- Building system Integration
- Strategies for smart design for high performance and optimising operation and maintenance
- Sensors in relation with BAS
- Communication and integration, decision support
Figure 5-9: Deduced Results of “Design Issues”
The knowledge rules induced from the “Design Issues” are listed as in Table 5-3:

Table 5-3: Induced Knowledge Rules in relation to “Design Issues”

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R19DC01</td>
<td>Building systems design and maintain adequately.</td>
<td>These will ensure the overall building performance and comfortable environment.</td>
</tr>
<tr>
<td>R20DC02</td>
<td>Building systems occur problems</td>
<td>These will result in the occupant uncomfortable and complaints.</td>
</tr>
<tr>
<td>R21DC03</td>
<td>BAS designs support by the decision support tools</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R22DC04</td>
<td>The integration of the building systems is appropriate</td>
<td>It will save energy, increase security and comfort.</td>
</tr>
<tr>
<td>R23DC05</td>
<td>The integration of the building systems is appropriate</td>
<td>It will increase the building performance, effectiveness and efficiency.</td>
</tr>
<tr>
<td>R24DC05</td>
<td>The integration of the building systems is appropriate</td>
<td>It will ease maintenance of the building.</td>
</tr>
<tr>
<td>R25DC06</td>
<td>Application of sensors for the control and monitoring of the building systems.</td>
<td>It will save energy, increase security and comfort.</td>
</tr>
<tr>
<td>R26DC06</td>
<td>Application of sensors for the control and monitoring of the building systems.</td>
<td>It will ease maintenance of the building.</td>
</tr>
<tr>
<td>R27DC07</td>
<td>BAS designs support by the information of product cost and performance.</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R28DC07</td>
<td>Designers intimately communicate with the building developers.</td>
<td>These will facilitate good BAS designs</td>
</tr>
</tbody>
</table>
5.2.4 Knowledge extraction in “Assessment”

The induction results of “Assessment” as DDR01-DDR05 are illustrated as in Figure 5-10:

From this induction results (DDR01-DDR05), the results in the aspect of assessment can be deduced and concluded under six major headings shown as in Figure 5-11:

- Building assessment, optimising operational and maintenance practices
- Select suitable building maintenance strategies.
- Select applicable and reliable BAS products
- Building process integration
- The status of office building and BAS application
- Strategies for sustainable maintenance and security/fire system design
Figure 5-11: Deduced Results of “Assessment” from the Design Issues

- **DDR01**: Building system evaluation is the major step to ensure the high building performance and energy conservation (KDD0101)
  - Evaluation has the functions: to qualify the building status, to examine the performance of the systems and to facilitate the energy conservation.

- **DDR02**: Building maintenance needs applicable strategies (KDD0201)
  - Various strategies of maintenance have their specific purpose and have their pros and cons, limitations and advantages.

- **DDR03**: BAS design needs to embed the maintenance consideration. (KDD0202)
  - Design activities are directly impact on the life time operation and maintenance.

- **DDR04**: Building process integration needs enhancement in practice. (KDD0301)
  - It is still a challenge for the traditional building process, hopefully process integration will breakthrough the bottle neck of the practice in the life cycle considerations.

- **DDR05**: How to optimise the high building performance and energy conservation? (KDD0401)
  - High performance and energy conservation are the needs of the end users during the building life.

- **DDR06**: How to enhance operation and maintenance? (KDD0402)
  - Operation and maintenance are the major process of the building services in relation to the building performance and energy conservation.

- **DDR07**: How to promote the relationships between different parities of the building process? (KDD0501)
  - Close relationships can interdigitate enhancements and learning between the different parties, and improve the problems and effective supports.

---

**Building assessment, optimising operation and maintenance practices**

**Select suitable building maintenance strategies**

**Building process integration**

**The status of office building and BAS application**

**Strategies for sustainable maintenance and security/fire system design**

**Building process integration**
The knowledge rules induced from “Assessment” of design are listed as in Table 5-4:

Table 5-4: Induced Knowledge Rules in relation to “Assessment”

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R29DD01</td>
<td>Application of the assessment tools for the BAS.</td>
<td>It will verify the performance of building and energy conservation.</td>
</tr>
<tr>
<td>R30DD02</td>
<td>Poor BAS performance</td>
<td>It will decrease the building performance.</td>
</tr>
<tr>
<td>R31DD02</td>
<td>Poor BAS performance</td>
<td>It will increase energy consumption</td>
</tr>
<tr>
<td>R32DD02</td>
<td>Poor BAS performance</td>
<td>It will affect the building maintenance.</td>
</tr>
<tr>
<td>R33DD02</td>
<td>Lack of instruction</td>
<td>It will result in inappropriate operation and maintenance of the building systems.</td>
</tr>
<tr>
<td>R34DD02</td>
<td>Operation of the building systems is inappropriate</td>
<td>It will decrease the building performance.</td>
</tr>
<tr>
<td>R35DD02</td>
<td>The maintenance of the building systems is improper.</td>
<td>It will decrease the building performance.</td>
</tr>
<tr>
<td>R36DD02</td>
<td>The maintenance of the building systems is improper.</td>
<td>It will increase the maintenance costs.</td>
</tr>
<tr>
<td>R37DD02</td>
<td>Designs have deficiencies or shortages</td>
<td>It will decrease the building performance.</td>
</tr>
<tr>
<td>R38DD02</td>
<td>Designs have deficiencies or shortages</td>
<td>It will increase energy consumption</td>
</tr>
<tr>
<td>R39DD03</td>
<td>Designers provide instruction and guidelines to facilities managers.</td>
<td>They will help the building maintenance.</td>
</tr>
<tr>
<td>R40DD04</td>
<td>Operation and maintenance are adequate.</td>
<td>These will facilitate the energy conservation.</td>
</tr>
<tr>
<td>R41DD04</td>
<td>Energy conservation designs</td>
<td>These will facilitate the energy conservation.</td>
</tr>
<tr>
<td>R42DD04</td>
<td>Selection BAS is appropriate</td>
<td>It will facilitate the energy conservation.</td>
</tr>
<tr>
<td>R43DD04</td>
<td>Adequate BAS integration with building systems</td>
<td>It will facilitate the energy conservation.</td>
</tr>
<tr>
<td>R44DD05</td>
<td>Designers intimately communicate with facilities managers after building delivery.</td>
<td>They will help the building maintenance.</td>
</tr>
</tbody>
</table>
5.3 Knowledge Extraction from Maintenance Professionals

With respect to BAS Maintenance issues, four specific subjects as “Overall status”, “Management”, “Technical issues”, and “Assessment” have been discussed and shown in Chapter 4 which detailed the data analysis of the surveys. This section will further extract knowledge and induce knowledge rules to formulate a knowledge base for decision support applications as illustrated in Figure 5-12.

![Knowledge Extraction Diagram]

Figure 5-12: Outline of the Maintenance Knowledge Extraction
5.3.1 Knowledge Extraction in “Overall Status”

The induction results of “Overall status” as MAR01-MAR06 are illustrated as in Figure 5-13:

- **Overall Status**
  - BAS function (MA01)
  - Problems/ Troubles (MA02)
  - Reasons for poor BAS performance (MA03)
  - Regulations and Specifications (MA04)
  - Standard Operation Procedures (Sops) provided (MA05)
  - Expectations of clients (MA06)

- Smart/ intelligent features, Comfortable/ healthy, BAS maintenance, Energy consumption
- Electrical systems, Mechanical systems, Automatic operation/ monitoring systems
- Design deficiency/ shortage, Inappropriate operation, Improper maintenance, Lack of instruction, Unsuitable material/ elements/systems
- Building regulation/ codes, Product specification
- In-house qualified staff, Design consultants, Maintenance consultants, Facility manager
- Feasibility/ Adaptability/ Accessibility, Friendliness/ Comfort/ Convenience, Minimisation of energy consumption, Performance/ Effectiveness/ Responsiveness

![Figure 5-13: Induction Results of “Overall Status” from the Maintenance Issues](image)

Based on these induction results of the data analysis detailed in Chapter 5, the knowledge extraction can be undertaken from the maintenance point of view to explore the current client’s needs and expectations. Through the induction/ deduction method, the findings eventually can be concluded as in Figure 5-14 under nine major headings:

- What is intelligent building with BAS?
- How to sustain the comfort and healthy requirements?
- What is current BAS situation and future development?
- How to minimise the energy consumption?
- How to optimise operation and maintenance?
- Strategies for sustainable maintenance
- Strategies for smart design and system integration
- Selection of applicable and reliable BAS products
- Strategies for high performance, energy conservation and comfort
CHAPTER 5 KNOWLEDGE EXTRACTION

What is intelligent building and BAS?

Smart and intelligent building and BAS are commonly accepted by the building occupants and maintenance professionals. (KMA0101)

Office buildings should be maintained to sustain the comfortable and healthy workplace to meet the needs of the users.

Either the design specifications and functions are not effectively pass onto the maintainers or they are not competent in facilities maintenance.

How to sustain the comfort and healthy requirements?

The conditions of the office building reflect that the performance and problem prevention can be through good maintenance and management. (KMA0201)

Office buildings can be maintained to sustain the performance of building, and comfortable and healthy workplace to meet the needs of the users.

The operation and maintenance instructions are the basic documents for action and management.

How to optimise operation and maintenance?

Maintainers needs applicable operation and maintenance instructions

Sustainable competencies of maintenance rely on regular training such as on-job training.

Strategies for sustainable maintenance

BAS design needs to be enhanced. (KMA0303)

BAS can be designed well to meet with the needs in the light of the rapid growing technology innovation and products development.

Strategies for smart design and systems integration

Energy consumption is still a challenge for the client expectations. (KMA0404)

Lack of the energy conservation design or strategies to minimise the energy consumption.

How to minimise the energy consumption?

Office buildings should be maintained to sustain the comfortable and healthy workplace to meet the needs of the users.

The operation and maintenance instructions are the basic documents for action and management.

How to optimise operation and maintenance?

Training of the maintenance skills is needed. (KMA0302)

Sustainable competencies of maintenance rely on regular training such as on-job training.

Strategies for sustainable maintenance

BAS design needs to be enhanced. (KMA0303)

BAS can be designed well to meet with the needs in the light of the rapid growing technology innovation and products development.

Strategies for smart design and systems integration

Building codes and specifications are the base of optimising the BAS (KMA0401)

To optimise the building performance need to over enhance the requirements by using the reliable BAS products.

Selection of applicable and reliable BAS products

BAS designers should extend their service for the building life to sustain the quality of the building systems (KMA0501)

Technical competencies need continued training and support by the designers and related professionals such as the product manufacturers and BAS professionals.

Strategies for high performance, energy conservation and comfort

Office buildings should sustain the requirements of high performance, energy conservation and comfort. (KMA0601)

To facilitate the high performance and energy conservation and comfort can meet the expectations of the end users.

Strategies for high performance, energy conservation and comfort

Induction Results Deduction Issues Reasoning Knowledge Subjects

Figure 5-14: Deduction of “Overall Status” from the Maintenance Issues
The knowledge rules induced from the “Overall Status” are listed as in Table 5-5:

Table 5-5: Induced Knowledge Rules in relation to “Overall Status” of Maintenance

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R45MA01</td>
<td>BAS maintenance is appropriate</td>
<td>It will facilitate energy conservation</td>
</tr>
<tr>
<td>R46MA01</td>
<td>BAS maintenance is appropriate</td>
<td>It will facilitate comfortable/ healthy environment.</td>
</tr>
<tr>
<td>R47MA01</td>
<td>BAS maintenance is appropriate</td>
<td>It will enhance the smart/ intelligent features.</td>
</tr>
<tr>
<td>R48MA02</td>
<td>Poor maintenance of building electrical systems</td>
<td>It will increase energy consumption.</td>
</tr>
<tr>
<td>R49MA02</td>
<td>Poor maintenance of building electrical systems</td>
<td>It will affect the comfort environment.</td>
</tr>
<tr>
<td>R50MA02</td>
<td>Poor maintenance of building electrical systems</td>
<td>It will affect the performance of building</td>
</tr>
<tr>
<td>R51MA02</td>
<td>Poor maintenance of building mechanical systems</td>
<td>It will increase energy consumption.</td>
</tr>
<tr>
<td>R52MA02</td>
<td>Poor maintenance of building mechanical systems</td>
<td>It will affect the comfort environment.</td>
</tr>
<tr>
<td>R53MA02</td>
<td>Poor maintenance of building mechanical systems</td>
<td>It will affect the performance of building</td>
</tr>
<tr>
<td>R54MA02</td>
<td>Poor maintenance of BAS</td>
<td>It will increase energy consumption.</td>
</tr>
<tr>
<td>R55MA02</td>
<td>Poor maintenance of BAS</td>
<td>It will affect the comfort environment.</td>
</tr>
<tr>
<td>R56MA02</td>
<td>Poor maintenance of BAS</td>
<td>It will decrease the performance of building</td>
</tr>
<tr>
<td>R57MA04</td>
<td>The BAS maintenance complies with the building regulation/ codes</td>
<td>It will assure the quality of BAS maintenance</td>
</tr>
<tr>
<td>R58MA04</td>
<td>The BAS maintenance complies with the product specification</td>
<td>It will assure the quality of BAS maintenance</td>
</tr>
<tr>
<td>R59MA05</td>
<td>BAS maintenance is in accordance with the standard operation procedures (SOPs)</td>
<td>It will result in the quality of BAS maintenance.</td>
</tr>
<tr>
<td>R60MA06</td>
<td>The building systems are feasible/ adaptable/ accessible</td>
<td>These will meet with the occupants' expectations</td>
</tr>
<tr>
<td>R61MA06</td>
<td>The building systems are friendly/ comfortable/ convenient</td>
<td>These will meet with the occupants' expectations</td>
</tr>
<tr>
<td>R62MA06</td>
<td>The building systems are designed to minimise the energy consumption</td>
<td>These will meet with the occupants' expectations</td>
</tr>
<tr>
<td>R63MA06</td>
<td>The building systems are effective/ responsive.</td>
<td>These will meet with the occupants' expectations</td>
</tr>
</tbody>
</table>
5.3.2 Knowledge Extraction in “Management”

The induction results of “Management” as MBR01-MBR06 are illustrated as in Figure 5-15:

Based on these induction results in relation to the products, the knowledge extraction can be deduced and concluded as in Figure 5-16 under nine major headings:

- Strategies for sustainable maintenance
- Select suitable professionals
- Optimise the operation and maintenance
- Building system integration
- Select suitable maintenance strategies
- ICT and DSS application and support
- Relationships between design and maintenance
- Promote healthy, comfortable and sustainable environments
- Building process integration
BAS operations need applicable support and maintenance instruction to sustain the quality of the buildings. (KMB0101)

The BAS instruction and manuals need to be current and to be effective. (KMB0201)

BAS contracted and management professionals are critical for the building life. (KMB0102)

Updated BAS instruction and manuals can enhance the effective operation and maintenance.

The right selection of maintenance contractors and professionals can assure the quality of the building maintenance.

BAS system integration is needed to improve and increase the awareness of benefits. (KMB0202)

BAS system integration is essential for the office building to facilitate the performance and energy conservation and comfort.

BAS effective maintenance is needed to ease the implement (KMB0301)

Free or effective maintenance can facilitate the performance of buildings and save costs as well.

Computer aided management is needed (KMB0302)

Computer aided support can promote the effectiveness and performance of building systems, and management as well.

Communication between building maintainers and designers is needed. (KMB0303)

The relatively communications are helpful for the operation and maintenance between designers and maintainers, and feedbacks from the maintainers are also promoting a good design.

Building systems integration is advantageous for the building management and performance enhancement. (KMB0401)

The benefits of the systems integration can facilitate the building performance and save the life cycle costs.

The problem solving procedures, dealing with the complaints and tracking problem solving are core issues of building management. (KMB0501)

Dealing with the problems and complaints are basic requirements for ensuring the comfort.

BAS designers provide their service for the building. (KMB0601)

Building life services are needed to effectively minimise the life cycle costs.

Feedback from the building maintainers to the designers is needed. (KMB0602)

Feedback can present reference for building system design and support.

Figure 5-16: Deduced Results of “Management” from the Maintenance issues
The knowledge rules induced from the “Management” are listed as in Table 5-6:

Table 5-6: Induced Knowledge Rules in relation to “Management”

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R64MB02</td>
<td>BAS integration is appropriate.</td>
<td>It will result in the quality of BAS maintenance.</td>
</tr>
<tr>
<td>R65MB02</td>
<td>BAS integration is appropriate.</td>
<td>It will facilitate energy conservation</td>
</tr>
<tr>
<td>R66MB02</td>
<td>BAS integration is appropriate.</td>
<td>It will facilitate comfortable/ healthy environment.</td>
</tr>
<tr>
<td>R67MB02</td>
<td>BAS integration is appropriate.</td>
<td>It will enhance the smart/ intelligent features.</td>
</tr>
<tr>
<td>R68MB03</td>
<td>BAS maintenance rates in the office building are high.</td>
<td>These will increase the maintenance costs.</td>
</tr>
<tr>
<td>R69MB03</td>
<td>Maintenance strategy is appropriate.</td>
<td>It will reduce the BAS maintenance rate.</td>
</tr>
<tr>
<td>R70MB03</td>
<td>BAS maintenance rates in the office building is low.</td>
<td>These will decrease the maintenance costs.</td>
</tr>
<tr>
<td>R71MB03</td>
<td>BAS maintenance utilises the computer aids.</td>
<td>It will optimise the BAS maintenance and effectiveness.</td>
</tr>
<tr>
<td>R72MB03</td>
<td>Facilities managers often communicate with the occupants and designers.</td>
<td>These will meet with the occupants' expectations</td>
</tr>
<tr>
<td>R73MB04</td>
<td>Integration of the building systems is appropriate.</td>
<td>It will facilitate energy conservation</td>
</tr>
<tr>
<td>R74MB04</td>
<td>Integration of the building systems is appropriate.</td>
<td>It will facilitate comfortable/ healthy environment.</td>
</tr>
<tr>
<td>R75MB04</td>
<td>Integration of the building systems is appropriate.</td>
<td>It will enhance the smart/ intelligent features.</td>
</tr>
<tr>
<td>R76MB05</td>
<td>Problem solving is effective.</td>
<td>It will meet the occupant's expectations.</td>
</tr>
<tr>
<td>R77MB05</td>
<td>Dealing with complaints is effective.</td>
<td>It will meet the occupant's expectations.</td>
</tr>
<tr>
<td>R78MB05</td>
<td>Tracking problem solving is effective.</td>
<td>It will meet the occupant's expectations.</td>
</tr>
<tr>
<td>R79MB06</td>
<td>Maintenance supports by the designers and venders.</td>
<td>It will ease the BAS maintenance</td>
</tr>
<tr>
<td>R80MB06</td>
<td>Occupants communicate complaints to facilities manager.</td>
<td>These will ease the BAS maintenance</td>
</tr>
<tr>
<td>R81MB06</td>
<td>Facilities managers deliver problems to designers.</td>
<td>These will enhance the BAS design.</td>
</tr>
</tbody>
</table>
5.3.3 Knowledge Extraction in “Technical Issues”

The induction results of “Technical Issues” as MCR01-MCR05 are illustrated as in Figure 5-17:

From these induced results (MCR01-MCR05), results in the aspect of design issues can be deduced and concluded as in Figure 5-18 under four major headings:

- Promote health, comfort and sustainable environments
- Sensors in relation with BAS
- Strategies for security system/ fire system design and maintenance
- BAS and building management
Figure 5-18: Deduced Results of “Technical Issues”
The knowledge rules induced from the “Technical Issues” are listed as in Table 5-7:

**Table 5-7: Induced Knowledge Rules in relation to the “Technical Issues”**

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R82MC01</td>
<td>Office buildings apply individual controls.</td>
<td>These will facilitate energy conservation.</td>
</tr>
<tr>
<td>R83MC01</td>
<td>Office buildings apply individual controls.</td>
<td>These will facilitate comfortable/healthy environment.</td>
</tr>
<tr>
<td>R84MC01</td>
<td>Office buildings apply individual controls.</td>
<td>These will enhance the smart/intelligent features.</td>
</tr>
<tr>
<td>R85MC01</td>
<td>HVAC operation is appropriate.</td>
<td>It will facilitate energy conservation</td>
</tr>
<tr>
<td>R86MC02</td>
<td>Security systems are equipped with separate power supply.</td>
<td>These will ensure the life safety and security.</td>
</tr>
<tr>
<td>R87MC03</td>
<td>Security systems are interfaced with the fire systems.</td>
<td>These will ensure the life safety and security.</td>
</tr>
<tr>
<td>R88MC04</td>
<td>Access control is equipped with smart cards/ key code/ ID cards.</td>
<td>It will enhance the smart/intelligent features.</td>
</tr>
<tr>
<td>R89MC04</td>
<td>Access control is equipped with smart cards/ key code/ ID cards.</td>
<td>It will ease security management.</td>
</tr>
<tr>
<td>R90MC04</td>
<td>CCTV presence detectors is archiving equipped.</td>
<td>It will enhance the smart/intelligent features.</td>
</tr>
<tr>
<td>R91MC04</td>
<td>CCTV presence detectors is archiving equipped.</td>
<td>It will ease the security management.</td>
</tr>
</tbody>
</table>
5.3.4 Knowledge extraction in “Assessment”

The induction results of “Assessment” as MDR01-MDR07 are illustrated as in Figure 5-19:

![Diagram of Knowledge Extraction in Assessment]

Figure 5-19: Induced Results of “Assessment” from the Maintenance Issues

From these induced results (MDR01-MDR07), results in the aspect of assessment can be deduced and concluded as in Figure 5-20 under seven major headings:

- Smart design for sustainable maintenance
- Strategies for high performance, energy conservation and comfort
- Select suitable maintenance strategies
- Optimise the operation and maintenance
- Building systems and BAS
- Select applicable and reliable BAS products
- Building process and service integration
CHAPTER 5 KNOWLEDGE EXTRACTION

Figure 5-20: Deduced Results of “Assessment” from the Maintenance issues
The knowledge rules induced from the “Assessment” are listed as in Table 5-8:

Table 5-8: Induced Knowledge Rules in relation to the “Assessment” of the Maintenance

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R92MD01</td>
<td>Maintainers support by up-to-day information and instruction/manual.</td>
<td>These will ease maintenance.</td>
</tr>
<tr>
<td>R93MD01</td>
<td>Maintainers support by the historical records.</td>
<td>These will ease maintenance.</td>
</tr>
<tr>
<td>R94MD03</td>
<td>Maintenance is scheduling as monthly and yearly.</td>
<td>It will assure the quality of BAS maintenance</td>
</tr>
<tr>
<td>R95MD04</td>
<td>BAS evaluation is carried out by the facilities manager.</td>
<td>It will assure the quality of BAS maintenance</td>
</tr>
<tr>
<td>R96MD04</td>
<td>BAS evaluation is supported by the evaluation tools.</td>
<td>It will assure the quality of BAS maintenance</td>
</tr>
</tbody>
</table>
5.4 Decision Making Procedure

5.4.1 Decision Making Process

Decision-making is an activity of deciding on the appropriate action under particular conditions or situations. It is reliant on information in the sense that information is seen as reducing uncertainty in decision-making; information is data interpreted in some context by some particular person or group, on which as information relies on data, good decision making is reliant on good (accuracy, age, time horizon, level of summarisation, completeness, accessibility, and relevance) data (Beynon-Davies, P. 2002). There are four general stages in any decision making process as illustrated in Figure 5-21 (Simon, H. 1960):

The above illustration has a number of explicit feedback loops implying that most decision-making is iterative. For instance, at the design phase the questions may arise that require further intelligence gathering. Most human decision-making appears to be satisfying rather than rational behaviour, since they normally make decisions in a limited amount of time, based on limited information and with a limited ability to process information (Beynon-Davies, P. 2002).
Reviewing the decision making process, the early stage of building design is an art as well as a science; the later stages of the design process tend to be narrower and more defined. The office building automation design and maintenance relating to the BAS practical application is more artificial. Hence, the decision could be made along a more scientific path. It can be carried out in a general process in the following steps: (1). Assess the situation (2). Identify choices of possible decisions (3). Make decision (4). Validate the decision, the process and the results.

(1). Assess the situation: Subjects, Questions/ problems

- Consider decision to be made (in the form of a question)
- Identify critical factors involved in decision
- Review what is known about each factor
- Check for what is not known about each factor
- Discover resources for fact-finding
- Complete fact-finding

(2). Identify choices of possible decisions: Descriptions and analysis

- List feasible, realistic and possible decision
- Note positive and negative consequences for each with rationale
- Eliminate decisions of lesser value through rationale

(3). Make decision: Find strategies/ solutions

- Choose the applicable strategies/ solutions
- Realise the advantages and disadvantages

(4). Validate and discuss:

- Certify the decision process and results
- Discuss pros and cons
5.4.2 Decision Making Checklists

To effective decision making, a step-by-step checklists as the follows can help the decision makers to accomplish the process.

(1) Assessment Step:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Q 1</th>
<th>Q 2</th>
<th>Q 3</th>
<th>Q 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Decision to be made (questions):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Critical factors involved</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Information known</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Information needed (unknown)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. Resources for fact-finding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. Answers to each question</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(2) Identification Step:

<table>
<thead>
<tr>
<th>Possible Decisions</th>
<th>Negative Consequences</th>
<th>Positive Consequences</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision #1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decision #2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(3) Make decision:

<table>
<thead>
<tr>
<th>Priority</th>
<th>Choice</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(3) Validation Step:

<table>
<thead>
<tr>
<th>Final decision with rationale</th>
<th>First Choice</th>
<th>Second Choice</th>
<th>Third Choice</th>
<th>Fourth Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Validate decision:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
During the decision making process, the relevant information with respect to the critical factors of the problems or questions should be firstly gathered and assessed. They will include known and unknown information, and relevant resources. Identification step will list the possible solutions and strategies and their negative and positive consequences. Once the possible solutions and strategies have been listed, they can be ordered under the priorities with their advantages and disadvantages. Consequently, the decisions can be reviewed and finalised by means of the validation of the process and results. The best possible choice at this time can be revised as more information about problems, thus a new decision might become a better choice.
5.5 Summary of the Knowledge Extraction

The knowledge gained from deduced survey results with respect to design and maintenance professionals and practice has been systematically extracted and illustrated along with the knowledge rules. The knowledge extraction associated with the integration context of design and maintenance has been summarised as listed in Table 5-9. The variables relating to the knowledge rules have been summarized with codes as listed in Table 5-10. The knowledge rules which will be formulated a knowledge base can be used for the decision support application as listed in Table 5-11. The Knowledge inference flow is illustrated as in Figure 5-23.

The knowledge extraction process has produced more focused issues on design compared to feedbacks from maintenance to design. This is because that the research focuses aim at the integration between design and maintenance, during the integration progress most strategies rely on the support and service from design phase. Meanwhile, if the design knowledge can be effectively applied for the maintenance practice, it will be worthier than maintenance feedbacks to design for the new project.

In conclusion, the extracted knowledge can be further categorised into three pillars: (1) Strategies for raising awareness and understanding (2) General strategies and (3) Operational checklists illustrated as in Figure 5-22.
In addition to raising the awareness and understanding of the integration between design and maintenance, regarding office building automation performance and energy conservation and comfort, the guide should be expanded from information and generated from actual operations to help improve the status of integration in the office building industry, eventually to satisfy the objectives of this research. The guide will be described and illustrated in these three pillars detailed in the next chapter.
<table>
<thead>
<tr>
<th>Status of current office building automation</th>
<th>DESIGN</th>
<th>MAINTENANCE</th>
<th>MEETING OCCUPANTS’ EXPECTATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QUALITY, SMART DESIGN</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Independent and fragmental design and maintenance</td>
<td>Needs of the owners/occupants</td>
<td>Access smart design, Security interfaced with fire systems</td>
<td>Accessible</td>
</tr>
<tr>
<td>High maintenance costs</td>
<td>Process integration consideration</td>
<td>Systems integration</td>
<td>Integrated, Responsive Efficient</td>
</tr>
<tr>
<td>Needs of comfortable and security and healthy environments</td>
<td>Regulations/ Codes, Historical records</td>
<td>Sensor control/monitoring, Individual control</td>
<td>Effective, Comfortable</td>
</tr>
<tr>
<td>First cost mentality</td>
<td>Products costs, Historical records</td>
<td>Life cycle costs consideration</td>
<td>Costs reduction</td>
</tr>
<tr>
<td>Lack of life time instruction and historical records</td>
<td>Requirements of the owners/occupants</td>
<td>Energy conservation design</td>
<td>Quality design, Energy conservation</td>
</tr>
<tr>
<td>Design Deficiency/Shortage</td>
<td>Poor building systems, BAS</td>
<td>BAS integration, BAS selection</td>
<td>Meeting regulation/product specifications</td>
</tr>
<tr>
<td>Requirements of smart and intelligent performance</td>
<td>Problems</td>
<td>Problem Solving</td>
<td>Quality Design</td>
</tr>
</tbody>
</table>

Table 5-9: Summary of knowledge extraction associated with the integration context of design and maintenance.
### Table 5-10: Variables with Codes of the Knowledge

<table>
<thead>
<tr>
<th>Variables</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access control is equipped with smart cards/ key code/ ID cards</td>
<td>ACS</td>
</tr>
<tr>
<td>HVAC operation is appropriate</td>
<td>AHVACO</td>
</tr>
<tr>
<td>BAS &amp; building systems integration is appropriate.</td>
<td>AI</td>
</tr>
<tr>
<td>BAS maintenance is appropriate</td>
<td>AM</td>
</tr>
<tr>
<td>Maintenance strategy is appropriate</td>
<td>AMS</td>
</tr>
<tr>
<td>Operation is appropriate</td>
<td>AO</td>
</tr>
<tr>
<td>Affect the performance of building</td>
<td>BP</td>
</tr>
<tr>
<td>Building systems occur problems</td>
<td>BSP</td>
</tr>
<tr>
<td>Contribute to the maintenance costs reduction</td>
<td>DMC</td>
</tr>
<tr>
<td>Designers consider the BAS meeting with the client requirements.</td>
<td>MR</td>
</tr>
<tr>
<td>Facilitate comfortable/ healthy environment.</td>
<td>CS</td>
</tr>
<tr>
<td>Designers mostly realise the BAS benefits</td>
<td>DB</td>
</tr>
<tr>
<td>Dealing complaints is effective</td>
<td>DC</td>
</tr>
<tr>
<td>Designers intimately communicate with the building developers.</td>
<td>DCD</td>
</tr>
<tr>
<td>BAS design requirements and product specifications obtain from the client discussion</td>
<td>DRCD</td>
</tr>
<tr>
<td>BAS design communicates with the building owners and the facilities managers.</td>
<td>DCF</td>
</tr>
<tr>
<td>BAS design requirements and product specifications obtain from the sub-contractor's recommendation</td>
<td>DCR</td>
</tr>
<tr>
<td>BAS design communicates with the product vendors.</td>
<td>DCV</td>
</tr>
<tr>
<td>Designers deliver the information and manual of BAS operation and maintenance.</td>
<td>DDI</td>
</tr>
<tr>
<td>Decrease energy consumption.</td>
<td>DE</td>
</tr>
<tr>
<td>Decrease energy consumption.</td>
<td>DEC</td>
</tr>
<tr>
<td>BAS design feedbacks from the previous use.</td>
<td>DFU</td>
</tr>
<tr>
<td>BAS design requirements and product specifications obtain from the feedback of the previous user</td>
<td>DFU</td>
</tr>
<tr>
<td>Developers are less focusing on BAS</td>
<td>DLBAS</td>
</tr>
<tr>
<td>BAS designs take into consideration of the life-cycle cost</td>
<td>DLCC</td>
</tr>
<tr>
<td>Decrease the maintenance costs.</td>
<td>DMC</td>
</tr>
<tr>
<td>Decrease the building performance.</td>
<td>DP</td>
</tr>
<tr>
<td>BAS design requirements and product specifications provide by the product manufacturers.</td>
<td>DPM</td>
</tr>
<tr>
<td>Designers consider the BAS meeting with the regulation</td>
<td>DR</td>
</tr>
<tr>
<td>BAS responsibilities for the building maintenance</td>
<td>DRM</td>
</tr>
<tr>
<td>BAS design in accordance with the building regulation and product specification</td>
<td>DRS</td>
</tr>
<tr>
<td>Design has a deficiency or shortage</td>
<td>DS</td>
</tr>
<tr>
<td>BAS design supports by the information of product cost and performance</td>
<td>DSCPC</td>
</tr>
<tr>
<td>Designers provide instruction and guidelines to facilities managers</td>
<td>DSF</td>
</tr>
<tr>
<td>BAS design supports by the historical records.</td>
<td>DSH</td>
</tr>
<tr>
<td>BAS design requirements and product specifications obtain from the statistical information</td>
<td>DSI</td>
</tr>
<tr>
<td>BAS design supports by the information of the product pros/ cons</td>
<td>DSPC</td>
</tr>
<tr>
<td>BAS design supports by the update product information.</td>
<td>DSPIC</td>
</tr>
<tr>
<td>BAS design supports by the decision support tools</td>
<td>DST</td>
</tr>
<tr>
<td>Energy conservation design</td>
<td>ECD</td>
</tr>
<tr>
<td>BAS evaluation is carried out by the facilities manager</td>
<td>ECF</td>
</tr>
<tr>
<td>Ease maintenance.</td>
<td>EM</td>
</tr>
<tr>
<td>Designers consider the BAS meeting with easy operation and maintenance</td>
<td>EOM</td>
</tr>
<tr>
<td>The building systems are effective/ Responsive.</td>
<td>ER</td>
</tr>
<tr>
<td>Ease security management.</td>
<td>ESM</td>
</tr>
<tr>
<td>BAS evaluation is supported by the evaluation tools</td>
<td>EST</td>
</tr>
<tr>
<td>The building systems are feasible/ adaptable/ accessible</td>
<td>FAA</td>
</tr>
<tr>
<td>The building systems are friendly/ comfortable/ convenient</td>
<td>FCC</td>
</tr>
<tr>
<td>Facilities managers often communicate with the designers.</td>
<td>FCD</td>
</tr>
<tr>
<td>Facilities managers often communicate with the occupants</td>
<td>FCO</td>
</tr>
</tbody>
</table>
Facilities managers deliver problems to designers.  
Responses and feedbacks provide from the facilities managers.  
BAS maintenance rate in the office building is high.  
BAS reliability is high  
Office buildings apply individual controls  
Ensure the comfortable environment.  
Affect energy conservation.  
Increase energy consumption.  
Result in inappropriate operation and maintenance of the building systems.  
Increase the maintenance costs.  
Operation of the building systems is inappropriate  
Increase the building performance, effectiveness and efficiency.  
Need to learn the BAS benefits  
Lack of instruction  
BAS maintenance rate in the office building is low  
BAS design quality is low  
BAS reliability is low  
BAS maintenance utilises the computer aids  
BAS maintenance complies with the building regulation/ codes  
Meet with the occupants' expectations  
BAS maintenance complies with the product specification.  
Maintenance is scheduling as monthly and yearly  
Maintainers support by the designers and vendors  
Maintainers support by the historical records  
Maintainers support by up-to-day information and instruction/ manual  
BAS maintenance is in accordance with the standard operation procedures (SOPs)  
Help the new building design.  
Result in the occupant uncomfortable and complaints.  
Occupants respond complaints to facilities manager.  
CCTV presence detectors and archiving is equipped.  
Facilitate the building process integration.  
Poor maintenance of BAS  
Poor maintenance of building electrical systems  
Poor maintenance of building mechanical systems  
Poor BAS performance  
Designers consider the BAS meeting with performance of the systems  
Problem solving is effective.  
Produce a good BAS design  
Assure the quality of BAS maintenance  
Reduce the BAS maintenance rate  
Selection BAS is appropriate  
Application of sensors for the control and monitoring of the building systems  
Security system is interfaced with the fire systems  
Enhance the smart/ intelligent features  
Ease security management  
Security system is equipped with separated power supply  
Ensure the life safety and security  
Tracking problem solving is effective  
Verify the energy conservation.  
Verify the performance of building
Table 5-11: Induced Knowledge Rules of BAS Design and Maintenance

<table>
<thead>
<tr>
<th>Rule Code</th>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>R01DA01</td>
<td>Developers are less focusing on BAS</td>
<td>They will need to learn the BAS benefits</td>
</tr>
<tr>
<td>R02DA02</td>
<td>Designers mostly realise the BAS benefits and BAS responsibilities for the building maintenance</td>
<td>They will facilitate good BAS designs</td>
</tr>
<tr>
<td>R03DA03</td>
<td>Designers are not very interested in the reliability and price or cost of the BAS.</td>
<td>They will affect the BAS design quality and need to learn the life-cycle cost of the BAS.</td>
</tr>
<tr>
<td>R04DA03</td>
<td>BAS design quality is low</td>
<td>BAS reliability is low</td>
</tr>
<tr>
<td>R05DA03</td>
<td>BAS design quality is high</td>
<td>BAS reliability is high</td>
</tr>
<tr>
<td>R06DA03</td>
<td>Designers consider the BAS meeting with the regulation and easy operation and maintenance, performance of the systems, and the client requirements.</td>
<td>They will facilitate good BAS designs</td>
</tr>
<tr>
<td>R07DA04</td>
<td>BAS designs take into consideration of the life-cycle cost and performance of the building</td>
<td>They will contribute to the maintenance costs reduction</td>
</tr>
<tr>
<td>R08DA05</td>
<td>BAS design requirements and product specifications are provided by the product manufacturers.</td>
<td>These will provide the current BAS product for design application.</td>
</tr>
<tr>
<td>R09DA05</td>
<td>BAS design requirements and product specifications are obtained from the feedback of the previous user, client discussion, and sub-contractor’s recommendation and statistical information</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R10DA06</td>
<td>BAS designs are in accordance with the building regulation and product specification</td>
<td>These will assure the quality of the BAS designs</td>
</tr>
<tr>
<td>R11DB01</td>
<td>BAS designs support by the update product information and the historical records.</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R12DB01</td>
<td>BAS designers communicate with the product vendors.</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R13DB02</td>
<td>BAS designs support by the information of the product pros/ cons</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R14DB03</td>
<td>BAS designers communicate with the building owners and the facilities managers.</td>
<td>They will support the building maintenance.</td>
</tr>
<tr>
<td>R15DB03</td>
<td>BAS designs gain information from the previous use.</td>
<td>These will help the new building designs.</td>
</tr>
<tr>
<td>R16DB04</td>
<td>Designers deliver the information and manual of BAS operation and maintenance to facilities managers.</td>
<td>They will support the building maintenance.</td>
</tr>
<tr>
<td>R17DB05</td>
<td>Responses and feedbacks provide by the facilities managers.</td>
<td>These will help the new building designs.</td>
</tr>
<tr>
<td>R18DB05</td>
<td>Responses and feedbacks provided by the facilities managers.</td>
<td>These will facilitate the building process integration.</td>
</tr>
<tr>
<td>R19DC01</td>
<td>Building systems design and maintain adequately.</td>
<td>These will ensure the overall building performance and</td>
</tr>
<tr>
<td>Rule</td>
<td>Premise</td>
<td>Conclusion</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>R20DC02</td>
<td>Building systems occur problems</td>
<td>These will result in the occupant uncomfortable and complaints.</td>
</tr>
<tr>
<td>R21DC03</td>
<td>BAS designs support by the decision support tools</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R22DC04</td>
<td>The integration of the building systems is appropriate</td>
<td>It will save energy, increase security and comfort.</td>
</tr>
<tr>
<td>R23DC05</td>
<td>The integration of the building systems is appropriate</td>
<td>It will increase the building performance, effectiveness and efficiency.</td>
</tr>
<tr>
<td>R24DC05</td>
<td>The integration of the building systems is appropriate</td>
<td>It will ease maintenance of the building.</td>
</tr>
<tr>
<td>R25DC06</td>
<td>Application of sensors for the control and monitoring of the building systems.</td>
<td>It will save energy, increase security and comfort.</td>
</tr>
<tr>
<td>R26DC06</td>
<td>Application of sensors for the control and monitoring of the building systems.</td>
<td>It will ease maintenance of the building.</td>
</tr>
<tr>
<td>R27DC07</td>
<td>BAS designs support by the information of product cost and performance.</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R28DC07</td>
<td>Designers intimately communicate with the building developers.</td>
<td>These will facilitate good BAS designs</td>
</tr>
<tr>
<td>R29DD01</td>
<td>Application of the assessment tools for the BAS.</td>
<td>It will verify the performance of building and energy conservation.</td>
</tr>
<tr>
<td>R30DD02</td>
<td>Poor BAS performance</td>
<td>It will decrease the building performance.</td>
</tr>
<tr>
<td>R31DD02</td>
<td>Poor BAS performance</td>
<td>It will increase energy consumption</td>
</tr>
<tr>
<td>R32DD02</td>
<td>Poor BAS performance</td>
<td>It will affect the building maintenance.</td>
</tr>
<tr>
<td>R33DD02</td>
<td>Lack of instruction</td>
<td>It will result in inappropriate operation and maintenance of the building systems.</td>
</tr>
<tr>
<td>R34DD02</td>
<td>Operation of the building systems is inappropriate</td>
<td>It will decrease the building performance.</td>
</tr>
<tr>
<td>R35DD02</td>
<td>The maintenance of the building systems is improper.</td>
<td>It will decrease the building performance.</td>
</tr>
<tr>
<td>R36DD02</td>
<td>The maintenance of the building systems is improper.</td>
<td>It will increase the maintenance costs.</td>
</tr>
<tr>
<td>R37DD02</td>
<td>Designs have deficiencies or shortages</td>
<td>It will decrease the building performance.</td>
</tr>
<tr>
<td>R38DD02</td>
<td>Designs have deficiencies or shortages</td>
<td>It will increase energy consumption</td>
</tr>
<tr>
<td>R39DD03</td>
<td>Designers provide instruction and guidelines to facilities managers.</td>
<td>They will help the building maintenance.</td>
</tr>
<tr>
<td>R40DD04</td>
<td>Operation and maintenance are adequate.</td>
<td>These will facilitate the energy conservation.</td>
</tr>
<tr>
<td>R41DD04</td>
<td>Energy conservation designs</td>
<td>These will facilitate the energy conservation.</td>
</tr>
<tr>
<td>R42DD04</td>
<td>Selection BAS is appropriate</td>
<td>It will facilitate the energy conservation.</td>
</tr>
<tr>
<td>R43DD04</td>
<td>Adequate BAS integration with building systems</td>
<td>It will facilitate the energy conservation.</td>
</tr>
<tr>
<td>R44DD05</td>
<td>Designers intimately communicate with facilities managers after building delivery.</td>
<td>They will help the building maintenance.</td>
</tr>
<tr>
<td>R45MA01</td>
<td>BAS maintenance is appropriate</td>
<td>It will facilitate energy</td>
</tr>
<tr>
<td>Reference</td>
<td>Statement</td>
<td>Effect</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------</td>
<td>--------</td>
</tr>
<tr>
<td>R46MA01</td>
<td>BAS maintenance is appropriate</td>
<td>It will facilitate comfortable/healthy environment.</td>
</tr>
<tr>
<td>R47MA01</td>
<td>BAS maintenance is appropriate</td>
<td>It will enhance the smart/intelligent features.</td>
</tr>
<tr>
<td>R48MA02</td>
<td>Poor maintenance of building electrical systems</td>
<td>It will increase energy consumption.</td>
</tr>
<tr>
<td>R49MA02</td>
<td>Poor maintenance of building electrical systems</td>
<td>It will affect the comfort environment.</td>
</tr>
<tr>
<td>R50MA02</td>
<td>Poor maintenance of building electrical systems</td>
<td>It will affect the performance of building</td>
</tr>
<tr>
<td>R51MA02</td>
<td>Poor maintenance of building mechanical systems</td>
<td>It will increase energy consumption.</td>
</tr>
<tr>
<td>R52MA02</td>
<td>Poor maintenance of building mechanical systems</td>
<td>It will affect the comfort environment.</td>
</tr>
<tr>
<td>R53MA02</td>
<td>Poor maintenance of building mechanical systems</td>
<td>It will affect the performance of building</td>
</tr>
<tr>
<td>R54MA02</td>
<td>Poor maintenance of BAS</td>
<td>It will increase energy consumption.</td>
</tr>
<tr>
<td>R55MA02</td>
<td>Poor maintenance of BAS</td>
<td>It will affect the comfort environment.</td>
</tr>
<tr>
<td>R56MA02</td>
<td>Poor maintenance of BAS</td>
<td>It will decrease the performance of building</td>
</tr>
<tr>
<td>R57MA04</td>
<td>The BAS maintenance complies with the building regulation/codes</td>
<td>It will assure the quality of BAS maintenance</td>
</tr>
<tr>
<td>R58MA04</td>
<td>The BAS maintenance complies with the product specification.</td>
<td>It will assure the quality of BAS maintenance</td>
</tr>
<tr>
<td>R59MA05</td>
<td>BAS maintenance is in accordance with the standard operation procedures (SOPs)</td>
<td>It will result in the quality of BAS maintenance.</td>
</tr>
<tr>
<td>R60MA06</td>
<td>The building systems are feasible/adaptable/accessible</td>
<td>These will meet with the occupants' expectations</td>
</tr>
<tr>
<td>R61MA06</td>
<td>The building systems are friendly/comfortable/convenient</td>
<td>These will meet with the occupants' expectations</td>
</tr>
<tr>
<td>R62MA06</td>
<td>The building systems are designed to minimise the energy consumption</td>
<td>These will meet with the occupants' expectations</td>
</tr>
<tr>
<td>R63MA06</td>
<td>The building systems are effective/responsive.</td>
<td>These will meet with the occupants' expectations</td>
</tr>
<tr>
<td>R64MB02</td>
<td>BAS integration is appropriate.</td>
<td>It will result in the quality of BAS maintenance.</td>
</tr>
<tr>
<td>R65MB02</td>
<td>BAS integration is appropriate.</td>
<td>It will facilitate energy conservation</td>
</tr>
<tr>
<td>R66MB02</td>
<td>BAS integration is appropriate.</td>
<td>It will facilitate comfortable/healthy environment.</td>
</tr>
<tr>
<td>R67MB02</td>
<td>BAS integration is appropriate.</td>
<td>It will enhance the smart/intelligent features.</td>
</tr>
<tr>
<td>R68MB03</td>
<td>BAS maintenance rates in the office building are high.</td>
<td>These will increase the maintenance costs.</td>
</tr>
<tr>
<td>R69MB03</td>
<td>Maintenance strategy is appropriate.</td>
<td>It will reduce the BAS maintenance rate.</td>
</tr>
<tr>
<td>R70MB03</td>
<td>BAS maintenance rates in the office building is low.</td>
<td>These will decrease the maintenance costs.</td>
</tr>
<tr>
<td>R71MB03</td>
<td>BAS maintenance utilises the computer aids.</td>
<td>It will optimise the BAS maintenance and effectiveness.</td>
</tr>
</tbody>
</table>
Facilities managers often communicate with the occupants and designers. These will meet with the occupants' expectations.

Integration of the building systems is appropriate. It will facilitate energy conservation.

Integration of the building systems is appropriate. It will facilitate comfortable/healthy environment.

Integration of the building systems is appropriate. It will enhance the smart/intelligent features.

Problem solving is effective. It will meet the occupant's expectations.

Dealing with complaints is effective. It will meet the occupant's expectations.

Tracking problem solving is effective. It will meet the occupant's expectations.

Maintenance supports by the designers and vendors. It will ease the BAS maintenance.

Occupants communicate complaints to facilities manager. These will ease the BAS maintenance.

Facilities managers deliver problems to designers. These will enhance the BAS design.

Office buildings apply individual controls. These will facilitate energy conservation.

Office buildings apply individual controls. These will facilitate comfortable/healthy environment.

Office buildings apply individual controls. These will enhance the smart/intelligent features.

HVAC operation is appropriate. It will facilitate energy conservation.

Security systems are equipped with separate power supply. These will ensure the life safety and security.

Security systems are interfaced with the fire systems. These will ensure the life safety and security.

Access control is equipped with smart cards/key code/ID cards. It will enhance the smart/intelligent features.

Access control is equipped with smart cards/key code/ID cards. It will ease security management.

CCTV presence detectors are archiving equipped. It will enhance the smart/intelligent features.

CCTV presence detectors are archiving equipped. It will ease the security management.

Maintainers support by up-to-date information and instruction/ manual. These will ease maintenance.

Maintainers support by the historical records. These will ease maintenance.

Maintenance is scheduling as monthly and yearly. It will assure the quality of BAS maintenance.

BAS evaluation is carried out by the facilities manager. It will assure the quality of BAS maintenance.

BAS evaluation is supported by the evaluation tools. It will assure the quality of BAS maintenance.
Figure 5-23: Knowledge Inference Flow
CHAPTER 6

GUIDELINES DEVELOPMENT

6.1 Introduction
6.2 Strategies for Raising Awareness and Understanding
   6.2.1 Principles of Process Integration between Design and Maintenance
   6.2.2 Building Life Cycle Process
   6.2.3 Responsibilities and Capabilities of Design and Maintenance
   6.2.4 Understand the High Performance and Energy Conservation of Office Building
   6.2.5 Employ Strategic Process Integration for BAS Design and Maintenance
   6.2.6 BAS Components
6.3 General Strategies for Promoting Design and Maintenance Integration
   6.3.1 Select Suitable Design Professionals
   6.3.2 Specify the Applicable and Constructible BAS Specification
   6.3.3 Ensure Appropriate Product/Systems Integration
   6.3.4 Integrate Systems with Infrastructure Functionality
   6.3.5 Optimise Operational and Maintenance Practices
   6.3.6 Select Appropriate Maintenance Strategy
   6.3.7 Facilitate Building Commissioning for Better Results
   6.3.8 Strategies for High Performance, Energy Conservation and Comfort
   6.3.9 Energy Efficient HVAC Design
   6.3.10 Select Energy Efficient Lighting and Electric Lighting Controls
   6.3.11 Minimise Energy Consumption
   6.3.12 Promote Healthy and Comfortable Environments
   6.3.13 Strategies for Security/Fire System Design and Maintenance
   6.3.14 Embed Life-Cycle Cost Analysis (LCCA) into Consideration
6.4 Operational Checklists
   6.4.1 Checklists for Building Automation System Implementation
   6.4.2 Select Applicable and Reliable Building Automation Systems and Products
   6.4.3 Execute BAS Maintenance Schedule checklist
   6.4.4 Checklist for BAS Design
   6.4.5 Checklist for BAS Installation
   6.4.6 Checklist for BAS Commissioning
   6.4.7 Checklist for BAS Maintenance
   6.4.8 Apply Life-Cycle Cost Analysis (LCCA)
   6.4.9 Project Delivery System (PDS)
6.5 Summary
6.1 Introduction

Conclusions from the previous chapters have demonstrated three necessities to further highlight conceptions and develop applicable strategies and checklists. This chapter will extend the results of survey and case study by deploying the extracted knowledge to generate a number of general strategies and operation checklists to improve application and then to form a knowledge database for the platform development of computerised decision support.

Expectations for performance, energy conservation and occupants comfort have become key issues for the office buildings development in recent years, as confirmed and verified in the previous chapters of this thesis. The gratification of these expectations are eventually judged by the building occupants. Therefore, building owners and managers are interested in having satisfied tenants. In addition, they are also interested in safety, systems reliability, and efficiency of building operation and maintenance. These should be the design goals set for the design and implementation teams.

Keeping the BAS smart and sustainable for maintenance is a challenge in office buildings. It can be seen from the professional surveys detailed in Chapter 5: the lack of consensus as to its importance and the lack of effective support tools during the decision making phase, either in the design or maintenance stage. In addition, it also reflected the needs of the applicable strategies for the process. In BAS practice, there are several strategies and principles that should be taken into consideration during the integration of design and maintenance processes.

The right decisions come from having sufficient and adequate information from using basic principles and applicable strategies. BAS design for the controlled devices and subsystems do not operate in vacuum. It must be associated and conciliated with the building systems and the structure.

Therefore the first basic rule of BAS design is to make the building suitable for the process or to ensure comfort requirements. The second rule is that a BAS must be properly designed to satisfy the processes or comfort requirements. For instance, the best HVAC system cannot overcome inherent deficiencies in the building. Only
when these criteria have been satisfied can a suitable BAS be applied (Roger W. Haines & C. Lewis W. 1998).

Discussed in the previous chapters, several strategic methods encompassing the Building Commissioning (BC), Total Quality Management (TQM) and Life Cycle Cost Analysis (LCCA) are effective and applicable for the improvement of building processes including design and maintenance. Based on the author’s experience in quality control and quality assurance of the aeronautical vehicle maintenance and construction/ building management, the effective application of the management techniques and program can enhance the quality to ensure the system performance. The following sections will step into the practical executive application by introducing the principles, strategies and checklists with embedding TQM, BC and LCC concepts, principles and techniques.

In this research the knowledge extraction from the design and maintenance practice, BAS product specification, relevant regulation and BAS technology application which are essential for improving the practice, have been compiled and listed as in the following guidelines and checklists. They can be primarily categorised into conceptual strategies, general strategies and operational checklists covering seven aspects:

(1) Integration concepts and principles,

(2) Smart design and integration,

(3) Sustainable maintenance,

(4) Performance, energy conservation of building and comfort,

(5) Fire/ security system,

(6) Life cycle costing consideration,

(7) BAS design and maintenance implementation.
The following guidelines and checklists have been designed in the form of the standard operation procedure (SOP) for easy application and update which includes Title, “Code”, “Purpose”, “Scope of Application”, “Process”, “References”, “Version”, “Published Date”, “Revised Date”, “Published Authority” and “Note”. During the application the users can check the titles related to the subjects, and then find the guidance lists to follow. The guidelines and checklists have been shown with the code system as in Figure 6-0, and they can be used as a base for further extension or expansion.

Figure 6-0: Guideline Development
6.2 Strategies for Raising Awareness and Understanding

Before executing the strategies and operational checklists, a complete and understanding of the office building status in energy conservation, performance expectations and strategic process integration and related issues are necessary. The guidelines with the codes have been outlined as in Figure 6-1:

The following sections will explain the generation of Guidelines G001-G008 in details.
6.2.1 Principles of Process Integration between Design and Maintenance

The implementation of process integration relies on sufficient understanding of the principles of integration, and applies strategies and operational actions. In this section, the principles of process integration will be firstly disclosed to raise an awareness of integration mechanism. The integration principles associated with different aspects are illustrated as in Guideline #01:

Guideline #01

<table>
<thead>
<tr>
<th>Title:</th>
<th>Principles of process integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code:</td>
<td>G001</td>
</tr>
<tr>
<td>Purpose</td>
<td>To enhance the awareness and understanding of the objectives</td>
</tr>
<tr>
<td>Application</td>
<td>Whole building process</td>
</tr>
</tbody>
</table>

Process Integration

- Integrated Design and Maintenance philosophy
- Motivation of Integration
- Identification of the needs
- Integration Preparations
- Interdependent parties

Understanding the relationship between design and maintenance

Integration Design and Maintenance

- Participants are educated about the issues
- Learned the prospective solutions
- Decisions are accelerated and verified
- Difficulties are diminished
- Design/ maintenance processes are interacted
- Important issues are explored

References §4.4
Version 1 Ed.
Pub. Date 1 OCT, 2004
Rev. Date
Pub. Authority QUT
Note
The purpose of process integration is to communicate closely between design and maintenance throughout the building life process. The process integration facilitates the exchange of ideas and information and allows integrated solutions, and encourages “cross fertilizing” and addresses problems by brainstorming at the outset of the building project. The process integration initiates from the needs and expectations through the strategic alliances to integrate the building phases as design and maintenance for the designated objectives. In the decision stage, the integration will refer relevant information and focus on the targets to undertake necessary activities including matrix organization constituting and meeting. Eventually, an execution team organised by the interdependent parties with intimate communication will accomplish the missions via the strategic methods such as TQM, BC and LCC.

6.2.2 Building Life Cycle Process

Design and maintenance decisions need to be made as an integral part of a circular building life-cycle process. Depending on the building project, all phases of the life-cycle process can have their lifetime implications as illustrated in Guideline #02:

Guideline #02

<table>
<thead>
<tr>
<th>Title</th>
<th>Building life cycle process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G002</td>
</tr>
<tr>
<td>Purpose</td>
<td>To certify the relationship between different entities.</td>
</tr>
<tr>
<td>Applications</td>
<td>Whole building process</td>
</tr>
<tr>
<td>Process</td>
<td>Design development, Specification, Plan</td>
</tr>
<tr>
<td></td>
<td>Construction Commissioning</td>
</tr>
<tr>
<td></td>
<td>Operation and Maintenance</td>
</tr>
<tr>
<td>References</td>
<td>ASHRAE 2003; FCC 2001; §4.2.3.1</td>
</tr>
<tr>
<td>Version</td>
<td>1 Ed.</td>
</tr>
<tr>
<td>Pub. Date</td>
<td>1 OCT, 2004</td>
</tr>
<tr>
<td>Rev. Date</td>
<td></td>
</tr>
<tr>
<td>Pub. Authority</td>
<td>QUT</td>
</tr>
<tr>
<td>Note</td>
<td></td>
</tr>
</tbody>
</table>
The design and construction and maintenance of most office buildings are rooted in similar design decisions, construction practices, and economic assumptions. Optimism is an endless process, since there is an increasing expectation of high-performance office buildings which can offer owners and users to increase worker satisfaction and productivity, improve health and flexibility, and to enhance energy and environmental performance. Realisation of the building life cycle process can help optimise the initial investments in design, systems selection and installation, furthermore, to ensure cost-effective operations and maintenance activities.

6.2.3 Responsibilities and Capabilities of Design and Maintenance

The guidelines of the integration between design and maintenance for office building automation can be applied for three different groups such as design, maintenance, and building owner/developer in accordance with their respective responsibilities and capabilities. The practitioners from all parties should be assembled as a team or a matrix team to execute and coordinate the tasks and missions during the process. They will include:

- Architect, planner, BAS designer and consultants (Design)
- Facilities managers, and maintainers (Maintenance)
- Building Developers/owner, occupants, and users (Building owners/Developers)

The following guideline is associated with the responsibilities and capabilities of these representatives which can be outlined as in Guideline #03:
Guideline #03

<table>
<thead>
<tr>
<th>Title</th>
<th>Responsibilities and capabilities of design and maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G003</td>
</tr>
<tr>
<td>Purpose</td>
<td>Distinguish the liabilities</td>
</tr>
<tr>
<td>Application</td>
<td>Design stage, operation and maintenance stage</td>
</tr>
</tbody>
</table>

### Responsibilities and Capabilities

- **Design**
  - Compiling relevant technical information of design and maintenance
  - Writing up the specification of BAS and standard operation procedures
  - Coordinating the facilities specialists and systems providers
  - Integrating the BAS with the building design
  - Providing life time support for the building maintenance
  - Providing technical support for building systems renewal

- **Maintenance**
  - Maintenance manager participating in the charter organised by the architectural designer
  - Realising BAS specification and the function of designated systems
  - Auditing the building commissioning
  - Handing over the building systems from the designer
  - Managing the maintenance management during the building life
  - Coordinating the systems specialists and providers to maintain them
  - Responding status of the building maintenance such as failures of facilities and systems, technical problems

- **Building owners/Developers**
  - Assembling a committee for the building management
  - Organising and participating in a charter including designers, contractors, the developer or building owner during the design and construction stage
  - Training the managing officers and facilities maintainers to understand the facilities and functions of the building and to know how to operate and manage
  - Commissioning the building facilities to assure the quality of requirements during various project delivery
  - Decision making on the style of building maintenance and management as:
    - Setting up an independent organisation to run and manage the building
    - Contracting a maintenance company to execute the maintenance
    - Outsourcing the maintenance specialists

### References

- §4.4

### Notes

- QUT

Realisation of the responsibilities and capabilities of the design and maintenance can facilitate a better understanding of the liabilities of different phases among project participants. At the same time, it also might promote the support to others for the smooth continuum of building process.
6.2.4 Understand Comfort, Healthy and Energy Conservation of Office Building

No matter how people describe what constitutes an "Intelligent office building", occupants generally expect that office buildings can provide comfort, healthy environment and energy conservation. Thus, to reach these expectations, office buildings should have several attributes such as being integrated, flexible, safe, healthy, comfortable, energy efficient, life cycle cost considerations, and properly constructed and maintained. These attributes are described as in Guideline #04, their associated HVAC systems and controls are listed as in Guideline #05:

Guideline #04

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library.
Office building should be innovated with the rapid advanced technology to meet the client’s increasing expectations. After office buildings delivery and occupied, maintenance through an insistent process of metering, monitoring and reporting to inform maintenance operations and the feedback will be available to new design efforts. Integrated, flexible and properly constructed/ maintained buildings with life cycle cost consideration can sustain a high performance and energy conservation and comfort environment.

Guideline #05

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library
6.2.5 Employ Strategic Process Integration for BAS Design and Maintenance

The fundamental concept of integration is to recognise that all building systems are interdependent and building processes are interactive, and the effective integration of both systems or processes is beneficial for the building’s life. The strategic integration between design and maintenance allows people to communicate during the decision making process. To promote the benefits of the process integration, comparing it with the conventional process in office buildings to realise their pros and cons is necessary. Conventional building design tends to be undertaken with little interaction between the parties involved in the building life. The architect creates a design and hands it on to the engineers who then design their systems, sometimes independent of each other, before passing the design to the contractor. The building owners and the users will then take over to operate and maintain these building systems during the rest of the life of buildings.

In contrast, based on this inherent occupancy process and the above benefits of the process integration, the integrated building design and maintenance approach could incorporate all parties. They would be involved in the building project working together from the start to coordinate and optimise the design of the building by constantly communicating and supporting each other, to assure the technical continuum and quality of service during the building’s lifetime.

Comparing the current independent conventional process with process integration, the benefits of the process integration can be summarised as in Guideline #06:
Guideline #06

<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>Benefits of process integration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code</strong></td>
<td>G006</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>Aware of the benefits of process integration</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Whole building process</td>
</tr>
</tbody>
</table>

**Benefits**

- Ineffective design and system installation resulting in excess capital investment and redundant costs
- Failing to meet needs/functional requirements of the owners and occupants
- Occupant discomfort
- Decreased occupant productivity
- Poor energy performance
- Harmful environmental impact
- High operating and maintenance costs

**Benefits of process integration**

- Optimised the design and system application
- Satisfying the needs/functional requirements of the owners and occupants
- Improved occupant comfort and health
- Increased occupant productivity
- Energy efficiency
- Environmental sustainability and positive environmental impact
- Low operating and maintenance costs

**Limitations of Conventional Process**

- Ineffective design and system installation resulting in excess capital investment and redundant costs
- Failing to meet needs/functional requirements of the owners and occupants
- Occupant discomfort
- Decreased occupant productivity
- Poor energy performance
- Harmful environmental impact
- High operating and maintenance costs

**References**

§2.2.7

**Version**

1 Ed.

**Pub. Date**

1 OCT, 2004

**Pub. Authority**

QUT

**Note**

Based on the integrated building systems which has been installed in the building, via strategic methods- BC, TQM, LCC as Guideline #01, the designers extend their service and support to building operation and maintenance after building delivery. BC, TQM and LCC are focusing on the customer’s satisfaction, commissioning the gaps and life time costs as discussed in Section 2.6.2~ 2.6.4. The intimate communication and support can facilitate the integration between design and maintenance processes. Therefore, the ineffectiveness and inefficiency in the initial
investment, operation and maintenance, energy conservation, occupant’s comfort can be enhanced and converted to the effectiveness and efficiency through the process integration.

6.2.6 BAS Structure

The objective of a building automation system (BAS) is to achieve an optimal level of control for occupant comfort while minimising energy use. These control systems are the integrating components such as fans, pumps, heating/cooling equipment, dampers, mixing boxes, and thermostats. Monitoring and optimising temperature, pressure, humidity, and flow rates are key functions of modern building control systems. Modern control systems have three basic key elements: sensors, controllers, and the controlled devices as listed in Guideline #07:

Guideline #07

<table>
<thead>
<tr>
<th>Title</th>
<th>Components of BAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G07</td>
</tr>
<tr>
<td>Purpose</td>
<td>To realise the major components of BAS</td>
</tr>
<tr>
<td>Applications</td>
<td>Whole building process</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Components</th>
<th>Sensors</th>
<th>Controllers</th>
<th>Controlled Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="diagram.png" alt="" /></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References: UNESCO 1984; Eyke, M. 1988; §2.5.2

Version: 1 Ed.

Pub. Date: 1 OCT, 2004

Rev. Date:  

Pub. Authority: QUT

Note:  

234
There are increasing varieties and levels of sophistication of sensors available for use with modern control systems such as sensors for sensing temperature, humidity, pressure, flow rate, and tracking indoor air quality, lighting level, and fire or smoke.

Controllers may be very simple, such as a thermostat where the sensor and controller are usually co-located, to very sophisticated microprocessor based systems capable of powerful analysis routines. Thermostat, sophisticated microprocessor based systems compares a signal received from the sensor to a desired set point, and then sends out a corresponding signal to the controlled device for action such as terminal device receiving the signal from the controller, and air dampers, mixing boxes, control valves, fans, pumps, and motors which control the building systems and equipments.

The calibration of sensors in the BAS maintenance is an often ignored activity. However, sensors should be calibrated regularly as sensors out of calibration can lead to excess energy consumption. The key elements as sensors and actuators are listed as in Guideline #08:

Guideline #08

The media of sensoring mostly vary as air/ water, humidity and pressure. These sensors and actuators have a variety of applications for humidity as wet bulb
temperature or relative humidity (RH) sensors, for pressure as static pressure transmitters, and for air and water as:

◊ Outside air temperature
◊ Mixed air temperature
◊ Return air temperature
◊ Discharge or supply air temperature
◊ Air and water flow rates
◊ Terminal unit dampers and flows.
◊ Heating water supply temperature
◊ Condenser entering water temperature
◊ Chilled water supply temperature
◊ Space temperature sensors

6.3 General Strategies for Promoting Design and Maintenance Integration

The following sections will outline the strategies to promote the integration activities between design and maintenance in office building automation contexts. These strategies encompass smart design and sustainable maintenance, effective performance and energy conservation, security and comfort, life cycle costing consideration. These strategies will be helpful in facilitating the performance and quality of office buildings by means of the guidance and the recommendations provided within the categories of design and maintenance in this thesis.
The general strategies are illustrated in the diagram associated with the specific issues of BAS design and maintenance as in this outline of strategies:

Figure 6-2: Outline of the General Strategies
6.3.1 Select Appropriate Design Professionals

The success of a building project relies on the base of acquiring a design professional. It needs to start from the beginning with the selection of reliable designers as well as the application of an integration process. The criteria of selecting a suitable design professional for the office building project should primarily consider the execution and completion of the project, especially for office building automation system. During the selection process of a designer, their expertise and experience is fundamental for technical subjects as well as the non-technical key issues such as enthusiasm, responsibility, communication, serviceability, reliability, etc.

It is important that the panels responsible for professional selections have an understanding of the capabilities of BAS designers with the ability to compare the potential designers using the criteria such as previous experience, confidence, capacity to complete the work on time and to provide overall customer service. In brief, the instructions for the designer selection are illustrated as in Guideline #09:
Guideline #09

Title | Tips for the design professional selection
---|---
Code | G009
Purpose | Encompass major criteria for professional selection
Application | Initial design stage

**Notes**

The selection of the design professionals should compare their strength and weakness, professional expertise, associated with their experience to ensure the suitability for the project. To help define the boundaries of professional responsibility, adequate consultations and outsourcing support can be useful to the decision making of professional selection. The selection process can refer the related association or organization to seek relevant information and guidelines about the...
legal role of their members in the building design and construction process such as the Australian associations.

6.3.2 Specify the Applicable and Constructible BAS Specification

Optimised specification design of BAS not only help specify the needs and requirements of systems to perform the functions of installed facilities and facilitate the effectiveness of the system operations, but also gain the greater economy by reducing life costs of the building. The building projects are normally unique and specially planned for the particular facilities and for BAS to achieve their designated intentions, thus the BAS application should be designed through the specification instructions for the procurement, installation and maintenance. The optimised specifications provide a good template for system planning, procurement and system selection, and easy to achieve the commissioning which will ensure the quality of systems and the updating fundamental information. No sustained BAS specification would be countenanced the risk of abnormal functions and difficulties for future expansion. When ignored or not specified properly, these non-technical requirements can also be a source of argument (Jeffrey Cosiol 2001), therefore the strategies for designing BAS specification are summarised in Guideline #10, 11, 12:

Specification is a standard for execution to ensure the quality and meet the requirements during the BAS installation and commissioning process. The designed specification should consider the compromisation of the needs, execution requirements as well as the concise terms, in addition, integration with the contract tool for payment to ensure the quality of design as illustrated in Guideline #10.
Tailored specification with the needs initiates the BAS application. Integrated specification encompassed the whole stages will ease the completion of tasks. Clearly description of specification will reduce the arguments during the process and compromise the requirements. A essential and useful tool is the contracted payment which can ensure the quality and time requirements of the project.
Standard requirements of designing the specification will help the procurement, installation, operation and maintenance process. It includes general conditions, BAS design and future expansion requirements as illustrated in Guideline #11.

Guideline #11

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library.
To the specification design, the simple, instructive and acceptable specification is handful. It encompasses several tips as the reviews of the factory testing, project acceptance and testing requirements, basic contract practices, future expansion, and specification preparation which are summaried as in Guideline #12.

Guideline #12

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library
BAS has become one of the most important systems in office building, as a building owner, or a facilities engineer, facing the growing range of products from BAS manufactures and vendors that has made hundreds of systems available, it is essential to concentrate on selecting the right system for the building. The following tips in Guideline #13 could guide to avoid the most common mistakes.

Guideline #13

To avoid the possible pitfalls for BAS selection, several instructions are needed. As such, the availability of most components as sensors, transducers, dampers, valves, and actuators, as well as the DDC hardware can be provided. Localized training, the product/ service and support are available from multiple sources and effectively provided from the local area. The compatible products for the replacement are easily...
available with having complete documentation to prevent continuum problems. It is necessary to keep closely contacts between system maintainers and providers and gain their support. In addition, it also needs to avoid multiple manufacturers’ products to keep liability with a single manufacturer for the total support. A reference is required which is similar in size and scope to the system from other completed systems for the quality check.

Moreover, reliability of BAS is a great concern for office building occupants. Absence of reliability directly affects personal security and well-being. The building systems should function without interruption, otherwise it will affect the safety, health, and comfort of occupants, and reduce effectiveness.

Building occupants increasingly expect to work in comfort place without breakdowns. Building and information system disorders will not be tolerated. The workforce demand good working environments that enable them to do their best work. This calls for systems that perform reliably with good maintenance support.

Building users must be able to rely on facility hardware and software for health, life, safety, power, data, and voice delivery systems. These systems need to function consistently and be properly maintained. When the work environments are supported by functional and reliable systems that require minimal maintenance or downtime and have back-up capabilities to ensure negligible loss of service, worker productivity can be improved or maintained. The strategies for assuring the reliable systems is summarised in Guideline #14:
Guideline #14

In general, the building systems as HVAC, lighting, power supply, fire and security, and ICT infrastructure are affected by their reliabilities. To assure that the systems are reliable, these building systems not only rely on the right selection and installation performance based systems in the initial design, but also on appropriate maintenance strategy during the building life as utilizing the reliability-centred maintenance (RCM).
6.3.3 Ensure Appropriate Product/ Systems Integration

Building systems, materials and products incorporated into a design must be integrated to create a unified whole that achieves the desired functional purpose. System integration comes from considering the characteristics and properties of each system or product, its role and its needs for installation, requirements coordination with other building systems and O&M serviceability. System integration is described in Guideline #15:

Guideline #15

System integration initiates from the understanding the needs of occupants to explore a variety of design solutions. With the consideration of the pros/ cons of each alternative on the functional performance, it involves users to evaluate and understand design implications/ functionalities. During the process of the system integration, several strategies should be developed such as:

◊ Develop design concepts with a clear understanding facility's functional purpose,
◊ Address functional requirements and goals,

◊ Select appropriate systems and products with integrated design objectives.

◊ Select products/systems that are compatible with design objectives.

◊ realise the Owner's equipment requirements and integrate with the design.

◊ Anticipate the needs of the building maintenance as far as possible.

Finally, to assure the effective system integration, regular building systems maintenance should be accomplished by using the Building Commissioning (BC) approach and Total Quality Management (TQM) throughout the planning, design, construction, operation, maintenance life cycle.
6.3.4 Integrate Systems with Infrastructure Functionally

Information technology architecture calls for an effective, global, and secure information technology infrastructure that will support the growing demands of office buildings. Assuring flexibility to accommodate the dynamic nature of telecommunications systems starts first and foremost with properly designed pathways and spaces. The strategies for integrating with the infrastructure are listed in Guideline #16:

Guideline #16

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

To construct an integrated, configurable, and distributable infrastructure for conforming with the requirements of office building automation, the hardware and software should be designed adequately. It encompasses data, information, voice, video and power systems and interfaces such as:
◊ Distribute Uninterrupted Power Supply (UPS) for reliable power.

◊ Monitor work environmental conditions with central systems, but maximise local control by occupants.

◊ Provide appropriate open riser space and manage wiring under floor or vertically through patch panels.

◊ Conduct a multidiscipline plenum with structural, fire, networking, HVAC to integrate systems in the floor.

◊ Provide flexibility using flexible connectors and design for expandability, disassemblability, re-cyclability and internet compatibility.
6.3.5 Optimise Operational and Maintenance Practices

Throughout the building's life cycle, operation and maintenance should seek to optimise the procedures and keep the process simple, enhance the training, be equipped with automated devices and minimise the path of the activities in Guideline #17:

Guideline #17

To reach the optimization of the design and maintenance, it needs to implement a comprehensive, effective maintenance program to keep all building systems functioning as intended by design and to provide operation and maintenance support for facilities managers and maintenance personnel, and to use adequate sensors for controlling the lighting and HVAC systems, and to support digital transfer to avoid unnecessary air travel.

Sustainable maintenance can help the efficiency of the system’s functionality and performance. However, for life cycle considerations an applicable maintenance strategy would be needed for people to follow to effectively execute the regular maintenance tasks and the maintenance continuum. The following section will introduce several common strategies for maintenance.
6.3.6 Select Appropriate Maintenance Strategy

In order to execute effective maintenance for an office building, a suitable maintenance strategy is essential for the BAS application and service, which should be adequately selected. Varying strategies should take into consideration so that the ones selected will correspond to the needs during the maintenance process. In brief, the right choice relies on maintainers’ fully understanding the needs and understanding the advantages and disadvantages of maintenance strategies.

They commonly include reactive maintenance, preventive maintenance, reliability centred maintenance (RCM), and predictive maintenance approach. Reactive maintenance is a run to failure maintenance. Preventive maintenance which is simply the scheduling of regular maintenance actions to prevent the occurrences of failures to a product. Reliability centred maintenance (RCM) is a maintenance scheme based on the reliability of the various components of the system or product in question. Predictive maintenance approach attempts to detect the onset of equipment degradation and to address the problems as they are identified.

An appropriate maintenance strategy could help ensure the performance and functionalities of BAS and subsystems. Guideline #18 provides a snapshot of the different strategies with their pros and cons assessed respectively.
Guideline #18

<table>
<thead>
<tr>
<th>Title</th>
<th>Strategies for selection maintenance strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G018</td>
</tr>
<tr>
<td>Purpose</td>
<td>To carry out the maintenance tasks effectively</td>
</tr>
<tr>
<td>Applications</td>
<td>Operation and Maintenance stage</td>
</tr>
</tbody>
</table>

**Strategies**

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Reactive maintenance                | ◇ Has lower initial costs  
                                             ◇ Requires fewer staff        | ◇ Increases costs due to unplanned downtime of equipment  
                                             ◇ Increases labor costs, especially if overtime is needed for untimely repairs or replacement  
                                             ◇ May increase costs associated with repair or replacement  
                                             ◇ Is an inefficient use of staff resources |
| Preventive maintenance              | ◇ Is cost effective in many capital intensive processes and equipment  
                                             ◇ Provides flexibility for the adjustment of maintenance | ◇ Does not eliminate catastrophic failures  
                                             ◇ Is more labor intensive  
                                             ◇ Includes |
| Predictive maintenance              |                                                                         |                                                                              |
| Reliability centered maintenance (RCM) |                                                                     |                                                                              |
### Reliability centred maintenance (RCM)

- Increases component life cycle
- Generates energy savings
- Reduces equipment and/or process failures

- Performs increased component operational life and availability
- Allows for preventive/ corrective actions
- Results in decrease in equipment and/or process downtime
- Lowers costs for parts and labor
- Provides better product quality
- Improves worker and environmental safety
- Raises worker morale
- Increases energy savings

- Can be the most efficient maintenance program
- Lowers costs by eliminating unnecessary maintenance
- Minimises the frequency of overhauls
- Reduces probability of sudden equipment failures
- Focuses maintenance activities on critical system components
- Increases component reliability

### Predictive maintenance approach

- Performs increased component operational life and availability
- Allows for preventive/ corrective actions
- Results in decrease in equipment and/or process downtime
- Lowers costs for parts and labor
- Provides better product quality
- Improves worker and environmental safety
- Raises worker morale
- Increases energy savings

- Can have significant startup costs associated with staff training and equipment needs
- Savings potential is not readily seen by management

### References

### Notes

6.3.7 Facilitate Building Commissioning for Better Results

Building commissioning should be tailored to match with the building project and completed to assure meeting the requirements the quality of design. The strategies for building commissioning can be summarised in Guideline #19:

**Guideline #19**

<table>
<thead>
<tr>
<th>Title</th>
<th>Strategies for building commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G019</td>
</tr>
<tr>
<td>Purpose</td>
<td>To ensure the quality of building systems as the designed</td>
</tr>
<tr>
<td>Applications</td>
<td>Hand-over stage, Operation and Maintenance stage</td>
</tr>
</tbody>
</table>
### Strategies

#### Scopes
- The HVAC Commissioning Process provides a blueprint for the commissioning of HVAC systems.

#### Activities
- Commissioning should begin during the earliest phases of project and design.
- It is essential that the assurance building systems meet design intent be captured as a premise for all activity.
- Building Commissioning must be a clear appreciation of the Scope, Cost, and Timing of activities.
- Commissioning requires identifying any operational deficiency. This process begins in the design phase and lasts at least one year after project completion (e.g. the warranty period). It also includes training of operational and maintenance staff.

#### Strategies
- The building owner typically hires an independent third party or qualified person to perform commissioning.
- Select the Commissioning Authority at or before the design stage of a project - Beginning in the design phase of a project can reduce changes and project delays.
- Hire an experienced Commissioning Agent (CA)
- Have a written Commissioning Plan - With a written plan, all project participants can anticipate and plan for commissioning requirements and milestones.
- Document the results and findings of Commissioning - Documenting provides a record of the benefits - Can be used in the future for troubleshooting problems and optimising operating strategies.

#### Who Responsible
- Commissioning Agent should work directly for the Owner or the Owner's Construction Management representative where they can most objectively represent the owner's interest. The person taking this responsibility can be:
  - Architect and Engineer (A/E)
  - Construction Manager (CM)
  - Contractor
  - Independent Agent

#### Applications
- From previous experience, the building construction management process is likely a continuous process of quality assurance (QA) from the design stage, procurement process, construction, hand over, and maintenance process which are in relation to the procedure audits such as document and procedure credit, process inspection and product audit.
- The more complex the building type and the more integrated the building systems, the more likely that a formal building Commissioning process will prove valuable.

### References
- ASHRAE Guideline 1 Guideline for the Commissioning of HVAC Systems; Prowler 2004;
- Second National Conference on building Commissioning (1994); §4.4

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- 1 OCT, 2004

### Rev. Date

### Pub. Authority
- QUT

### Note
6.3.8 Strategies for ensuring the quality of design and maintenance

The ensure the quality and performance of office buildings, the building process from design to maintenance should need to have comprehensive plans and alternatives. Initially, the design objectives and priorities need to define. A quality assurance program would be helpful. Executing the role of facility management and operations and monitoring post occupancy performance, it needs several approaches such as Total Quality Management (TQM), Building Commissioning (BC) and maintenance strategy such as Reliability Centered Maintenance (RCM) to ensure the quality meeting the occupant expectations.

Guideline #20

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.
6.3.9 Energy Efficient HVAC Design

Energy-efficient design utilising high-performance HVAC equipment often requires more collaboration from the design team with the associated parties during the process. Guideline# 21 lists the applicable guidance for HVAC during the decision making process of design stage.

Guideline #21

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Put all significant factors together</td>
<td>Factors such as: efficient lighting systems, daylight dimming controls, energy conservation design</td>
</tr>
</tbody>
</table>
| Set goals as early as possible | ◊ Set the objectives at the outset of the project  
◊ Emphasise communication  
◊ Clarify goals to meet or exceed the minimum requirements of codes or regulations during design stage  
◊ Establish a quantitative goal for energy conservation  
◊ Develop a written proposal that put into words of the goals. |
| "Right Size" HVAC system design to ensure efficiency | ◊ Apply safety factors to a reasonable baseline.  
◊ Accept the HVAC safety factors and load allowance stated in ASHRAE/IES 90.1-1989 as an upper limit  
◊ Exploit the energy analysis tools to eliminate excess oversizing. |
| Consider part-load performance and reduce the load | ◊ Select systems and equipments that can operate efficiently at part-load.  
◊ Use BAS to avoid unnecessary peak demand charges.  
◊ Explore thermal storage systems and examine alternate sources for heating and cooling systems. |
| Plan for future expansion | ◊ Don’t provide excess capacity today for a future load  
◊ Provide the spare space required for additional equipment.  
◊ Design distribution systems that can easily accept additional equipment for the future expansion. |
| Commission the HVAC systems | ◊ Building commissioning as ASHRAE Guideline 1 can help facilitate the energy conservation |
| Establish an Operations and Maintenance plan | ◊ Identify systems that can be properly maintained.  
◊ Provide system interfaces to allow easily monitor and adjust.  
◊ Compose systems control, operation, and maintenance training plans  
◊ Establish a written, comprehensive operation and maintenance plan. |

References
ASHRAE/IES 90.1 (1989); ASHRAE Guideline 1; Graham, C. I. (2004); §4.4

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In addition to the HVAC, the electrical power and lighting systems play a major part in energy consumptions as well. In order to effectively achieve energy savings, the selection of efficient lighting equipment and the adaptation of effective control systems are essential. The following sections all present the strategies to this issue.

### 6.3.10 Select Energy Efficient Lighting Controls

The various electric lighting controls can be selected according to need. Selecting the appropriate lighting controls will help the lighting systems provide both comfort and energy conservation, which can be done by the enquiring of and coordinating with the selected control manufacturer. It will help to avoid surprises during construction and commissioning. The appropriate lighting controls can be selected in accordance with Guideline #22:

**Guideline #22**

<table>
<thead>
<tr>
<th>Title</th>
<th>Strategies for the selection of lighting control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G022</td>
</tr>
<tr>
<td>Main Features and Purpose</td>
<td>To effectively select the lighting control to facilitate the energy conservation</td>
</tr>
<tr>
<td>Applications</td>
<td>Whole building process</td>
</tr>
</tbody>
</table>
| Strategies             | 1. Properly circuiting design with the simple switches and relays to reduce the energy consumption  
                        | 2. Selecting occupancy sensors to automatically turn on/off lights.  
                        | 3. Selecting lighting control to automatically adjusting with the daylight.  
                        | 4. Considering the centralised or distributed controls for the lights.  
                        |   a. Centralized control can integrate lighting controls with mechanical or security systems.  
                        |   b. Distributed control can be equipped with the emergency system |
| References             | §4.4                                          |
| Version                | 1 Ed.                                         |
| Pub. Date              | 1 OCT, 2004                                  |
| Rev. Date              |                                               |
| Pub. Authority         | QUT                                           |
| Note                   |                                               |
### 6.3.11 Minimise Energy Consumption

Energy conservation is a global concern owing to the uncertainty of oil supplies. With concerns for energy are increasing and the impact of greenhouse gases on world climate is rising, it is essential to find ways to reduce energy load, increase efficiency, and utilise renewable fuel resources. During the BAS design and development process, building projects must have a comprehensive, integrated perspective to attain energy conservation as in Guideline# 23:

**Guideline #23**

<table>
<thead>
<tr>
<th>Title</th>
<th>Strategies for minimizing energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G023</td>
</tr>
<tr>
<td>Purpose</td>
<td>To ensure the energy conservation</td>
</tr>
<tr>
<td>Applications</td>
<td>Whole building process</td>
</tr>
<tr>
<td>Strategies</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Tips</strong></td>
</tr>
<tr>
<td>Specify Efficient HVAC and Lighting Systems</td>
<td>◊ Use energy efficient HVAC equipment and systems that meet ASHRAE 90.1 as the basis for energy efficiency and calculations. ◊ Use lighting systems that consume less than 1 watt/square foot for ambient lighting. ◊ Evaluate energy recovery systems that pre-heat or pre-cool in-coming ventilation air in office buildings. ◊ Investigate the use of integrated generation and delivery systems.</td>
</tr>
<tr>
<td>Optimise Building Performance and System Control Strategies</td>
<td>◊ Employ energy modelling programs early in the design process. ◊ Use sensors to control loads based on occupancy, schedule and/or the availability of natural resources such as daylight or natural ventilation. ◊ Evaluate the use of modular components such as boilers or chillers to optimize part-load efficiency and maintenance requirements. ◊ Evaluate the use of Direct Digital Controls.</td>
</tr>
<tr>
<td>Monitor Project Performance</td>
<td>◊ Use a comprehensive, building commissioning plan throughout the life of the project. ◊ Use metering to confirm building energy and environmental performance through the life of the project.</td>
</tr>
<tr>
<td>References</td>
<td>ASHRAE 90.1; WBDGMEC (2004); §2.6.3</td>
</tr>
<tr>
<td>Version</td>
<td>1 Ed.</td>
</tr>
<tr>
<td>Pub. Date</td>
<td>1 OCT, 2004</td>
</tr>
<tr>
<td>Rev. Date</td>
<td></td>
</tr>
<tr>
<td>Pub. Authority</td>
<td>QUT</td>
</tr>
<tr>
<td>Note</td>
<td></td>
</tr>
</tbody>
</table>
6.3.12 Promote Healthy and Comfortable Environments

Office building indoor environments can affect human health as well as occupant comfort. BAS design and development must have a comprehensive, integrated perspective that seeks to: maintain optimal thermal comfort, and create a high quality environment to enhance worker health, comfort and performance. The strategies for good design practice and sustainable maintenance can be summarised as in Guideline # 24:

Guideline #24

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximise Natural Daylight</td>
<td>◊ Integrate day-lighting with the electric lighting system.</td>
</tr>
<tr>
<td></td>
<td>◊ Consider dimming controls that continuously adjust lighting levels to</td>
</tr>
<tr>
<td></td>
<td>respond to daylight conditions.</td>
</tr>
<tr>
<td>Provide Quality Thermal and Ventilation Comfort</td>
<td>◊ At a minimum, comply with Australian codes and American Society of</td>
</tr>
<tr>
<td></td>
<td>Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)</td>
</tr>
<tr>
<td></td>
<td>◊ Provide individual air and temperature controls to ensure adequate</td>
</tr>
<tr>
<td></td>
<td>ventilation and comfort.</td>
</tr>
<tr>
<td></td>
<td>◊ Consider providing a temperature and humidity monitoring system to</td>
</tr>
<tr>
<td></td>
<td>ensure optimal thermal comfort performance.</td>
</tr>
<tr>
<td></td>
<td>◊ Evaluate the use of access floors with displacement ventilation for</td>
</tr>
<tr>
<td></td>
<td>flexibility, personal comfort, and energy savings.</td>
</tr>
<tr>
<td></td>
<td>◊ Utilise sensors to assess the air quality of spaces to adjust ventilation</td>
</tr>
<tr>
<td></td>
<td>and real time monitoring of air quality.</td>
</tr>
<tr>
<td></td>
<td>◊ Design the ventilation system to exceed ASHRAE Standard 62-</td>
</tr>
<tr>
<td></td>
<td>Ventilation for Acceptable Indoor Air Quality.</td>
</tr>
<tr>
<td></td>
<td>◊ Ensure that ventilation is effectively delivered and distributed.</td>
</tr>
<tr>
<td></td>
<td>◊ Consider separating thermal conditioning from ventilation.</td>
</tr>
<tr>
<td>Prevent Unwanted Moisture Accumulation</td>
<td>◊ Design the ventilation system to maintain the indoor relative humidity</td>
</tr>
<tr>
<td></td>
<td>between 30% and 50%.</td>
</tr>
<tr>
<td></td>
<td>◊ Design to avoid water vapor condensation.</td>
</tr>
<tr>
<td>Create a High Quality Visual Environment</td>
<td>◊ Integrate natural and electric lighting with BAS</td>
</tr>
<tr>
<td></td>
<td>◊ Balance the quantity and quality of light.</td>
</tr>
<tr>
<td></td>
<td>◊ Provide individual controls to task lighting and adjustable ceiling light.</td>
</tr>
</tbody>
</table>

References

ASHRAE Standard 55, 62; WDBGHC (2004); §2.6.1

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Note
6.3.13 Strategies for Security/ Fire System Design and Maintenance

The application and installation of BAS can serve to improve the security and safety by means of alarm and detection strategies, and communication systems. Backed by advanced technologies, each design must be tailored to achieve functional requirements on a case-by-case basis to select applicable safe systems and provide security. Guideline# 25 is offered to stimulate security thinking by demonstrating how security concepts and strategies may be applied.

Guideline #25

Preventive maintenance of the security system is essential whether the system is basic, serving a small installation, or complex, incorporating supervisory circuits in a high rise office building. Safety considerations for design and maintenance may include: information and data safety, human safety, and protection from terrorism etc. Fire warning and fire detection systems must be properly designed, installed and maintained such as:

◊ Installation commissioning should be carry out wherever a fire alarm system is installed.
◊ Fire precautions in the design, construction and use should be in accordance with the building regulations and Codes of Practice.
Mechanical ventilation systems should be designed so that in a fire air is drawn from protected escape routes and exits, or the system is closed down.

When a pressure differential system is installed, it should be compatible with any ventilation or air-conditioning systems in the building, should a fire break out.

All fire doors should be fitted with an automatic self-closing device.

6.3.14 Life-Cycle Cost Analysis (LCCA)

The LCCA as described in Guideline# 26 provides a significantly better assessment of the long-term cost-effectiveness of a project than alternative economic methods that focus only on first costs or on operating-related costs in the short run.

Guideline #26

LCCA can be repeated throughout the design process if more detailed cost information becomes available. Initially, construction costs are estimated by reference to historical data or cost estimating guides and databases. Non-fuel operating costs, and maintenance and repair costs are often more difficult to estimate than other building expenditures. Operating schedules, standards of maintenance vary from building to building; there is great variation in these costs even for buildings of the same type and age. Supplier quotes and published estimating guides sometimes provide information on maintenance and repair costs. Therefore, in the building life cycle, the historical records of building maintenance costs should be established.
6.4 Operational Checklists

The following sections will present sample checklists as the demonstration for the action guide and exploration for the integration template of design and maintenance. The outline of the operational checklists is shown in Figure 6-3.

Figure 6-3: Outline of the Operational Checklists
6.4.1 Checklists for Building Automation System Implementation

Comfort, safety and energy conservation of modern office buildings is controlled and maintained by whole building management systems. These building management systems include building control systems and the control of building systems such as (1) Heating, Ventilating and Air-conditioning systems (HVAC) and their associated systems, (2) Security and Fire systems, and (3) Building Automation System (BAS). BAS is the brain of the whole building management system. BAS operates and monitors the connected HVAC systems and security/fire systems by a series of programs and also provide information on the building control conditions to the building operation and maintenance personnel, and/or directly to the customers to meet with the expectation of occupants and the requirements of energy conservation.

In general the building systems alone can seldom provide adequate environmental conditions if there is no interaction with other systems. To assure the desired environmental conditions are meeting with occupant’s expectations, the building has to be designed from the early stages with the end goals in mind - which is occupancy comfort, safety, reliability and economical building operation. Architects, mechanical and control engineers, and building maintainers should, as one team, be participating in the whole design, installation, maintenance and turn over to the building owner to deliver an expected building environment to the occupants.

In order to guide effective BAS implementation, the checklists were designed and based on the Building Commissioning (BC), Total Quality Management (TQM) and Life Cycle Cost Analysis (LCCA) (Portland 1994; Boed, V. 1996, Sieglinde, F. 2004), and the author’s experience in quality control and quality assurance of the aeronautical vehicle maintenance and construction/building management. During the BAS implementation process, the checklists can be used as a design and maintenance tool to assure orderly progress during individual phases of the building project. Checklists in this section contain items that require attention at each phase of the project, as well as tips from design development through to maintenance implementation. Individual checklists were developed for each phase of the project and can be developed throughout the entire system implementation process.
Checklists are simple and valuable tools of providing an reminder and are used in many critical operations (MCCABE 1998). For example:

◊ In the field of aeronautical vehicle operation and maintenance, the checklists are popularly used to check the routine or complicated operation and maintenance works. Airline pilots do their pre-flight checks with checklists- a process they do before every take-off, during every flight. That would not be they could not remember which procedures to check, but to assure that all the important items are checked. They repeat the process throughout the most important ground and flight operations (Boed, V. 1996).

◊ In the building construction and management field, the facilities managers can use checklists accompanied with video camera for recording inspection of facilities during the maintenance process which can be used for trouble shooting and feed back to the designer during the whole building life.

For building automation systems implementation, checklists should be developed for every phase of the project - design, installation, commissioning and maintenance. This approach also encourages teamwork throughout the whole building process, which results in a historical record that contains inputs from mechanical, controls and facilities engineers. It will optimise the use of design, mechanical and controls systems in the building, and minimise the cost coming from wrong decisions throughout the implementation process. Focusing on quality to sustain the performance, checklist application will result in delivering a functioning building to the owner. The application of checklists will reliably maintain design parameters under designed conditions, and assure optimum first costs as well as operating and maintenance costs throughout the life cycle of the building.

The construction and building management process is regarded as a quality assurance process from the management view. Checklists should be used as tools to assure quality at every step of the systems implementation. Since every building and system is tailored for the proposed functions and purposes, the checklists should also need to be customised for the given building project.

Checklists included in this thesis only demonstrate several integration practice between design and maintenance for office building automation. These checklists can
not encompass the whole BAS field. The following sections are a compilation of selected checklists that have the most impact on building processes. They are divided into two major stages: design and maintenance. A full section of activities and checklists related to BAS’s system software development, operation, testing and validation are left out from this thesis. Nevertheless, they deserve to be taken into consideration since they are often least attention by architects, design and maintenance consultants, facilities managers and owners.

6.4.2 Select Applicable and Reliable Building Automation Systems and Products

While some of the building system problems can be traced back to poor installation on the part of the contractor, it is far more likely that the system selected was not matched to the needs of the facility. In these cases, the owner, the facility maintainer and the system designer did not do their work properly. They simply selected a particular system, and then forced it onto the facility. It was quick and simple. But the “quick and simple” approach does not work well when it comes to BAS installations. Although the application and purpose of BAS may vary, the selection process remains essentially the same. It is far better to make the adequate selection of a BAS as in Guide# 27 at the outset of the design stage than to make do during maintenance.
Guideline #27

A BAS cannot compensate for poorly performing systems, nor can correct design errors, improperly set up systems or poor maintenance. Analysing the financial impact of control systems and knowing what's needed for the facility are the key first steps toward picking the right system for a new BAS.
6.4.3 Checklist for BAS Design

BAS design has to provide the operating logic, alarm and reporting requirements and to meet the level of desired automation expected by the owner. The example of the BAS design checklist demonstrated in Guideline# 28 might be modified according to needs.

Guideline #28

<table>
<thead>
<tr>
<th>Title</th>
<th>Checklist for BAS design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G028</td>
</tr>
<tr>
<td>Purpose</td>
<td>To ensure the BAS design meeting with the owner’s expectations</td>
</tr>
<tr>
<td>Applications</td>
<td>Whole building process</td>
</tr>
</tbody>
</table>

**Checklists**

- Designer should communicate with the building owner to confirm the expectations and requirements.
- Control and monitoring points should meet with the needs of clients.
- BAS specification should be conformed with needs of clients.
- BAS design consider the energy conservation and balance with the comfort expectation.
- Sensor and actuator should be layed out adequately to reduce the overlap and redundant.
- Designer should consider the operation and maintenance requirements and costs.
- BAS design should consider the technology development and future expansion to pre-allocate space of the new system installation.
- Training should be considered in the design planning and hand-over.
- Documentation of the design is critical during the whole building process.

**References**

§4.2.3

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QUT

**Note**
6.4.4 Checklist for BAS Installation

For a demonstration of design and maintenance, a checklist such as Guideline# 29 for BAS installation, is presented as an example which can be modified in accordance with the needs.

Guideline #29

<table>
<thead>
<tr>
<th>Title</th>
<th>Checklist for BAS installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G029</td>
</tr>
<tr>
<td>Purpose</td>
<td>To ensure the installation meeting with the requirements of design</td>
</tr>
<tr>
<td>Applications</td>
<td>Whole building process</td>
</tr>
</tbody>
</table>

Key check points of BAS installation as:

1. Specifications of the BAS hardware and software should be reviewed and followed.
2. BAS installation quantity should be checked before and after works to ensure the equipment completion and functioning.
3. BAS software should be installed and run test to ensure that their functionalities are working.
4. Installation of the sensors and actuators should be checked and tested.
5. The list of BAS control and monitoring points should be kept and checked.
6. BAS associated infrastructure and communication system should be checked and tested.
7. Emergency power supply should be installed adequately and run test.
8. Initial set up value of BAS systems should be kept and checked.
9. Grounding and insulation of BAS systems should be checked.
10. Documents of the hardware and software should be kept.

References

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Note

BAS installation should focus on hardware such as DDC, sensors (space, duct, water), control valves and actuators, dampers, power supplies and transformers, communication wiring, and software including application software and points list, documentation.
6.4.5 Checklist for BAS Commissioning

To ensure the success of BAS installation, the commissioning activities are essential, especially during the hand-over and warranty periods. BAS commissioning includes the final adjustment, calibration, and tuning of the various components. This process requires the participation of the building owner, a commissioning agent, the designer, a manufacturer's representative, and building maintenance personnel. The example demonstrated in Guideline# 30 is a short version of a checklist for BAS commissioning.

Guideline #30

<table>
<thead>
<tr>
<th>Title</th>
<th>Checklist for BAS commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G030</td>
</tr>
<tr>
<td>Purpose</td>
<td>To ensure the BAS quality</td>
</tr>
<tr>
<td>Applications</td>
<td>Hand-over, warranty periods, operation and maintenance stage</td>
</tr>
<tr>
<td>Checklists</td>
<td>Key check points of BAS commissioning as:</td>
</tr>
<tr>
<td>1. Documentation</td>
<td>It initiates from the design stage. It includes general information and specifications, and technical manuals of installation. It should be hand-over to the occupants.</td>
</tr>
<tr>
<td>2. Training</td>
<td>Design team associated with the relevant technical contractors should take the responsibilities to train the staff and personnel of the operation and maintenance (O/M).</td>
</tr>
<tr>
<td>3. Emergeny treatment</td>
<td>Emergency training and equipments should be especially focused.</td>
</tr>
<tr>
<td>4. Operational calibration</td>
<td>It should become regular works.</td>
</tr>
<tr>
<td>5. Reporting</td>
<td>feedback and problem reflection and tracking should become the regular works.</td>
</tr>
<tr>
<td>References</td>
<td>§4.4</td>
</tr>
<tr>
<td>Version</td>
<td>1 Ed.</td>
</tr>
<tr>
<td>Pub. Date</td>
<td>1 OCT, 2004</td>
</tr>
<tr>
<td>Rev. Date</td>
<td></td>
</tr>
<tr>
<td>Pub. Authority</td>
<td>QUT</td>
</tr>
<tr>
<td>Note</td>
<td></td>
</tr>
</tbody>
</table>

BAS commissioning should check the control and alarm items, reporting, scheduling and emergency strategies including their operation, verified Set-points, constant alarm limits, operating interface, and documentation.
### 6.4.6 Checklist for BAS Maintenance

The example demonstrated in Guideline# 31 is a short version of a checklist for BAS maintenance.

**Guideline #31**

<table>
<thead>
<tr>
<th>Title</th>
<th>Checklist for BAS maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G031</td>
</tr>
<tr>
<td>Purpose</td>
<td>To execute the BAS maintenance for sustaining their designed functionalities.</td>
</tr>
<tr>
<td>Applications</td>
<td>Operation and maintenance stage</td>
</tr>
</tbody>
</table>

**Checklists**

- 1. Check control and monitoring system as designed calibration and functionality.
- 2. Check and verify the conditions of BAS system and report.
- 3. Check power supply and UPS linkage and testing.
- 4. Simulate emergency shut-down handling.
- 5. Manually handle BAS functionalities under emergency shut-down.
- 6. Test smoke alarm system and security alarm regularly

**References** §4.2.4

**Version** 1 Ed.

**Pub. Date** 1 OCT, 2004

**Rev. Date**

**Pub. Authority** QUT

**Note**

BAS maintenance should check the status of: temperature control, pump control, DP Control, condensation alarm, reset schedule, alarm reporting, emergency shut-down, power supply, and specific items to verify their condition as being normal or broken, calibration, repair or replace, or waiting for check.
6.4.7 Execute BAS Maintenance Schedule checklist

Maintenance of the sensors and actuators of BAS should be executed regularly in accordance with the manufacturers instructions to maintain their performance and functionalities as in Guideline #32.

Guideline #32

<table>
<thead>
<tr>
<th>Title</th>
<th>Schedule of checklist for sensor and actuator maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G032</td>
</tr>
<tr>
<td>Purpose</td>
<td>To regularly execute the maintenance tasks</td>
</tr>
<tr>
<td>Applications</td>
<td>Operation and Maintenance stage</td>
</tr>
</tbody>
</table>

Checklists

- 1. Overall visual inspection to make sure all equipment operating safely: daily
- 2. Check time clocks after every power outage: daily
- 3. Verify control schedules software that schedules are accurate for season and occupancy: daily
- 4. Verify all set-points are accurate for season and occupancy: daily
- 5. Check all gauges to make sure readings as designed: weekly
- 6. Check schedules: weekly
- 7. Check all dead-bands for accuracy as designed: monthly
- 8. Calibrate time clocks for accuracy: half-yearly
- 9. Check all sensors such as temperature, pressure, humidity, smoke, flow as designed: half-yearly
- 10. Calibrate all sensors: yearly

References §4.2.4

Version 1Ed.

Pub. Date 1 Oct, 2004

Rev. Date

Pub. Authority QUT

Note
6.4.8 Apply Life-Cycle Cost Analysis (LCCA)

The practical application of LCCA can start from the Life-Cycle Cost calculation after identifying all costs by year and amount and discounting them to present value. These amounts are added together to arrive at total life-cycle costs for each alternative as in Guideline #33:

Guideline #33

LCCA can be applied to any capital investment decision in which relatively higher initial costs are attempted to reduce future costs. It is particularly suitable for the evaluation of building design alternatives that satisfy a required level of building performance but may have different initial investment costs, different operating and maintenance and repair costs, and possibly different lifespans.

LCCA provides a significantly better assessment of the long-term cost-effectiveness of a project than alternative economic methods that focus only on first costs or on operating-related costs in the short term.
6.4.9 Project Delivery System (PDS)

During the life time of building development process, building project contracts are designed to shift the principal contractor’s focus to the performance of the building construction (Fujitsu C. and BRC, 1998). Clients of today’s building construction have many different project delivery systems (PDS) to select from. According to CSI (2005), project delivery is the contractual relationships between the owner, architect/engineer (A/E), contractor(s), and the management services utilized to design and construct a project. Project delivery moves a project from a concept to a completed facility.

PDS is defined as a set of procedures and relationships by which a project is delivered to an owner (Dorsey R.W. 1996). Project delivery systems for building construction can exhibit many different forms such as “Traditional design-bid-build”, “design-negotiate-build”, “construction management”, “Design and Construct”, and “Owner build such as ‘Build, Own Transfer (BOT)’, ‘Build, Own, Operate and Transfer (BOOT)’ or ‘Public Private Partnerships (PPP)’” (Mohyla, L. V 1996; Hampson, K. et al. 2001). Each delivery method can have variations in terms of contract payments (such as lump sum, unit price, and cost plus,) scheduling (such as fast-track), and number of contracts (such as single or multiple-prime contracts). Competitive market forces compel most owners to select a project delivery system that will achieve a balance between the factors of project extent, risk, cost, and time (CSI 2005).

There are two essential issues to be considered when choosing a project delivery system. First is to be realistic about the nature of the project, for example, the risks, the budget constraints, the unknowns, the time constraints, the expectation of quality, the level of client involvement. The second is to assess the various project delivery strategies against the above criteria (Hampson, K. et al. 2001; CSI 2005). In building construction practice, there are many types of project delivery systems to be applied, but no single ideal one. Generally, a good PDS enables various tasks and procedures to be executed efficiently and provides a mechanism for co-ordination and control. Project delivery rules and procedures ensure that tasks get done and are carried out efficiently. Good system ensures that information flows and decisions are taken. Thus the success of a project relies on effective coordinating of design and
construction and of main contractors and specialist sub-contractors. This highlights the importance of project delivery as well as the focus on technical elements in this research to extend the scope to more than management issues. Realising the benefits and limitations of various project delivery systems (as described in Table 6.1) will help make decisions for the projects.

Table 6.1: Implications of the PDS for design and maintenance

<table>
<thead>
<tr>
<th>PDS</th>
<th>Implications of D/M</th>
<th>Benefits</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fully documented “traditional” design-bid-build</strong></td>
<td>◊ An architect/designer and the building contractor plays little task of the project after the design-build project completion. ◊ The building contractor usually has no role in the on-going operation and maintenance of the building either, as the builder is contracted purely to construct the building.</td>
<td>(1) Roles and responsibilities are well established and known for all participants in the building industry. (2) Design has been completed before bidding, the project schedules can be established in advance. (3) With design-bid-build, the owner has a separate contract with an A/E firm for the design and the construction stage. (4) Owners can be actively and fully involved in the project design, and realize the greatest amount of control. (5) Competitive bidding can reduce costs, and also creates a cumulative savings on the entire work involved.</td>
<td>(1) The competitive bidders may tempt to bid the project with little or no profit, and may affect the quality of construction. (2) The errors, discrepancies, and contradictory information may lead to change orders, claims, and disputes with the contractor. (3) Competitive bidding provided the lowest cost allows little margin for error to rework which will affect the efficiency of construction and maintenance. (4) The shortness of the time forces bidders to respond quickly without proper consideration, it may cause the dilemma between quality and cost.</td>
</tr>
<tr>
<td><strong>Design-negotiate-build</strong></td>
<td>◊ In negotiating cost and contract details of a design negotiate-build project delivery, a construction contract may achieve mutual benefits to the parties involved in the project. ◊ The negotiated</td>
<td>(1) The owner can select a firm based upon the experience, expertise, and interest in the project, as well as the firm’s reputation and financial capacity. (2) This contract can be developed to include contractor as a team member during the design process. The early participation</td>
<td>(1) Modifications to design documents may become change orders that affect time and cost, and may lead to claims and disputes. (2) Negotiated agreements may limit some responsibilities, and require additional time for</td>
</tr>
<tr>
<td>Construction management</td>
<td>Construction management is effectively applied to a construction project from conception to completion for controlling project time, cost, and risk. Construction management can supplement the owners’ or developers’ role in the project. Construction management can be used for most projects that require extensive coordination between disciplines as design, construction and maintenance.</td>
<td>Construction management provides basic and intensive services such as: information management, coordination, cost and time management, quality assurance, construction-site safety, and commissioning. These can help achieve an effective design and communication. The fast track scheduling encourages design decisions to be made and documented earlier through the cooperation between the construction manager, A/E, and contractor owner.</td>
<td>(1) The additional level of authority resulting from the use of a construction manager requires communication, reporting, and other contract administration paperwork for processing and record keeping. (2) For overall contract administration efficiency, it can be time consuming and expensive for the A/E and the contractor(s). (3) The owner is relying heavily on the expertise and professional integrity of the construction manager, A/E, and contractor to deliver a project.</td>
</tr>
</tbody>
</table>

| Design and construct | The building contractor is responsible for both the design and construction, either engaging designers, or having them integrated. In this PDS, the building contractor usually has no role in the on-going | The single-contract for design and construction offers more control over project timing and costs. With the fast-track scheduling method, the design-builder is able to maximize the value of the project in the shortest time for the least cost. The contractor can | (1) Preparation of the project description may be a difficult task for the owner, particular for the complex projects. (2) The owner’s project should clearly indicate necessary requirements, including the design documentation, as well as quality assurance/quality control requirements. |
Practically, the quality and performance of a building often can be easily demonstrated through the technical features of the facilities and building systems. However, the efficiency of management during the process is commonly difficult to assess. Notwithstanding, the management issue in the process of project delivery is also essential to ensure the quality and sustainability of the building project during the delivery process. For most projects, recognising the role and responsibilities of developer will help improve building project delivery to facilitate the design and maintenance works. This can be summarised as:

| Owner build such as ‘Build, Own Transfer (BOT)’, ‘Build, Own, Operate and Transfer (BOOT)’ or ‘Public Private Partnerships (PPP)’ | operation and maintenance of the building, being purely responsible for design and construction. | influence product selections by providing information regarding cost, availability, and performance. (4) The design-builder may also have specialized information regarding design and constructability of project. | (3) Dispute resolution may require maintaining historic records for use if disputes arise. (4) The design-builder may have increased risk due to expanded roles in design and construction to make assurances to meet the owner’s expectations. | (1) Most owners are large corporate entities and contractor/developer with financial backing to absorb the risk of problems or other losses during process. (2) The owner with flexibility can effectively and efficiently complete projects by controlling whole project with mutually beneficial business relationships. (3) The owner can select contractors with successful records of work for building. (4) The developer and contractor have a strong motive to be interested in the benefits of a BAS. | (1) The control of the project afforded to the owner by functioning as the contractor also transfers much of the risk for project completion and quality to the owner. (2) In order to relieve the primary risk of not being able to complete the project, the contractor is often required to provide performance and payment bonding. However, this does not mean that the entire project is bonded. (3) Usually, there is no option for errors, discrepancies, or omissions from the construction documents. |
◊ Select suitable project delivery system (PDS) for the projects.
◊ Compare benefits and limitations of different types of PDS.
◊ Find consultants to make decision of PDS for supporting smart design to ease maintenance.
◊ Compromise the commercial benefits and environment impacts in the life cycle consideration

Recognising the relationships between different stakeholders, the role of developers and their responsibilities will help all stakeholders to realise and appreciate many respective focus and interests such as capital costs, sell benefits, or operation and maintenance costs. Designers initially play an essential role help the selection of the applicable project PDS through the design specification and consultation during the design stage. A right PDS decision will facilitate the project not only in the effectiveness of design and construction, but also in the efficiency of the on-going operation and maintenance. The commissioning in different types of project delivery during design and maintenance process and BAS applications should be considered their commercial benefits of the quality and performance as selling fast as a motive and life time cost decreasing during the design stage. For various project delivery types, the adequate consideration will aid the execution of project. Generally, it will be advantageous for better design and maintenance decision if the consideration on different type of project delivery as described in Guideline #34.
Guideline #34

<table>
<thead>
<tr>
<th>Title</th>
<th>Project Delivery System in D/M Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>G034</td>
</tr>
<tr>
<td>Purpose</td>
<td>To instruct the efficient project delivery</td>
</tr>
<tr>
<td>Applications</td>
<td>Design and Maintenance stage</td>
</tr>
</tbody>
</table>

Checklists

- **Fully documented “traditional” design-bid-build**
  - In a traditional design-bid-build delivery method, commissioning is needed to provide services throughout the project, and makes design decisions and the best interests of the owner. It is necessary that the contractor provides a completed project that meets the requirement of the contract in the bidding price and ensures the construction works as designed. After project delivery of construction, operation and maintenance D/M should consider further development of the effective commissioning activities to ensure the quality and performance of building systems.

- **Design-negotiate-build**
  - In negotiated contracts, construction excellence and time are usually the primary considerations. In addition, the life time service should be considered during the negotiated process. Negotiated contracts can be beneficial if parties involved understand their roles and respect the roles of others. The key to successful negotiated contracts is compromising to achieve balanced results and forming a cohesive team relationship among the owner, the contractor, and the A/E. The commissioning activities are necessary between project delivery process to ensure the quality and performance of building.

- **Construction management**
  - The roles of the parties involved in a construction management contract should be carefully defined in their respective contracts. The potential for conflict between parties should be evaluated to provide management services through the processes. The construction management allows owners to control the project from beginning to end with a higher level of assurance. The construction management can be considered to extend their commissioning and support services for the life time process by the contracts to ensure the quality and performance of building.

- **Design and construct**
  - This method should be used primarily where contracts can be negotiated. The project should be clearly and completely defined the building requirements for the owner. The roles of the parties involved in a design-build contract should be carefully defined in the contract. Design-build organizations should provide benefits that some owners desire, including specialized expertise during design, economy in cost and time, and maximized value of the finished project. It should be considered to extend their commissioning and support services for the life time process to ensure the quality and performance.

- **Owner build such as ‘Build, Own Transfer (BOT)’, ‘Build, Own, Operate and Transfer (BOOT)’ or ‘Public Private Partnerships (PPP)’**
  - Balance between capital building cost and O/M costs will ensure the quality and performance of the project. The efficiency and effectiveness of whole project require an independent
In the project development process and commercial process, the building projects through the lifecycle process such as design and maintenance require adequate commissioning to ensure the quality of process not only in the technical aspects, but also in the management issues. It implicates that the various project delivery systems influence the efficiencies of the process. As a result, the integration of design and maintenance can be effectively enhanced through carrying out the distinguished role of the key stakeholders.
6.5 Summary

The above guidelines for office building automation have provided several feasible and strategic solutions for high level decision making regarding BAS design and maintenance. For different types of project delivery, adequate commissioning activities and distinctive responsibilities of building phases and key stakeholders can help facilitate the effectiveness and efficiency of building process. The guidelines, including strategies and checklists for design/maintenance of the building automation, have explored a way of integration to create a mutual platform between different building processes during the implementation of office building project. These guidelines provide important information/instruction and a communication template for the designers, operation and maintenance (O&M) personnel, and building developers/owners. As part of the hand over documentation during the delivery and continuum, these guidelines will become an invaluable resource for building maintenance for re-testing and re-calibrating the building operating parameters, and design references. These will also be a good source of information for years after the job is completed for design engineers involved with building systems or renovation of building automation. The study is a basic integration practice for the building processes; it could be spanned over the whole of the building’s life to improve the performance of office building, minimise energy consumption, and enhance security and comfort as well.

Basically, the guidelines is extracted from the principles and concepts of the BAS knowledge and practice, and it should be updated in accordance with technology innovations and changing environments. On the other hand, in order to easily and effectively employ the guidelines for the BAS decision making, computerised tools would be an applicable, and a more efficient and effective way. Therefore one of the major parts of this study is to create an example of a decision support model for the execution of decision making in design and maintenance. This will be detailed in the following section. The list of guidelines for optimising design and maintenance to provide operational references for high performance, energy conservation and comfort decision making is illustrated in Figure 6-4, which can be integrated with the knowledge rules detailed in Chapter 5 for decision support application as in Figure 6-5.
Figure 6-4: Guideline Application Flow
The integrated guidelines with the knowledge rules as in Figure 6-5 can be utilised to explore feasible solutions. For decision making in office building automation, the process can be done manually for the design and maintenance subjects. These findings might also be used to develop a computer based decision support prototype. The development of prototype decision support will be demonstrated in the following chapter.
CHAPTER 7

DEVELOPMENT OF DECISION SUPPORT SYSTEM

7.1 Introduction
   7.1.1 Overview of Decision Support Systems
   7.1.2 Structure of Decision Support Systems

7.2 Pilot System Testing
   7.2.1 Introduction
   7.2.2 Objectives
   7.2.3 Methodology Adopted in the System Development
   7.2.4 Development Process
   7.2.5 Illustration of the Pilot System
   7.2.6 Discussion

7.3 Prototype System Development
   7.3.1 Development of SBASpro Knowledge Base
   7.3.2 Model

7.4 Running SBASpro Model and Examples
   7.4.1 Evaluation Model
   7.4.2 Practice BAS Decision Support
   7.4.3 Decision Support Application and Development
   7.4.4 SBASpro Demonstration

7.5 Validation

7.6 Discussion
7.1 Introduction

This section presents the development of a prototype decision support system in order to effectively employ the knowledge based database detailed in Chapters: 5 and 6. The development includes two stages: the first stage is pilot system testing to explore the feasibility of decision support alternative; the second stage is to accomplish design of the whole model of prototype decision support system to integrate the design and maintenance knowledge extracted from the professional survey and experienced case study.

Decisions and decision making are crucial for any action, especially for the complex nature of the construction industry. Top quality and successful decision making requires sufficient understanding of the problems we are facing. In nowadays' dynamic and rapidly changing environment we need applicable methods and tools for improving changes for successful decisions. Integrated decision support is a research exploration where methods and tools are developed to model in order to provide enhanced decision support for office building participants.

The model has been designated as namely Supporting Building Automation System Pro (SBASpro). The SBASpro model consists of six major functions including decision making quiz, hot topics, case study, evaluation, links and search as shown in the homepage of model program. The knowledge was extracted from the questionnaires which were conducted to the selected relevant professionals in the field of building automation of the office building design, construction and maintenance, and was verified by an experienced case study to enhance its reliability; then it is formulated a knowledge database for the further system development. The structure and development of the SBASpro model are described with a demonstrated example of using SBASpro to practice the integration between design and maintenance in the office building context.

The potential benefits of using SBASpro during the design stages are also discussed:

Designers could benefit from the previous experts’ knowledge and experience through the knowledge based database built in the decision support system model. A
self evaluation could facilitate the fine-tuning of project and could help learn from the previous experience.

The SBASpro model can assist in documenting successes and improvement of the decision making for the BAS design; and it may also provide the reference during the commissioning/maintenance period after occupation, thereby identifying right strategies in building operation.

This research asserts that there is a need for designers to assess information and instructions of office building automation, the model developments would enable designers to improve a BAS design decision, and maintainers to realize and meet the expectations of clients and users. Development of a decision support system model could provide designers and maintainers or building developers/owners a working platform to integrate the building process of office buildings automation.

7.1.1 Overview of Decision Support Systems

Decision support systems are computer tools that can be used to model the expertise of humans in a specific domain. Expertise in knowledge has generally been acquired through discipline and experience over a period of time in a specific domain and is heuristic in nature. Decision support systems provide a technique to model the reasoning processes of experts and use their knowledge to support specific decision purpose. Such systems can be used by non-experts to improve decision making capabilities. Decision support systems can also be used by professionals as knowledgeable assistants. Decision support systems are used to propagate scarce knowledge resources for improved consistency of results. Such systems could function better than a single human expert in making value judgments in a specific area of expertise.

Decision support systems are best known as self-contained entities that exist quite separately from other computer-aided design systems. Important is the notion of embedding explicit knowledge of the kind that is encoded in decision support systems within more general computer design tools. The development of the decision support system developed in the research is to integrate knowledge with relevant D/M of office building automation, make inferences, arrive at conclusions, and explain its conclusions.
7.1.2 Structure of Decision Support System

The development of the *SBASpro* decision support system based on the developmental prototyping methodology is illustrated as in Figure 7-0:

The *SBASpro* model is composed of two major parts: (1) the development environment; and (2) the consultation (run time) environment. The developmental environment is used to build the components and to introduce knowledge into the system. The development environment contains components that facilitate the creation of decision support systems: knowledge acquisition facility, inference engine, and knowledge base such as:

- The knowledge acquisition facility provides a way to store experts’ qualitative knowledge to address a given requirement.
- The inference engine controls the reasoning process and decides how the stored knowledge will be implemented.
The consultation environment is used to obtain expert knowledge and advice. The consultation environment contains components that facilitate the use of the model and provides the users with expert advice and answers their queries. There is an interface, explanation facility, and recommended action facility as:

- The interface: allows human-machine and machine-machine communication and interaction. The human-machine interface should be as simple and easy as possible. The machine-machine interface must allow for communication with other computer programs (e.g., databases and graphical interfaces).

- The explanation facility knowledge: is being applied and why a certain decision support system is following a specific line of reasoning. This explains why and how such conclusions were reached.

- The recommended action facility: allows revision of some of the system’s reasoning processes by the users who learn to make additions and modifications to the system.

In simplification, the system development initiates from the program environment study, then, pilots a simple example to explore the feasibilities of research intentions. Once the pilot system has been tested and reviewed, the prototype system will be developed. The structure of the system development is illustrated as in Figure 7-1.


7.2 Pilot System Testing

7.2.1 Introduction

This section presents a pilot system testing of the proposed decision support system. The pilot system testing as a platform would be advantageous for creating the whole system during the research process. This prototype system program has been tested for Windows environment. In the aspect of research scope, the research focused on the elements related to the high-level decision making in the office building automation for the practitioners such as designers, design and maintenance (D/M) consultants, facilities managers, and developers or owner representatives. The system concentrated on the most important parts of building automation system associated with HVAC, electrical power system, lighting system, fire and security system.

In order to demonstrate a typical decision support system, the pilot system has adopted a simple element —“sensor”, which is a principle element of Building Automation System (BAS). The pilot system will serve as a working platform, which can be duplicated and expanded as necessary during the progress of research, it could also be updated and modified, eventually to develop a practical decision making tool for the office building automation.

7.2.2 Objectives

The main objective of the pilot system is to explore the feasibility for the proposed intention of the decision support in optimising the performance and enhancing the lifetime value of office building automation. The pilot system which has been created will help the research to reach the following objectives:

- To pre-test the methodology of the system design
- To create a template for the creation of initial knowledge database, model database and interaction interface
- To set up a platform for the research to easily feed the knowledge extracted from the collated data and information into the database
7.2.3 Methodology Adopted in the System Development

The methodology adopted for the development of the decision support was based on the developmental prototyping methodology detailed in Chapter 3 section 3.2.8 as:

- System development: includes planning, analysis, and design, Implementation (prototype testing and validation).
- Knowledge: extracted from the literature reviews, professional survey questionnaires and case study to create knowledge based database.
- Programming: by means of Microsoft visual Basic 6.0 and Access XP to create a computerised decision support template and interface as a working platform during the process.

7.2.4 Development Process

The process of the pilot system development is summarised as the following:

- Planning and Analysis:
  - Literature reviews
  - Desk research on the problems and potential of office building automation (theories and case study)
  - Building industry survey- professional questionaries
  - Case study- experience in the BAS office building design and maintenance
  - Analysis and knowledge extraction to formulate knowledge database
  - Guidelines of design and maintenance of office building automation

- Design and Implementation:
  - Design and testing of the pilot system
  - Pilot system construction (Programming)
  - Pilot system testing and validation
7.2.5 Illustration of the Pilot System

The pilot system has been initially designed and programmed with a user friendly interface to guide the whole system development. It focuses on the exploration of the feasibility of the prototype system and presents an applicable decision support solution for the integration between design and maintenance of office building automation. The exploration stage has adapted an essential element- sensor in the office building automation as the simulating example to create a knowledge database. The programming of the interface has enlisted MS Visual Basic software, integrated with MS Access as database. It has been demonstrated as shown in Figures 7-2, 7-3 & 7-4 and Appendix F.

![Sensor Selection Decision Support Manager](image)

Figure 7-2: Pilot System (1)- Information Retrieval Process
CHAPTER 7 DEVELOPMENT OF DECISION SUPPORT SYSTEM

Figure 7-3: Pilot System (2)- Information Retrieval Process

Figure 7-4: Pilot System(3)- Retrieval Result
7.2.6 Discussion

The pilot system has tested the function of integration between design and maintenance in a simple case of sensor selection, which is an element of BAS. However, in reviewing the program, it reveals that it did only show the basic retrieval function. In addition, the knowledge is also quite simple. Therefore, to develop the complete decision support system, advanced functions such as comparison, updating, searching and extraction should be embodied together with more comprehensive knowledge base to provide applicable support for decision making during the process. Thus the development of whole system would be continually programming with the following goals to enhance functions and database, to create an easy operated and up-datable platform and interface for the advanced development:

- Striving for simplicity
- Maintaining consistency
- Identifying toolbar button functions

On the other hand, the basic Windows operating environment has been tested as above by means of Visual Basic 6; however it was limited in a closed scope only applicable to the individual application. To consider the future extensive purposes and development for broad and prompt support linking with Internet, the programming tools might be extended to utilise the next generation programming tool as Visual Studio.Net including Visual Basic.NET, ADO.NET, and ASP.NET for the advanced expansion.
7.3 Prototype System Development

This section presents the advanced procedures of the \textit{SBASpro} model including knowledge extraction and analysis, knowledge-base development, decision trees, demo of the model, and validation.

7.3.1 Development of \textit{SBASpro} Knowledge Base

\textit{SBASpro’s} knowledge base models the procedure of consultation for professional advices. It can be categorised into four design and maintenance knowledge bases such as “Trend (Overall status)”, “Design issues (Technical)”, “Products (Maintenance)”, and “Assessment”. The initial knowledge base stored in the \textit{SBASpro} was extracted from the questionnaire’s results, the knowledge base can be modified and updated by the user’s inputs utilising the updating function.

The relationships established through the previous stages were implemented together in the form of “production rules.” From the analysis of the professional questionnaires and case study, the results were used to construct the knowledge base on the model. The knowledge base was then constructed in the form of production rules, which comprised a set of rules, each consisting of a left side (a pattern that determines the applicability of the rule) and a right side (that describes the action to be performed if the rule is applied) of the rule equation, for example:

\begin{center}
\begin{tabular}{|l|l|}
\hline
\textbf{Rule:} for the selection of a applicable control/ monitoring system & \\
\textbf{If} & a medium office building and apply control/ monitoring points below 500 \\
\textbf{Then} & it might be reasonable \\
\hline
\end{tabular}
\end{center}

The knowledge base was incorporated into the program in the form of IF-THEN rules. The knowledge extraction was encoded to form the function rules in the knowledge base.
7.3.2 Model

After the successful demonstration run on the computer, the SBASpro model was similarly completed and validated through the following steps:
1. The rules covering the full scope of the SBASpro model was tested.
2. The execution rules were added to complete the program.
3. Validation of the SBASpro model was similarly carried out as for the demo.

The structure of the SBASpro model indicates the importance of continuous interactions between users and the model as the main stream of data flow to perform the evaluation. The system architecture of the SBASpro, which can be divided into four units as bellows:

**Knowledge acquisition user interface:** This interface provides for users to achieve knowledge and modify the knowledge base.

**Evaluation user interface:** This interface provides a channel for end-users to evaluate the concepts and questions and to obtain solutions, then to search the guidelines.

**Knowledge base:** This knowledge base contains a case base that stores previous cases and knowledge including the professional database and guidelines.

**Inference processes:** This unit includes all inference processes that derive a final solution from a given question and extend to search the supports.
7.4 Running SBASpro Model and Example

SBASpro is developed on a personal computer environment under MS Windows XP with an Intel Pentium 4, 1.6G processor and 512 MB of RAM. It can be run on the MS Windows XP and 2000 with Intel Pentium 3, 800M processor above and 256 RAM. To satisfy the functions of model as described, three software programs supporting the dynamic data exchange (DDE) used to develop the prototype. The employed software packages are MS Access™, and MS Visual Studio.Net™.

SBASpro employs MS Access™ to manage the case base as a database to easily transfer the case base’s data into another format. The SBASpro system uses a knowledge-based application development system that provides a rule induction algorithm to construct ‘if-then’ rules from cases, to provide a rule induction function to organize domain expert’s knowledge and to provide rule-based reasoning. The user interface and control procedures in the pilot prototype system are developed by Microsoft Visual Basic™ and in the SBASPRO are developed by Visual Basic .NET, Visual Studio.Net (ADO.Net and ASP.Net).

SBASpro has been designed for the high level (managers) decision making to practice decision support. To simulate the practical decision making process in the office building automation design and maintenance, the users can familiarise the integrated template of decision making process and know how to employ and accumulate the expert knowledge for the practice; meanwhile, it can also be used to realise the relationships of design and maintenance, and learn the associated strategies, guidelines and action checklists. SBASpro application can start from the basic operation of example demonstrated as the following sections.


7.4.1 Evaluation Model

(1). Criteria rule

Rule 1: Taking the surveyed professional/expert questionnaire results (means value) as an initial criterion to decide the answer which is pass or fail.

Rule 2: If answer is greater than or equal to the means value, then it is accounted as “pass”.

Rule 3: If answer is less than the means value, then it is accounted as “fail”.

Rule 4: If it fails, then get a message; else try again.

Rule 5: If it passes, then get a recommendation or guideline/checklist.

(2). Knowledge database: Extracted from literature study and professional questionnaire survey in the form as in Table 7-1:

Table 7-1: Expression of the Knowledge Base

<table>
<thead>
<tr>
<th>Questions:</th>
<th>Q1, Q2, Q3, Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answers:</td>
<td>A1, A2, A3, A4</td>
</tr>
<tr>
<td>Criteria:</td>
<td>Pass/ Fail</td>
</tr>
<tr>
<td>Results:</td>
<td>Errors (Do it again) / Minor modification</td>
</tr>
<tr>
<td>Actions:</td>
<td>Guidelines/ recommendation/ checklists/ strategies</td>
</tr>
</tbody>
</table>
(3). Evaluation process is demonstrated as in Figure 7-5.

Figure 7-5: Evaluation Process
7.4.2 Example of BAS Decision Support

In order to test and validate the system model, demonstrating a specific example is necessary. Building Automation System (BAS) practice usually starts from the needs and requirements, current status to the future expansion. The example was selected to demonstrate the decision making mechanism of the model as:

“How to select a suitable control and monitoring system for a given office building or a group of buildings?”

(1) Information behind the example is outlined as in Figure 7-6 (Source: Elmahdy, A. H. 2004).
(2) Decision support process is described as follows (Source: Elmahdy, A. H. 2004):

1. Starting text for the system:
   
   “SBASpro will help you select a suitable system for a given office building to ensure the high performance, energy conservation and comfort.”

2. What is the given office building?
   
   • Class A: Medium/ Large or 10000-20000 m² floor areas
   • Class B: A group of buildings/ Larger buildings and some building complexes
   • Class C: 20 buildings or more/ Building complexes
   • Class D: Small office building/ buildings in a wide geographical area of a single location

3. What suitable control and monitoring systems/ functions are required?
   
   • As in Table 7-1 (Supported from the knowledge database)

4. How many control and monitoring points are needed?
   
   • Below 100
   • 100-200, Below 500
   • 500-1500, Below 2000
   • Exceed 2000

5. What maintenance strategy is suitable?
   
   • Reactive maintenance
   • Preventive maintenance
   • Reliability Centred Maintenance (RCM)
   • Predictive maintenance approach
   (Supported from the knowledge database)

6. What guideline can be provided?
   
   (Supported from the database of guidelines)

7. Overall recommendations:
   
   Summary the user’s situation and selection, then gain a recommendation for the choice and guidance of execution.
(3) Control and monitoring points in relation to the application is listing in Table 7-2 (Source: Elmahdy, A. H. 2004).

Table 7-2: The Application of the Control and Monitoring Points

This figure is not available online. Please consult the hardcopy thesis available from the QUT Library.
(5) The control and monitoring functions is summarised as in Table 7-4:

Table 7-4: List of the Control and Monitoring Functions (Source: Elmahdy, A. H. 2004)
(6) The decision support process is illustrated as the flow chart in Figure 7-7:
(7) Running this example in the **SBASpro**, the demonstration is shown in the following Figures 7-8 ~ 7-13.

Figure 7-8: Design and Maintenance Example Home

Figure 7-9: Building Type Selection
CHAPTER 7 DEVELOPMENT OF DECISION SUPPORT SYSTEM

Figure 7-10: Control and Monitoring Points Selection and Decision Support

<table>
<thead>
<tr>
<th>Control and Monitoring Points</th>
<th>Associated Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 100 points</td>
<td>Decision Support</td>
</tr>
<tr>
<td>100-200, Below 500 points</td>
<td>Decision Support</td>
</tr>
<tr>
<td>500-1500, Below 2000 points</td>
<td>Decision Support</td>
</tr>
<tr>
<td>Exceed 2000 points</td>
<td>Decision Support</td>
</tr>
</tbody>
</table>

Figure 7-11: Recommendation and Guidelines

**Given Office Building:** Medium/ Large building or 10000-20000m² floor areas

**Selected Points of Control and monitoring:** 100-200, below 500 points

**Recommendation:**
Class A system might be used at a reasonable cost

**Description:**
Class A system includes several control and monitoring functions as:

<table>
<thead>
<tr>
<th>Control Point</th>
<th>Code of BAS Code</th>
<th>Name of Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F801</td>
<td>A</td>
<td>StandBy</td>
<td>Scheduled start and stop different HVAC equipment automatically according to a pre-determined schedule, displace air most effectively, etc.</td>
</tr>
<tr>
<td>F802</td>
<td>A</td>
<td>Fire alarms</td>
<td>Simplified event fire alarms</td>
</tr>
<tr>
<td>F803</td>
<td>A</td>
<td>Smoke detectors</td>
<td>Simplified event smoke detectors</td>
</tr>
<tr>
<td>F804</td>
<td>A</td>
<td>Security checks</td>
<td>Simplified event security checks</td>
</tr>
<tr>
<td>F805</td>
<td>A</td>
<td>Load cycling/ Load balance</td>
<td>Load cycling is connecting excessed customers after some elapsed time while disconnecting others. The mode of operation maybe adapt when load control duration is accordingly long, when buildings are such that long. Elevators simply can not be tolerated by the customers (or conditions in the summer, for example).</td>
</tr>
</tbody>
</table>

**Guidelines:**
1. Install basic functions of the control and monitoring systems.
2. System maintenance can further explore the suitable strategy for the life time benefits, please click the right button.
Figure 7-12: Maintenance Strategy Selection

Figure 7-13: Guidelines of the Selected Maintenance Strategy
7.4.3 Decision Support Application and Development

Following the structured decision making process, the decision support can be categorized into two stages as in Table 7-5:

Table 7-5: Decision Support Application

<table>
<thead>
<tr>
<th>Application stages</th>
<th>Functions</th>
<th>Purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic decision support</td>
<td>• Example</td>
<td>Demonstration</td>
</tr>
<tr>
<td></td>
<td>• Simple Quiz</td>
<td>Testing and training</td>
</tr>
<tr>
<td></td>
<td>• Hot Topics</td>
<td>Decision support</td>
</tr>
<tr>
<td></td>
<td>• Links</td>
<td>Decision support</td>
</tr>
<tr>
<td></td>
<td>• Information Retrieval</td>
<td>Decision support</td>
</tr>
<tr>
<td>Advanced decision support</td>
<td>• BAS design/ Maintenance knowledge quiz</td>
<td>Raising the awareness and understanding</td>
</tr>
<tr>
<td></td>
<td>• Professional/ Guidelines search</td>
<td>Decision support</td>
</tr>
<tr>
<td></td>
<td>• Modification/ new information</td>
<td>Updating</td>
</tr>
</tbody>
</table>

The development of *SBASpro* can base on the above functions and purposes to extend and modify. In addition, the model provides an updateable function, thus, the users can create their own knowledge database and do modification during the process.

7.4.4 *SBASpro* Demonstration

In addition to the decision support example, *SBASpro* has basically explored the decision support approach in the aspects of the learning and decision making practice, which is composed of six main utilities such as: (1) general D/M Quiz, (2) Evaluation, (3) Search, (4) Update, (5) Hot Topics and (6) Links. It also includes a demo of video clip to demonstrate the practical operation and application.

The following demonstrations will illustrate the *SBASpro* operations and applications as in Figures 7-14 ~ 7-31 and Appendix G. They have shown the complete functionalities in the type of the static images, it can also be operated in the accompanied *SBASpro* software program to explore and exercise the high lever decision making process.
(1) General D/M Quiz: It is an initial warm-up step to realise the integration concept and learn the evaluation process of the system as in Figure 7-14 & 7-15.

Figure 7-14: General Quiz

Figure 7-15: Quiz Result
(2) Evaluation: It can be used to evaluate the BAS design and maintenance issues to verify the concept and practical situations to explore the guidance as in Figure 7-16 ~ 7-19.

Figure 7-16: Evaluation Home

Figure 7-17: Evaluation End
The needs

From a survey in the importance of office building automation systems (BAS) to the clients, building owners and developers respectively are different, it revealed that the clients and owners of buildings are more interested in the building developers who were more emphasized on what can make it to increase the sale profits, therefore the developers are rarely focused on BAS for the life cycle benefits as table: Importance of BAS preference.

The designers mostly realized the benefits of BAS in office building and aware their responsibilities to the BAS during the design stage. They believe the BAS is relevant to the performance and cost of the building, especially in relation to the building life-cycle cost. Their major considerations of BAS during the design stage include four aspects such as easy operation, maintenance, meeting regulation, performance of systems and meeting client requirement; Conversely, the reliability and system price or cost are not very interested or paid attention by the designers during the design stage as table: Major consideration of BAS preference.

<table>
<thead>
<tr>
<th>Maintenance Item</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maintenance</td>
<td>34</td>
<td>21.2</td>
</tr>
<tr>
<td>2. Easy operation</td>
<td>28</td>
<td>17.5</td>
</tr>
<tr>
<td>3. Performance</td>
<td>32</td>
<td>18.2</td>
</tr>
<tr>
<td>4. Cost-effective</td>
<td>34</td>
<td>20.2</td>
</tr>
<tr>
<td>5. Reliability</td>
<td>2</td>
<td>1.25</td>
</tr>
<tr>
<td>6. Presentation</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>66</td>
<td>100.3</td>
</tr>
</tbody>
</table>

The current building regulation and BAS product specification are mostly affected on the BAS design. In practice the designers obtained the requirement and specification of the BAS products mainly from the product manufacturer; alternatively, from the feedback of previous user, client discussion, consultants’ or subcontractor’s recommendation and statistical information. It implicates that the sufficient instruction and feedback would be needed and could be assisting to the practice.

Figure 7-18: Evaluation Result

Figure 7-19: Evaluation Guideline
(3) Search: It can be used to search the professionals of the design and maintenance, and guidance of the design and maintenance issues as in Figure 7-20 ~ 7-23.
CHAPTER 7 DEVELOPMENT OF DECISION SUPPORT SYSTEM

Figure 7-22: Guideline Search

Figure 7-23: Guideline Search Result

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(4) Update: It can be used to update the knowledge database of the professional and guidelines, which are updateable for the users to add and modify the information as in Figure 7-24 & 7-25.

Figure 7-24: Update Home

Figure 7-25: Update Result
(5) Hot Topics: It includes the recent issues of the BAS design and maintenance, which provides the information and research findings for the users as in Figure 7-26 & 7-27.

Figure 7-26: Hot Topics Home

Figure 7-27: Hot Topic Example
(6) Links: It can be links to intranet and internet of the World Wide Web (WWW) for exploring the wide range information as in Figure 7-28 & 7-29.

Figure 7-28: Links Home

Figure 7-29: Links Result
(7) Help: It includes the introduction and a demo of video clips to demonstrate the operation procedure as in Figure 7-30 & 7-31.
7.5 Verification and validation

In software quality assurance, the assurance of customer acceptance is essential as well as the assurance of technical correctness. To assure the system that is building right and run well, the process of verification and validation are necessary.

Validation is the best practice for checking user’s inputs and response. Validating a system requires an understanding of the sequence of operation that must be executed to achieve a goal. The validation is carried out by examining how the system operates at run time. The demonstration was first developed for testing purposes. It is structurally a complete decision support system but on a smaller scale. The purpose of developing a demonstration was to ensure that the system was capable of producing valid results that professionals would reach. The demonstration was applied to practice a decision making and learned an integration D/M process of the BAS application in a specific example.

The validation of the demonstration was carried out by taking a hypothetical case of an office building and manually checking the outcome by applying the rules developed from the extracted knowledge of the professionals during the surveys.

The computational SBASpro working program was distributively installed and run for the same hypothetical case. The computational demo provided an evaluation of performance and energy conservation identical to the one reached by the manual method. The validation test of the run time operation is summarised and listed in Table 7-6.

The prototype of the SBASpro and the outline of the guidelines have been delivered to the previous participants of the mailing questionnaires and the building management agency to review the applicability for the practice. The preliminary responses have reported that it is a new decision support approach which has the potential in practice and commercialising opportunities. Their comments and suggestions are concluded as the follows:

1. The project outline has introduced an integration concept and an approach to fill the gaps between design and maintenance.
2. The guideline is a good instruction for the BAS design and maintenance. Especially, it is good for building developer to realise the benefits of BAS application during building life time process.

3. Application of the prototype decision support tool:
   a. It is a new attempt for bridging the design and maintenance phases.
   b. It is a useful template to establish own knowledge database to accumulate the historical records.
   c. It is also a good training tool to learn BAS application.
   d. It is an easy tool with a friendly interface.

4. Suggestions:
   a. The guideline should provide cost information for the procurement practice and various examples for reference.
   b. The prototype decision support tool should be developed for the Web application to gain simultaneous supports, particularly, for the knowledge base update.
   c. Can it have a commercial package?

Reviewing the prototype system development and testing, the windows application has run in the .NET Framework with a self- supportive environment. However, with the widespread deployment of browsers in organizations, Web solutions are growing in popularity as an alternative to Windows applications. Web applications can be accessed in an identical manner whether a user is at work or at home. One especially attractive advantage of a Web application over a Windows application is that the client workstation for a Web application does not require the .NET Framework. It is unlike that when running a Windows application, the client workstation must have the .NET Framework installed. Nonetheless, the positive and supportive comments have encouraged the further research and development.
<table>
<thead>
<tr>
<th>Type of Validation</th>
<th>Test Component/ Functionality</th>
<th>Validity Testing</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completeness check</td>
<td>When several fields must be entered before the form can be processed</td>
<td>Input</td>
<td>Expected Output</td>
</tr>
<tr>
<td>Demonstration example</td>
<td>Select check box and support buttons</td>
<td>Reveal next check box and information/ strategies</td>
<td>As required</td>
</tr>
<tr>
<td>D/M Quiz</td>
<td>Check questions</td>
<td>Succeed or fail</td>
<td>As required</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Check D/M issues and search guidelines</td>
<td>Reveal the results</td>
<td>As required</td>
</tr>
<tr>
<td>Search</td>
<td>Check interested issues</td>
<td>Reveal the required professionals and relevant guidelines</td>
<td>As required</td>
</tr>
<tr>
<td>Update</td>
<td>Add and update the established professionals and guidelines</td>
<td>Reveal the modified results</td>
<td>As required</td>
</tr>
<tr>
<td>Hot Topics</td>
<td>Click issues</td>
<td>Reveal information</td>
<td>As required</td>
</tr>
<tr>
<td>Links</td>
<td>Click Website</td>
<td>Reveal the result of linking</td>
<td>As required</td>
</tr>
<tr>
<td>Consistency checks (Ensure combinations of data are valid)</td>
<td>When data are related</td>
<td>Input</td>
<td>Expected Output</td>
</tr>
<tr>
<td>Demonstration example</td>
<td>Check each box</td>
<td>Reveal correspondent information</td>
<td>As required</td>
</tr>
<tr>
<td>D/M Quiz</td>
<td>Check each question</td>
<td>Reveal correspondent results</td>
<td>As required</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Check each D/M issue</td>
<td>Reveal correspondent recommendation and guidelines</td>
<td>As required</td>
</tr>
<tr>
<td>Search</td>
<td>Check each function</td>
<td>Reveal D/M professionals</td>
<td>As required</td>
</tr>
</tbody>
</table>
### Database checks (Compare data against a database to ensure they are correct)

<table>
<thead>
<tr>
<th>Update</th>
<th>Check each utility on the screen</th>
<th>Reveal modified results</th>
<th>As required</th>
<th>Test completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Topics</td>
<td>Check each topic</td>
<td>Reveal correspondent information</td>
<td>As required</td>
<td>Test completed</td>
</tr>
<tr>
<td>Links</td>
<td>Check each established Web site</td>
<td>Reveal correspondent Web link</td>
<td>As required</td>
<td>Test completed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demonstration example</th>
<th>Check building type</th>
<th>Reveal correspondent information and strategy guidelines</th>
<th>As required</th>
<th>Test completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>D/M Quiz</td>
<td>Check each question</td>
<td>Reveal correspondent result</td>
<td>As required</td>
<td>Test completed</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Check D/M issues</td>
<td>Reveal correspondent guideline</td>
<td>As required</td>
<td>Test completed</td>
</tr>
<tr>
<td>Search</td>
<td>Check each professional and guideline search</td>
<td>Reveal correspondent results</td>
<td>As required</td>
<td>Test completed</td>
</tr>
<tr>
<td>Update</td>
<td>Check each utility</td>
<td>Reveal the modified results</td>
<td>As required</td>
<td>Test completed</td>
</tr>
<tr>
<td>Hot Topics</td>
<td>Check each issue</td>
<td>Reveal correspondent information</td>
<td>As required</td>
<td>Test completed</td>
</tr>
<tr>
<td>Links</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
7.6 Discussion

From the above demonstration and validation, the SBASpro model could be run for a variety of possible modifications and the evaluation of decision making results assessed for BAS design and maintenance. A SBASpro model was developed and simulated the evaluation and reasoning process carried out by professionals in the field of office building automation. The SBASpro model has explored several capabilities and feasibilities as:

- To provide explanations of knowledge, it can be applied for the various design and maintenance applications
- To point out the deficiencies for users to revisit and enhance, it provides a comparison of results after revisit made.
- To facilitate useful decision support, it can be to evaluate the outcomes to a building design and maintenance evaluation.
- To provide the feasibility of updating, knowledge database can be modified in terms of the experience and advanced knowledge during the life time of the practice.

Test runs of the SBASpro model reveal that the functionalities and scopes of application have provided several decision support utilities. However, it runs primarily to demonstrate the functionalities for user education purpose and to simulate the integration feasibilities, not yet includes practical support for industry. It was also constrained in the fields of the technical and management issues as well as lack of the historical records of costing which should be essential part in the aspect of the life cycle consideration of the buildings. Decision making is hard to predict for the future change, especially in the shortage of the historical and holistic data related to the cost of BAS. However, it could be able to use the “update” utility of the program to modify information to compensate this shortage.

Nevertheless, the SBASpro model has explored the possibility of the process integration and decision support by deploying the computerized programming that has established and provided an interactive communicating platform for the design and maintenance practice with an updateable utility which could balance the system shortage and endow with functionality enhancement. It also has designed by the next
CHAPTER 7 DEVELOPMENT OF DECISION SUPPORT SYSTEM

generation programming tools- Visual Studio.NET which can be further applied for the Web application development to provide the advanced decision support.
8.1 Introduction
8.2 Conclusions Relating to Research Objectives
8.3 Reviews
  8.3.1 Reviews and Improvement in Design and Maintenance Practice
  8.3.2 Reviews of the Decision Support System Development
8.4 Limitations
8.5 Recommendations
8.6 Conclusions
8.7 Contributions
8.8 Implications and Further Research
CHAPTER 8 CONCLUSIONS

8.1 Introduction

The research was motivated by the experience in the office building industry. The ineffective and redundant practice prevails in the construction building fields and processes. Problem identification and research objectives were reviewed in Chapter 1. These objectives led the development of an appropriate research approach described in Chapter 3. The achievement of the assured objectives is described in this chapter through the conclusions, contributions and implications of this research.

This research was initiated to collect data on the office building automation practice regarding the integration between different building phases. An extensive literature review revealed that building performance and effectiveness is influenced by the building systems as well as the building processes. This research contributes to knowledge in the management field as well as the building design and maintenance practice.

This chapter concludes the thesis by considering the implications of the research findings and compare the research objectives.

Firstly, it examines the limitations of the research process and assesses its impact on the research results.

Secondly, this chapter provides a discussion of the implications for the knowledge and practice.

Finally, it presents several suggestions for future research.
CHAPTER 8 CONCLUSIONS

This chapter puts up on previous research developments of the integration between design and maintenance of office building automation. In Section 8.2, reviews are divided into three sections, based on the objectives. Verification of the improvement in design and maintenance has been summarised in Section 8.3. Limitations of the study are described in Section 8.4. Section 8.5 provides several recommendations for additional research. Finally, Section 8.6 concludes the thesis with a brief summary of findings. Section 8.7 presents the contributions to the body of knowledge and implications to knowledge and industry. Section 8.8 implicates an outlook to the future research. Three types of findings from the research will be presented in the latter sections:

- **Conclusions**: review the results of the surveys and case study and the computer based prototype program. Results were derived from the industry survey using the approach described in Chapter 3. Chapter 4 and 5 provide data analysis to verify the questions raised at the beginning of this survey when the research objectives were formulated. In particular, they confirm the questions that structured the objectives of this research.

- **Contributions** are both for knowledge and building industry.

- **Implications** are listed for researchers and building industry practice. This decision support approach including a computer based prototype system is a platform for the process integration between different building phases.
8.2 Conclusions Relating to Research Objectives

It is possible to illustrate the conclusion that the objectives of the research were achieved, which were: (1) understanding how the process integration is affecting the office building performance, energy conservation and comfort; (2) understanding the effective guidelines are facilitating the practice; (3) the development of the prototype computer based decision support system can enhance the practical decision making.

The first objective of the research was to identify problems and limitations of BAS between design and maintenance. The achievement of the second objectives was being established a series of guidelines for the improvement of design and maintenance of office building automation. The third objective was to develop a prototype decision support system to demonstrate the potential of integrating design and maintenance tasks of office building automation. Although the prototype decision support system is created in a demonstration purpose, the integration exploration may also be a new direction for the knowledge and practice. Conclusions relating the three objectives are described in Sections 8.2.1, 8.2.2, and 8.2.3.

8.2.1 Objective 1:

“To identify the problems and limitations of building automation practice between the design and maintenance phases.”

Through the literature study, industry survey and case study, this research has identified the problems of design and maintenance practice, including lack of close communication in providing life time services and support, insufficient historical records and effective integration alternatives. This research also shows that “First cost mentality” affects the design and maintenance under both time and budget pressures. The findings have been discussed in Chapter 2, 4 and 5. This research has accomplished the first objective.

8.2.2 Objective 2:

“To establish a guide for effective enhancement between design and maintenance of office building automation system.”

Through the industry survey, data analysis, knowledge extraction and guideline development, guidelines in relation to the enhancement of effective design and
maintenance in the office building automation context have been generated. It includes raising awareness and understanding, general strategies and operational checklists. The outcomes has been produced and detailed in Chapter 5 and 6. This research has accomplished the second objective.

### 8.2.3 Objective 3:

“To develop a computerised decision support prototype for ease in integrating the design and maintenance in office building automation.”

Through using of the developmental prototyping decision support method, a computer-based prototype decision support model has been explored and demonstrated. It demonstrates that an example: how to select BAS for the proposed office building to practice the decision making. In addition, the model also creates several utilities to show the functions of decision support. The development of the model has been demonstrated in Chapter 7. This research has accomplished the third objective.

Consequently, Reviewed the proposed plans with the outcomes as above, the research has accomplished the proposed objectives as shown in Figure 8-1.

![Figure 8-1: Accomplishment of the Research Process](image)

<table>
<thead>
<tr>
<th>Research Objectives</th>
<th>Literature Study</th>
<th>Industry Survey</th>
<th>Case Study</th>
<th>Data Analysis Knowledge Extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective 1: Barriers &amp; Limitations</td>
<td>General Status of Office Building Industry: IB, BAS, Design &amp; Maintenance</td>
<td>Close Communication</td>
<td>Integration Practice</td>
<td>Performance</td>
</tr>
<tr>
<td>Objective 3: Develop Computerised Decision Support</td>
<td>Required Information Strategies Development</td>
<td>Current Instruction &amp; Support</td>
<td>Quality Management</td>
<td>Security and Comfort</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strategies for Raising Awareness &amp; Understanding General Strategies Operational Checklists</td>
</tr>
</tbody>
</table>
8.3 Reviews

8.3.1 Reviews of the Improvement in Design and Maintenance Practice

The research objectives aim at the identification of design and maintenance (D/M) problems and limitations in practice to establish guidelines and develop a decision support tool. The research has pinpointed the problems analysed in Chapter 2: lack of effective communication and understanding which has been confirmed by means of the professional surveys. The outcomes of the industry status and reasons for the problems have also been deduced and detailed in Chapter 4. They were also verified by a case study leading to a possible approach for the problem solving which has been detailed in section 4.4. Based on the findings of the industry professional survey, as well as lessons learned from the case study and the clarified expectations of the practice, the knowledge extraction has composed a knowledge base to provide manual decision support approach, meanwhile to formulate a knowledge database with inference rules for the further development of decision support system which has been detailed as a guide in chapter 5, 6. These outcomes disclose the process integration is a feasible alternative. The process integration can be used to create a working platform, further undertake the development of a computer-based decision support model which was discussed in Chapter 7. Subsequently, the research has accomplished its objectives through the knowledge-based decision support development including: prototype system design and development, industry surveys and case study, establishing a D/M database, knowledge extraction and programming.

Consequently, the intended D/M integration knowledge based decision support has been developed and detailed in Chapter 4, 5 and 6. It would have a practiced integration decision support approach to explore the alternatives for improving the practice, but it is a start for the improvements in the office building process. In this research, a series of guidelines and checklists has demonstrated an example for the BAS decision making. It can serve as an integration platform and as a tool for improving the communication between design and maintenance, to further enhance the integrated benefits of office building automation.
Over-viewing the development of automation in construction, the advanced information and communication technologies have provided tools to develop interoperable alternatives for the integration between building design and maintenance, while the other essential matters require actual experience, since the best programs require people to execute them. In this research, the strategies and checklists developed as in Chapter 6 have been designed for decision making illustrated as in Figure 8-2 and 8-3. These decision support diagrams outline the office building automation status and expectations of occupants. They also illustrate and verify the decision making process for the design and maintenance concerns. In practice they also could be modified and updated to meet the practice, and a knowledge database established as well. These are rather useful template for the research contexts and practice.

Hence, optimising building processes for performance enhancement and maintainability could be done through the effective process integration between design and maintenance. The integration process would have the effects and benefits of enhancement building performance, energy conservation and comfort. Predicatively, the integration between different processes would be forming a new trend in practice.
CHAPTER 8 CONCLUSIONS
CHAPTER 8 CONCLUSIONS

Building life cycle process
- Attributes of high-performance and energy conservation office building
- Types of HVAC Systems and control
- Benefits of the process integration
- Tips for design professional selection strategy
- Strategies for designing the specification
- Requirements of Specification design
- Strategies for integrating with infrastructure
- Checklist for BAS design
- Checklist for BAS installation
- Checklist for BAS commissioning
- Checklist for BAS commissioning

G002, G003, G004, G005, G006, G009, G010, G011, G016, G025, G029, G030

Benefits of the process integration
- DSPC BAS design supports by the information of the product pros/ cons
- DSPC BAS design supports by the technical records
- DSPC BAS design supports by the historical records
- DSPC BAS design supports by the update product information
- DSPC BAS design supports by the information of product cost and performance

Type of HVAC Systems and control
- Benefits of the process integration
- DSPC BAS design supports by the information of the product pros/ cons
- DSPC BAS design supports by the technical records
- DSPC BAS design supports by the historical records
- DSPC BAS design supports by the update product information
- DSPC BAS design supports by the information of product cost and performance

Attributes of high-performance and energy conservation office building
- DSPC BAS design supports by the information of the product pros/ cons
- DSPC BAS design supports by the technical records
- DSPC BAS design supports by the historical records
- DSPC BAS design supports by the update product information
- DSPC BAS design supports by the information of product cost and performance

Strategies for designing the specification
- DSPC BAS design supports by the information of the product pros/ cons
- DSPC BAS design supports by the technical records
- DSPC BAS design supports by the historical records
- DSPC BAS design supports by the update product information
- DSPC BAS design supports by the information of product cost and performance

Strategies for assuring the reliable systems
- DSPC BAS design supports by the information of the product pros/ cons
- DSPC BAS design supports by the technical records
- DSPC BAS design supports by the historical records
- DSPC BAS design supports by the update product information
- DSPC BAS design supports by the information of product cost and performance

Tips of specification design
- DSPC BAS design supports by the information of the product pros/ cons
- DSPC BAS design supports by the technical records
- DSPC BAS design supports by the historical records
- DSPC BAS design supports by the update product information
- DSPC BAS design supports by the information of product cost and performance

DB, RBAS

Benefits of the process integration
- DSPC BAS design supports by the information of the product pros/ cons
- DSPC BAS design supports by the technical records
- DSPC BAS design supports by the historical records
- DSPC BAS design supports by the update product information
- DSPC BAS design supports by the information of product cost and performance

DB, RBAS

G012, G015

G016

G017

G018

G019

G020

G021

G022

G023

G024

G025

G026

G027

G028

G029

G030

Figure 8-3: Overviews of Decision Support Flow (2)
8.3.2 Reviews of the Decision Support System Development

Along with the research development, to ease practice and learn the decision support process, a computer based decision support program has also been developed and detailed in Chapter 7 which has developed several utilities to show the support functions such as evaluation capability and functionality of the BAS evaluation, information retrieval, updating and BAS professionals and guidelines search. It has also provided a demonstrated example for the basic application on the program. The developed program has explored an integration decision support approach which utilises the current popular personal computer software MS Access and next generation object- oriented programming tool MS Visual Studio.Net to develop an integration platform for use in the office building automation contexts. However, it should be seen as a prototype of a decision support tool which could be further developed through the enhancements in the function model and knowledge database.
8.4 Limitations

From the above verification and discussion, the research has created a platform for the integration between different building process-design and maintenance, which has experimented with a closed system- *SBASpro* windows application to support the decision making for the BAS design and maintenance. In spite of the contributions and implications of knowledge and practice, several limitations of this research should be examined. These limitations are partly from the shortage of data sources and partly from the inherent computerised decision support applications. They can be concluded as follows:

**Data and information**: the survey information was analysed in light of Australian construction and management companies, and the case study example selected from Taiwan. Subsequently, the development of the guidelines will be limited and can only be served as a model or initiated to further explore the global applications.

**Functionalities**: Reviewing the development of the decision support prototype, it should only be established as an experimental platform; since the knowledge stored in the system was just explored for the high level decision making support that could be enhanced and extended for application of multilevel decision making. In addition, it could be the future development to advance their functionalities for global application on an extensive scale. Current prototype program has been designed and distributed for Windows applications on personal computers. However, in a network environment, the web applications have seen widespread deployment around the world. Thus the web application of the program would be the next step in the further development for more extensive applications and sophisticated knowledge support.
8.5 Recommendations

Concluded from the above verification and discussion, the recommendations for the research and the presentation of the thesis have been suggested as:

- The BAS knowledge database could be enhanced and spread to the practical execution for the various decision-making levels.
- The computerised decision support approach could be developed for the practical applications and extended to the web applications.
8.6 Conclusions

From the literature study, the office building industry has made advances in developments along with the technology innovations affecting the working process and building systems. However, their efforts was mostly limited and only facilitated by building system innovations which have produced more integrated activities and products enhancing the effective functionalities in office building.

Nonetheless, the whole environmental expectations for office buildings are growing, the building performance improvement and enhancement not only relies on building system advances and integration, but also on the lifetime of the building process integration to integrate support and service. However, from this research it has become obvious that the integration of design and maintenance was still in the conceptual stage, far from the practical solutions.

Reviewing the office building status, the building performance and energy conservation and health/comfort expectations, these are still a challenge. In this research, the aims and objectives targeting on raising the awareness and understanding of the importance of process integration, guidelines compilation and computerised decision support exploration have resulted in outcomes such as a prototype decision support system, guidelines and checklists through literature study, industry surveys and the case study which provided first hand information to confirm the limitations and learned from the case study.

Additionally, the research has also extracted the knowledge from those with professional expertise and experience in the office building industry. This research has presented a comprehensive analysis and explored an integration template for practical use by developing a set of guidelines and a computerised decision support prototype.

In conclusion, this research has explored the problems and limitations existing in design and maintenance, and analysed the major possible reasons. It has also presented an alternative for the integration of design and maintenance in the high level decision making process such as the guidelines and strategies/checklists for the process integration between design and maintenance, and an updateable decision
support tool - SBASpro which might provide a feasible solution for the research proposition:

“Could possible alternatives be created to help the improvement of the problems which exist between the design and maintenance of office building automation during the lifetime of buildings?”

This research has confirmed and verified the problems, and has provided the alternatives with a series of knowledge extractions, guideline development and computer-based decision support exploration. Moreover, it has also presented contributions to the current knowledge base and to industry.
8.7 Contributions

This research has provided several contributions to the knowledge and industry as the follows:

- Explored and promoted the integration concept for design and maintenance of office building automation system (BAS).
- Developed and tested a new approach of BAS design and maintenance integration.
- Produced a computerised decision support environment for integrated consideration of design and maintenance issues in relation to BAS.
- Generated practical guidelines for BAS design and maintenance practice.
- Explored object-oriented software applications integrated with the database that crosses traditional professional fragmented design and maintenance.
- Created an integration platform for further extending the value of a prototype decision support system for the building industry.
- Produced three refereed papers for conference publication and presentation and prepared two more papers related to research outcomes for journal publication for the enrichments of literature.
8.8 Implications and Further Research

The limitations of the research in the knowledge database and functionalities of the decision support model have highlighted the potential for advanced study and development.

Therefore, the next step for further research would lead to broader and wide-ranging applications to provide more comprehensive information to enhance the functions in terms of the developed SBASpro program for both the academic field and the building industry to improve the performance and energy conservation of office building design and maintenance such as:

◊ Enhancement of the functionality and BAS design and maintenance knowledge database
◊ Development of the practical software application package, even commercial version through the joint venture with the industry.
◊ Web application development
Freedom Tower

Source: Skidmore Owings & Merrill
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    http://www.wbdg.org/design/do-print.php?cn=2.6.2
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WWW2.6.4.2 Life Cycle Costs & Benefits
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WWWBAS Building Automation Systems
    http://www.advancedbuildings.org/main_t_load_build_automation_sys.htm
LonWorks Building Autoamtion Benefits
    http://www.echelon.com/solutions/building/benefits.htm
WWWEC Environment Vocabulary
    http://www.tzafonet.org.il/kehil/sviva/envsite/edu/englishbook/appendix-a.doc
WWWHC Predicted Mean Vote (PMV) control
    http://global.daikin.com/global/our_product/sp_Inverter/3_techno.html#daikn8
WWWMPO Meet Performance Objectives WBDG
    http://www.wbdg.org/design/do-print.php?cn=2.4.3
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APPENDICES

Appendix A Postal Questionnaire for Design
Appendix B Postal Questionnaire for Maintenance
Appendix C Case Study Information
Appendix D Overview of BAS Design Knowledge Extraction
Appendix E Overview of BAS Maintenance Knowledge Extraction
Appendix F Demonstration of Pilot System
Appendix G Demonstration of the Protype Decision Support System
Appendix H Protype Decision Support System SBASpro
Appendix A
Postal Questionnaire for Design
The aim of the survey is to identify Office Building Design and Maintenance characteristics of Building Automation System (BAS) for the improvement of building performance and design/ maintenance practice”.

The survey questions consist of four main parts: The need, Products, Design issues, and Assessment. The information you provide in this survey will be kept strictly confidential and only used for research purposes. This questionnaire can be completed in 10-15 minutes. Please circle related rating or tick appropriate multiple choice (more than one can be chosen).

A. The need:

1. How do you rank the importance of office building BAS to the following people?

<table>
<thead>
<tr>
<th>People</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client (occupier)</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Building owner</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Building developer</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

2. How do you evaluate the role of BAS and its awareness among design and maintenance?

<table>
<thead>
<tr>
<th>Role/ Awareness</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role and benefits of BAS on the building operation and maintenance</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Responsibility for building maintenance during the BAS design stage</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

3. What are the main considerations during the BAS design stage?

- Meet regulation
- Easy operation and maintenance
- Performance of systems
- Meet client requirement
- Others (please specify): ________________________________________

4. How do you assess the major factors of consideration during the BAS design stage?

<table>
<thead>
<tr>
<th>Factors</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant BAS to the performance of the building</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Relevant BAS to the life-cycle cost of the building</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Others (please specify):</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. How do you realise the requirement and specification of the BAS products?

- From statistical information
- From product manufacturer
- Feedback from previous use
- Others (please specify): ____________________

6. How will building regulation and product specification affect the BAS design?

<table>
<thead>
<tr>
<th>Regulation/Specification</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current building regulation sufficient for BAS design</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Product specification appropriate for design requirement</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>
B. Products:

1. How do you estimate the availability of BAS in the office building?

<table>
<thead>
<tr>
<th>Products/Information</th>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAS products readily available from vendors</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>BAS products equipped with adequate performance instructions</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

2. How do you weigh up the access of information during the BAS design stage?

<table>
<thead>
<tr>
<th>Access information</th>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>New or to-date information of product</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Sufficient information relating product pros/cons, and application</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Sufficient data on historical records in practical usages</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

3. How important on the following measures for BAS design to meet present and future requirement?

<table>
<thead>
<tr>
<th>Solutions</th>
<th>Least</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback from previous use</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Availability of to-date information</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Communication with facility managers</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Communication with building owners</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Others (please specify):</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

4. Do you deliver information or manuals of BAS operation and service to facility managers or management agency of the buildings?  
   ○ Yes  ○ No

5. Do you receive responses from the design/ built building management agency regarding to the BAS operation and service after buildings delivery?  
   ○ Yes  ○ No

C. Design issues:

1. How do you rate the importance of BAS in relation to the following systems in an office building?

<table>
<thead>
<tr>
<th>Systems</th>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC/energy management</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Electrical power/ Lighting system</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Fire/ Security systems</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Lifts/ Escalator</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Parking equipment /Parking system</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Water supply/Drainage</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Others: (please specify)</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

2. How do you rate the BAS application in the following systems?

<table>
<thead>
<tr>
<th>Systems</th>
<th>Troublesome</th>
<th>Trouble free</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC/energy management</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Electrical power/ Lighting system</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Fire/ Security systems</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Lifts/ Escalator</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Parking equipment /Parking system</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Water supply/Drainage</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
3. What is the level of requirement for computer aided design (CAD) or decision support?

<table>
<thead>
<tr>
<th>Need</th>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD based softwares for BAS design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decision support tools for BAS design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Which systems are suitable for the integration in BAS to save energy and increase comfort levels?

- HVAC
- Security
- Lifts/escalator
- Fire
- Parking system
- Electrical power/ Lighting
- Others___________

5. For the following aspects, how important in the integration of related BAS?

<table>
<thead>
<tr>
<th>Importance</th>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance/ Effectiveness/ Efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy conservation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comfort/ Healthy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free maintenance/ Easy management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others (Please specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Which type of sensors/ type of control do you design for the building automation systems?

- Temperature
- Light
- Humidity
- Smoke
- Air
- Pressure
- Others___________

7. How do you weigh scales in relation to the technical and client requirement on the cost and performance aspects?

<table>
<thead>
<tr>
<th>Situations</th>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency between designers and building developers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sufficient support in relation to the cost and performance of BAS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D. Assessment:

1. How do you assess the following factors in relation to BAS?

<table>
<thead>
<tr>
<th>Factors</th>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicable BAS meeting with the requirement of clients</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance/ efficiency of BAS after delivery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available and sufficient instruction/ manual during the delivery stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balance of BAS cost between design requirements and client’s budget</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of the evaluation tools for BAS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. How do you rank the reasons resulting in poor BAS performance?

<table>
<thead>
<tr>
<th>Reasons</th>
<th>Low</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of instruction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inappropriate operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improper maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design deficiency/shortage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unsuitable material/elements/systems application</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others (Please specify):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Please indicate your situation in the following questions:

<table>
<thead>
<tr>
<th>Situations</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has been provided the to-date instruction of BAS from the vendors or manufactures?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Has provided the maintenance suggestion or guidelines to facility managers of buildings or consulting service during the operation?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. How do you estimate the affection of the following factors to minimize energy consumption?

<table>
<thead>
<tr>
<th>Key factors</th>
<th>Least</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy conservation design in BAS</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Selection of applicable BAS</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Suitable BAS integration</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Adequate operation and maintenance</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

5. When/How often do you meet/connect with the building facility managers?
   - Design stage
   - Delivery stage
   - After delivery
   - Problems happening
   - Never

6. In your opinion how can we improve the relationship and efficiency between BAS design and maintenance? (Please elaborate)

________________________________________________________________________________________________________________________________________________
________________________________________________________________________________________________________________________________________________
________________________________________________________________________________________________________________________________________________
________________________________________________________________________________________________________________________________________________
________________________________________________________________________________________________________________________________________________

The following information is optional and will remain confidential at QUT:

Your Name: ___________________________ Position: ___________________________

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!

(Please return the completed questionnaire using the prepaid envelope)
Appendix B

Postal Questionnaire for Maintenance
SURVEY OF THE BUILDING AUTOMATION SYSTEM (BAS) FOR OFFICE BUILDING IN AUSTRALIA

The aim of the survey is to identify Office Building Design and Maintenance characteristics of Building Automation System (BAS) for the improvement of building performance and design/maintenance practice. The survey questions consist of four main parts: Overall status, Management, Technical issues, Assessment. The information you provide in this survey will be kept strictly confidential and used only for research purposes. This questionnaire can be completed in 10-15 minutes. Please circle related rating or tick appropriate multiple choice (more than one can be chosen). Your response can be based on your general knowledge or experience on a specific office building, such as:

Building date: ____________________________ No. of stories:________________________
Location/ Address _____________________________________________________________

A. Overall status:

1. How well does the building function in relation to the use of BAS?

<table>
<thead>
<tr>
<th>Factors</th>
<th>Dissatisfy---Satisfy</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Smart/intelligent' features of Building Automation System (BAS)</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Comfortable/healthy work environment</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>BAS maintenance meeting the design specification</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Energy consumption meets the client requirement</td>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

2. How likely will the following problems occur during the building operation?

<table>
<thead>
<tr>
<th>Problems/Troubles</th>
<th>Least---------------Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual electrical systems out of order/malfunctioning</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Individual mechanical systems out of order/malfunctioning</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Automatic operation/monitoring systems downtime</td>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

3. What is the chance for the following problems to cause poor BAS performance?

<table>
<thead>
<tr>
<th>Reasons</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design deficiency/shortage</td>
<td>0 25 50 75 100</td>
</tr>
<tr>
<td>Inappropriate operation</td>
<td>0 25 50 75 100</td>
</tr>
<tr>
<td>Improper maintenance</td>
<td>0 25 50 75 100</td>
</tr>
<tr>
<td>Lacks of instruction</td>
<td>0 25 50 75 100</td>
</tr>
<tr>
<td>Unsuitable material/elements/systems</td>
<td>0 25 50 75 100</td>
</tr>
<tr>
<td>Others (please specify):</td>
<td>0 25 50 75 100</td>
</tr>
</tbody>
</table>

4. How do you evaluate the influence of the following on BAS maintenance?

<table>
<thead>
<tr>
<th>Regulation/Specification</th>
<th>Ineffective------Effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building regulation/codes for BAS management</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Product specification appropriate for BAS maintenance</td>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>
5. Standard Operation Procedures (SOPs) of maintenance were normally designed / provided by?

- In house qualified staff
- Design consultants
- Facility manager
- Others (please specify): _________________________

6. What are the levels of expectations of clients from BAS on the following issues?

<table>
<thead>
<tr>
<th>Expectations</th>
<th>Low</th>
<th>--------------</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility/ Adaptability/ Accessibility</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Friendliness/ Comfort/ Convenience</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Minimisation of energy consumption</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Performance/ Effectiveness/ Responsiveness</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

6. B. Management:

1. Who is responsible for the BAS operation/ service after delivery?

<table>
<thead>
<tr>
<th>Process</th>
<th>(a) In-house qualified staff</th>
<th>(b) Contracted services</th>
<th>(c) Management professional</th>
<th>(d) Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developing/ Reconfiguring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. How do you evaluate following observations?

<table>
<thead>
<tr>
<th>Situations</th>
<th>Not at all</th>
<th>Very Much So</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current instruction/ manual is available and sufficient for BAS management</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Existing integrated BAS is adequate for building operation and maintenance</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>BAS integration is strategic for BAS management</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

3. How do you evaluate importance of the following issues?

<table>
<thead>
<tr>
<th>Questions</th>
<th>Low</th>
<th>--------------</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Churn rate (number of times employee change work location per year)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>BAS maintenance rate in the office building</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Use of computer applications in facilities management</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Communications between building occupiers and design consultants</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

4. Which systems are suitable for the integration on BAS to reflect design and client requirement?

- HVAC
- Security
- Lifts
- Fire
- Electrical power/ Lighting
- Parking system
- MBAS
- Others

5. How do you rate the effectiveness of problem solving?

<table>
<thead>
<tr>
<th>Effectiveness</th>
<th>Least</th>
<th>--------------</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>The problem solving procedures</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Dealing with the complaints of building occupants</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Tracking/ solving problems of BAS</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

6. Please indicate your situation in the following questions:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you deliver problems of BAS operation and maintenance to the designers?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you obtain the applicable instruction from the designers, vendors or manufactures?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are there Problems/ complaints feedback from building occupants?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
C. Technical issues:

1. How important is the following?

<table>
<thead>
<tr>
<th>Present situation</th>
<th>Least---------</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan coil units in their own controller</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Controlled humidity in the occupier space</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Energy consumption in relation to HVAC system</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>

2. How do you estimate the proportions of complaints responding from building users?

<table>
<thead>
<tr>
<th>Complaints</th>
<th>Proportions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not enough fresh air</td>
<td>0 25 50 75 100</td>
</tr>
<tr>
<td>Inadequate temperature/ humidity control</td>
<td>0 25 50 75 100</td>
</tr>
<tr>
<td>Lack of individual control</td>
<td>0 25 50 75 100</td>
</tr>
<tr>
<td>Noise from HVAC system</td>
<td>0 25 50 75 100</td>
</tr>
</tbody>
</table>

3. Please answer the following questions:

<table>
<thead>
<tr>
<th>Questions</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there an overall security system with a secure separate power supply?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Does the security system interface with the fire systems and building management systems? (e.g are all closed door automatically released in case of a fire alarm/ direct CCTV cameras?)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. How do you evaluate importance of the following?

<table>
<thead>
<tr>
<th>Control/ system</th>
<th>Least--------</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintainability for access control using smart cards or key code or manual ID cards</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>How well CCTV presence detectors and archiving in security systems</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>

5. Which type of sensors used/ type of control usually is applied for the buildings?

- Light  - Temperature  - Humidity  - Smoke  - Air  - Pressure  - Others_____

D. Assessment:

1. How do you weigh up the availability of information for BAS maintenance?

<table>
<thead>
<tr>
<th>Availability of information</th>
<th>Insufficient---</th>
<th>Sufficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>New or to-date information of maintenance</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Instruction/ manual for BAS operation and maintenance</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Historic records of BAS operation</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>

2. How do you estimate the extent of the following factors to minimize energy consumption?

<table>
<thead>
<tr>
<th>Factors</th>
<th>Low---------</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy conservation design in BAS</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Applicable BAS</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Applicable BAS integration</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Adequate operation and maintenance</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>
3. How often is the BAS evaluation carried out?
   ○ Monthly ○ Seasonally ○ Half-Yearly ○ Yearly

4. Who will carry the assessment/evaluation of BAS?
   ○ Facility manager ○ Design consultant ○ Others (Please specify)____________________

5. How do you rate the importance of BAS related to the following systems in office building?

<table>
<thead>
<tr>
<th>Systems</th>
<th>Low</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC/Energy management system</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Electrical power/ Lighting system</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Fire/ Security system</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Lifts/ Escalator</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Parking equipment /Parking system</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Water supply/Drainage</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

6. How important are the following factors related to BAS?

<table>
<thead>
<tr>
<th>Factors</th>
<th>Least</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Most</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicable BAS meeting with the requirement of clients</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Performance/ efficiency of BAS after delivery</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Balance of BAS cost between design requirements and client’s budget</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Availability of the evaluation tools for BAS</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

7. When did you meet/connect with the building/ BAS designers?
   ○ Design stage ○ Delivery stage ○ After delivery ○ Problems happening ○ Never

8. In your opinion how can we improve the relationship and efficiency between BAS design and maintenance? (Please elaborate)

____________________________________________________________________________________________
____________________________________________________________________________________________
____________________________________________________________________________________________

The following information is optional and will remain confidential at QUT:

| Your Name: ___________________________ | Position __________________________ |
| 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!

(Please return the completed questionnaire using the prepaid envelope)
Appendix C
Case Study Information
亞洲商務中心

TAINAN R.O.C. 1989

一個國寶級地段和一幢世界級建築的完美結合！
无缺点计划，驾驭时空，睥睨全国！

建材设备

结构：
本大楼采用永久性结构系统钢筋钢架混合搭建RC结构，聘请著名工程公司施作并由结构博士毛昭熙及工学博士及陈心怀大梁博士结构技术联合设计。（具国际级超高层结构设计经验）并以电脑程式精确计算，依房屋局指定之施工规范及技术标准建造，符合CNS及国标安全基准。基础工程及基础安设均依国家标准，安全标准。

外观：
外型为新建筑建筑师王文忠、张明辉精心设计，整栋外观以现代风格设计，采用铝板与玻璃等建材，具备现代感与时尚感，且符合环保理念。

门厅：
1. 豪华门厅入口宽敞，规划高雅。
2. 入口大门及门扇采钢制结构，强化安全防盗。
3. 门厅周围及走廊设置玻璃窗，提升自然采光。

照明：
1. 廊道及公共区域采用照明设备，提升安全性。
2. 廊道及墙面上使用高亮度照明设备，确保安全。

庭园：
庭园设计以花园、植栽、户外休憩平台为主题，结合自然环境，提供居民休闲空间。

洗手间：
采用了TOTO、JACOB、SELS、HCG等知名品牌设备，提供舒适、卫生的使用环境。

网路设备：
中央监控系统、计算机网络设备。

地板铺装：
采用优质地板，提供安全、舒适的行走环境。

其他：
1. 电梯间：采用耐磨材质，提供安全、舒适的乘坐体验。
2. 消防设备：安装消防系统，确保安全。

※设备说明
本大楼一栋高层建筑在设计、抗震、安全等多重因素下，均按照国家安全标准进行设计，确保居民的安全。
冷氣支管、出風口、照明設備。)
2. 使用之分戶可獨立使用，節省電源，充分提高空調效率。

電氣設備：
1. 每戶獨立電錶，採用無熔絲開關，公共用電不另裝電錶，公共地下層設有受電室及發電機房。
2. 各層辦公室、一樓、地下室、地下一樓、地庫設有接線箱，以供客戶配合辦公室隔間及使用需要。
3. 所有電線、電纜及配管採用供應者標記之確認同類品，按設計圖紙施工。
4. 地下室配備全新發電機，裝置自動發電系統，隨時起動，以備停電供電梯、公共照明、抽水馬達、消防設備、安全系統等使用。
5. 公共用電系統包括公共電梯、戶外照明、梯間、電梯間、公共通道、地下室停車場、地下室監控室、公共設備空間、服務空間、受電室、管理員室、發電機房、茶水間……等本大樓公共使用部份。

給排水衛生設備：
1. 採用接附水方式，分高、低樓二段式，除銅管外，本水經由銅管及隔接水槽後流入地下室蓄水池，經由兩組自流泵，自動抽送至屋頂及14層水箱後送至各層用戶。室內排水系統三層以上統一隔層排水1～2層獨立隔層排水。
2. 本大樓排水系統採用雨水、廢水、污水分流到地下室排水總則由泵池自動抽水排出室外，污水泵及廢水泵採用水泵，以同步昇降自動控制。

緊急電源：
裝設小型發電機，供停電時動作起動供電供消防、公共照明、電梯，安全系統及各戶部份照明使用，以確保安全及運作之正常。

共同天線設備：
每層每戶設有UHF、VHF電視天線及FM天線。

避雷、飛航警報設備：
屋頂設有避雷電式或專電式避雷設備，屋頂及中間層均設有飛航警報器。

封閉式建築：
每戶入口門廳內設有中央控制室緊急連絡用封閉式建築。

緊急廣播系統：
廣播主機設於中央監控室，各層管理及電梯箱內設有廣播喇叭，以供緊急廣播使用。

消防緊急安全系統：
全面消防系統依消防法規定設計配置，安全方便。

1. 消防部份：每層樓設有消防水箱，內設有消防水帶及水閥，由水箱縮水或經由消防泵浦給水，地下層2～4層設有泡沫滅火設備。
2. 防火圖則：整棟大樓依國家規定分層分區作防火圖則。
3. 抽排煙：每層設有排煙室，設抽排風機及送排風機，各層樓均設有排氣門閥，由排煙感應器測知後控制開啓及送排風機運轉。
4. 火警系統：各層設有火警警報器，中央監控室設有火災受信機，隨時監視各層警報及異常狀況。

由控制中心電腦系統自動發出警報至各樓層並自動打118報警。

5. 照明系統：設緊急照明設備及避難方向指示燈，可供停電時照明及避難使用。
6. 緊急疏散系統：遇火災，主機設於中央監控室，各層各戶電梯箱內設廣播喇叭，以供緊急疏散使用。

防盜安全監視系統：
一樓門廳設有管理室，負責管理本大樓進出人員，公共門廳進出入口、車道進出口、各電梯箱、停車場。1樓均設有監視用視訊設備。並設有中央監控室，1樓均設有監視用視訊設備。並由中間監控室與1樓管理員服務台連線作業，以達監視功能。

停車場設備：
地下2～4樓設有汽車停車位(車庫及車位)。機車停車位，每車位編號及使用均納入管理及服務空間設備。(第14層)

1. 大型會議室：設有會議桌、椅、會議用廣播設備、電子黑板。
2. 企業家俱樂部：設有服務台、貴賓用桌椅、書報雜誌架等。
3. 健身房娛樂器材：
   a. 多功能跑步機二組。
   b. 男女用健身器各一組。
   c. 排球台一座。

智慧型系統(SA系統)：
BA(Building Automation)建築物自動化。
OA(Office Automation)辦公室自動化。
CA(Communication Automation)通訊自動化。
SA(Security Automation)安全系統自動化。
MA(Management Automation)管理自動化。

7
BA (Building Automation) 建築物自動化

(一) 電力系統：
■ 發電機定時起動測試及運轉監控……
■ 爲確保電機能於緊急狀況下正常運作，自動化系統平時亦能自動運作，並記錄運轉情況。
■ 發電機自動起動系統監測
■ 公共電費分戶計算
(二) 空調系統
■ 冷卻水塔、主機、泵浦等開關順序自動控制。
■ 冰水主機最佳開／停時間計算控制。
■ 客戶冷氣機最佳開／停時間計算控制。
■ 客戶空調費用自動計費。
(三) 送排風扇及換氣監控系統
■ 廢氣扇／送風扇定時開／停及節約週期運轉控制。
■ 停車場送風／排風扇定時開／停及節約週期運轉控制。
(四) 照明系統
■ 各樓層公共區間照明開／關及節約週期運轉控制。
■ 廣告及庭園照明開／關定時控制。
■ 停車場照明開／關定時控制。
(五) 總／排水設備
■ 地下室污水池位高低預警監控。
■ 廢水池位高低預警監控。
■ 浪水池位高低預警監控。
■ 污水池位高低預警監控。
■ 各泵浦運轉及壓力監控。
(六) 電梯設備監控系統
■ 電梯定時開／停控制。
■ 緊急狀況之自動處置。
(七) 停車場出入管制系統：
■ 車道出入口監控門禁管制。
■ 車道出入口自動門之安全聯鎖控制。
■ 車道車速監控自動控制。
OA (Office Automation) 辦公室自動化
客戶可由預設之資訊系統及平線轉換箱，構成辦公室各項 OA 設備之連接網路，以充分利用辦公自動化，辦公資訊快速轉遞。
■ 預設 OA 系統平面線路圖。
■ 預留 OA 系統及電力系統管線孔道。
■ 各辦公室大門設計之自動門禁系統。
■ 資訊設備設置之自動門禁。
■ 電話自動撥號系統。
CA (Communication Automation) 通訊自動化
■ 停留光纖通訊管道（含衛星通訊接收管路）

2. 經由資訊總線處理之電傳訊號設備，可取得各種傳輸率之交換、電報、電話、數據通訊功能。
3. 設有資訊處理系統之數據通訊，可進行各種通訊及電子郵件功能。
SAC (Security Automation) 安全系統自動化
為達到安全性要求，客戶設置安全系統，建築物門禁系統，安全門禁、電梯箱內、車道出入口及監控系統。
■ 火警警號自動遠程控制。
■ 消防設備盤面監控。
■ 緊急廣播系統。
■ 火警自動報警器119。
■ 空調系統自動停止。
■ 風扇、排煙機定時起動測試。
■ 各客戶大門刷卡門禁及防盜警報管制。
■ CCTV 監控系統。
■ 監控自動報警110。
MA (Management Automation) 管理自動化
大樓各項公共設施、公共事務由電腦自動化通報管理，定時表列各項公共設施之保養週期及清潔。
■ 定期更換消防系統保養工作單。
■ 定期更換發電機保養工作單。
■ 定期更換電梯保養工作單。
■ 定期更換消防系統保養工作單。
■ 定期更換消防系統清洗工作單。
■ 定期清洗污水池、抽水池清洗工作單。
■ 各樓層消火栓自動清潔保養工作單。
■ 各樓層消火栓自動清潔保養工作單。
■ 各樓層消火栓自動清潔保養工作單。
■ 遠端控制自動巡邏監視。
■ 清潔人員報警自動報告監視。
■ 離職新進人員資料盤存管理。
■ 人員出入管理。
■ 自動開列車費費用、公共水電費報表。
Appendix D

Overview of

BAS Design Knowledge Extraction
### Appendix D: BAS Design Issues: Questionnaire Survey Data Analysis and Knowledge Extraction

<table>
<thead>
<tr>
<th>Survey Question Category</th>
<th>Survey Issues</th>
<th>Survey Codes</th>
<th>Survey Objects</th>
<th>Data Analysis - Induction Results</th>
<th>Data Analysis - Deduction Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. The need</td>
<td>Importance of BAS to people</td>
<td>DS01</td>
<td>client (occupants)</td>
<td>Codes Low</td>
<td>Code High</td>
</tr>
<tr>
<td>B. Risk assessment of BAS</td>
<td>Low/ High</td>
<td>DS02</td>
<td>survey respondents</td>
<td>Codes Low</td>
<td>Code High</td>
</tr>
<tr>
<td>C. BAS code in design stage</td>
<td>Moderate/ High</td>
<td>DS03</td>
<td>building performance</td>
<td>Codes Low</td>
<td>Code High</td>
</tr>
<tr>
<td>E. Major factors of consideration</td>
<td>Building performance</td>
<td>DS04</td>
<td>building lifecycle cost</td>
<td>Codes Low</td>
<td>Code High</td>
</tr>
<tr>
<td>F. Realisation requirements specification</td>
<td>Data rationalisation</td>
<td>DS05</td>
<td>source rationalisation information from product manufacturer feedback from previous use</td>
<td>Codes Low</td>
<td>Code High</td>
</tr>
<tr>
<td>G. Regulation and specification</td>
<td>BAS regulation</td>
<td>DS06</td>
<td>building legislation</td>
<td>Codes Low</td>
<td>Code High</td>
</tr>
<tr>
<td>H. Availability of BAS</td>
<td>BAS products</td>
<td>DS07</td>
<td>BAS products available</td>
<td>Codes Low</td>
<td>Code High</td>
</tr>
</tbody>
</table>
The BAS design is directly affected by several factors including the feedback from previous users, availability of up-to-date information, communication with building owners and the facility managers. From the designer’s responses, it reflects that the BAS design requires effective information including relevant information and feedback, and communication with the practical maintenance personnel to collect information.

According to the responses, it is not comprehensively request the designers to deliver information or manuals of BAS operation and service to the facility managers or management agency of the building. The provision of the information and service impact on the practical maintenance after building delivery, hence it is necessary to build a systematic system or approach to provide support and service.

The building systems such as HVAC, electrical power/lighting system, Fire/security systems and lifts/escalator are both independent and interrelated. These are more complicated and important than the parking equipment, parking systems and water supply, drainage systems in the office building. All of the systems need to be adequately designed and maintained to ensure overall building performance and a comfortable environment to meet the occupants’ expectations during the life of the building.
## System's problem

<table>
<thead>
<tr>
<th>Component</th>
<th>Importance</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifts/Escalator</td>
<td>Low/ High</td>
<td>Below Average</td>
</tr>
<tr>
<td>Parking system</td>
<td>Low/ High</td>
<td>Below Average</td>
</tr>
<tr>
<td>Water supply/Drainage</td>
<td>Low/ High</td>
<td>Below Average</td>
</tr>
</tbody>
</table>

The application of the parking equipment, parking systems, water supply/drainage systems are normally more troublesome than the other building systems. However, HVAC systems present the most critical problems during the service than the others. Problems such as shutdown and malfunction will result in the uncomfortable of occupants and complaints. Therefore, in addition to adequate design, maintenance should be scheduled in conjunction with the execution of the appropriate maintenance strategies.

DCR02 Needs the BAS design and decision support computerised tools in the building process.

KDC020 The application of lifts/ escalator systems are more complex than mechanical systems need more maintenance and management.

KDC020 Electrical operation is an invisible environment needed to operate and take care preventively.

**Strategies for high performance, energy conservation and comfort**

**Strategies for Energy Efficient HVAC Design**

**Strategies for security/ fire system design and maintenance**

**Strategies for sustainable maintenance**

### Need for CAD decision support

<table>
<thead>
<tr>
<th>Component</th>
<th>Importance</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifts/Escalator</td>
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</tbody>
</table>

The requirement of decision support tools for BAS design has gained a high ranking in the level of success as well as in the computer aided design (CAD) utilisation in practice. Hence, the development of decision support tools to compare what CAD has done to ease decision making.

**Strategies for high performance, energy conservation and comfort**

**Strategies for Energy Efficient HVAC Design**

**Strategies for security/ fire system design and maintenance**

**Strategies for sustainable maintenance**

### Integration suitability

<table>
<thead>
<tr>
<th>Component</th>
<th>Importance</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Security/ Fire/ Parking system/ Electrical power/ Lighting system</td>
<td>Low/ High</td>
<td>Below Average</td>
</tr>
</tbody>
</table>

The integration between different building systems has several benefits such as increasing their effectiveness, decreasing energy consumption, increasing comfort, etc. In the survey, the HVAC, electrical power lighting systems, security systems, and lifts/escalator have been shown as being more suitable than fire and parking systems for the integration. It implies that system integration, if adequate and effective, will facilitate energy conservation, security and safety, and comfort. It also relates to the need for adequate coverage of these aspects in design and maintenance practice.

**Strategies for high performance, energy conservation and comfort**

**Strategies for Energy Efficient HVAC Design**

**Strategies for security/ fire system design and maintenance**

**Strategies for sustainable maintenance**

### Importance of integration

<table>
<thead>
<tr>
<th>Component</th>
<th>Importance</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance/ Efficiency</td>
<td>Low/ High</td>
<td>Below Average</td>
</tr>
<tr>
<td>Energy conservation</td>
<td>Low/ High</td>
<td>Below Average</td>
</tr>
</tbody>
</table>

In spite of the variation of the integration requirements, generally, there are several general functionalities such as performance, effectiveness, efficiency, energy conservation, and comfort. In this survey, these are as important as the free maintenance or easy management during the integration process in office buildings.

**Strategies for high performance, energy conservation and comfort**

**Strategies for Energy Efficient HVAC Design**

**Strategies for security/ fire system design and maintenance**

**Strategies for sustainable maintenance**

### Objectives of the BAS integration

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Objectives of the BAS integration

KDC040 Integration the different systems has produced good outcomes for the building service.

KDC040 Building systems integration are helpful for the building management.

**Strategies for high performance, energy conservation and comfort**

**Strategies for Energy Efficient HVAC Design**

**Strategies for security/ fire system design and maintenance**

**Strategies for sustainable maintenance**

### Integration the different systems

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**Strategies for high performance, energy conservation and comfort**

**Strategies for Energy Efficient HVAC Design**

**Strategies for security/ fire system design and maintenance**

**Strategies for sustainable maintenance**
The Importance of Comfort/Healthy to the Integration of BAS

The designers and building developers have different concerns about cost and performance. There is little consistency in the cost and technical support in relation to performance. Generally, the designers are more focused on performance and the developers are focused on the costs.

The major reasons causing poor BAS performance include: lack of maintenance, inappropriate operation, improper maintenance, use of non-reliable systems, and design deficiency/shortage. These factors contribute to unsatisfactory results and poor BAS performance. The major strategies to improve BAS performance are to reduce maintenance costs, improve BAS design, and ensure proper BAS materials/elements/system integration.

The sensors are one of the major elements in BAS, which play a key role in the sensitive response to the change and meets the needs.

Communication and integration, decision support

Sufficient support to the cost and performance of BAS

The designer is more focused on the performance and the developer is focused on the cost.

Lack of communication and the sufficient support in relation to the cost and performance of BAS between designers and developers.

- Lack of technical support
  - Design deficiency
  - Inadequate building design requirements
  - Insufficient technical support

- Lack of maintenance
  - Inadequate maintenance
  - Inadequate design deficiency/shortage

- Lack of materials/elements/system integration
  - Integration deficiency
  - Insufficient materials/elements/system integration

- Lack of maintenance, improper operation
  - Improper maintenance
  - Inadequate design deficiency/shortage

- Lack of instruction
  - Inadequate instruction

- Design deficiency/shortage
  - Design deficiency
  - Design instruction

- Consistency between designers and building developers

- Communication and integration, decision support

- Sufficient support to BAS cost and performance

- Design deficiency

- Inadequate building design requirements

- Insufficient technical support

- Lack of maintenance

- Inadequate maintenance

- Inadequate design deficiency/shortage

- Lack of materials/elements/system integration

- Integration deficiency

- Insufficient materials/elements/system integration

- Lack of instruction

- Inadequate instruction

- Design deficiency

- Design instruction

- Design deficiency

- Insufficient instruction

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- Design deficiency

- Insufficient materials/elements/system integration

- Lack of maintenance

- Inadequate maintenance

- Inadequate design deficiency/shortage

- Lack of materials/elements/system integration

- Integration deficiency
### Building Process Integration Needs

KDD0301

It is still a challenge for the enhancement in the practice. Expectantly, the process integration will break through the neck bottle of the practice in the life cycle considerations.

### Traditional Building Process

The provision of up-to-date instructions on the use of BAS from the vendors or manufacturers is not very satisfactory to the designers. They passively provide maintenance suggestions or guidelines to facility managers of buildings or provide a consulting service. It reflects that the longitudinal integration between each diverse professional as designers, products providers and facility managers in building industry is not sufficient to provide support and communication during the operation and maintenance processes. So the process integration across the different phases such as design and maintenance has the potential to facilitate the communication and augment which will improve BAS applications.

### Information Support

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### Ongoing to-date instruction of BAS

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### Effective operation and maintenance

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<tr>
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### DOS03 (Building process integration needs enhancement in the practice)

KDD0401

The communication between different parties in the building process affects the effectiveness of the building service. In practice, from the survey, it was found that the designers normally meet with the building facility managers during the design and delivery stages, or as problems occur, but rarely provides life-cycle service after building delivery.

### DOS04 (How to optimise the high building performance and energy conservation?)

KDD0402

How to enhance the high performance and energy conservation? Management of BAS application.

### DOS05 (How to promote the relationships between different parties of the building process?)

KDD0501

The closely relationships can interdigitate enhancements and learn between the different parties, and improve the problems and effective supports.

### DOS06 (Checklist for BAS design)

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### DOS07 (Principles of the integration)

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### DOS08 (Implementation)

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### DOS09 (Benefits of the process integration)

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### DOS10 (Appendix D page 5 of 5)

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Appendix E

Overview of BAS Maintenance Knowledge Extraction

The Integration between Design and Maintenance of Office Building Automation: A Decision Support Approach
The problems of building systems can be categorised into three classes: electrical, mechanical and control monitoring systems. Each class includes individual systems or subsystems such as electrical systems, mechanical systems, and control monitoring systems, respectively. The survey results show that the problems of building systems are mainly related to electrical systems, mechanical systems, and control monitoring systems in that order. In practice, it has been recognised that the operation and maintenance of the building system is crucial for the successful operation of the building. However, there are many factors that affect the operation and maintenance of the building, such as the design deficiency, inappropriate operation, and the lack of support from the maintenance staff. Accordingly, the building management company needs to improve the operation and maintenance of the building system to meet the client's requirements. Therefore, it is necessary to establish a systematic approach to the operation and maintenance of the building system.

The problems of the building management system can be categorised into four classes: energy consumption, energy conservation, energy efficiency, and energy management. The survey results show that the problems of the building management system are mainly related to energy consumption and energy conservation in that order. In practice, it has been recognised that the operation and maintenance of the building management system is crucial for the successful operation of the building. However, there are many factors that affect the operation and maintenance of the building management system, such as the design deficiency, inappropriate operation, and the lack of support from the maintenance staff. Accordingly, the building management company needs to improve the operation and maintenance of the building management system to meet the client's requirements. Therefore, it is necessary to establish a systematic approach to the operation and maintenance of the building management system to meet the client's requirements.
In the rapidly changing environments, and the increasing expectations of clients, the occupants are highly demanding of the building functions and performance as well as energy conservation and comfort.

In-house qualified staff of design consultants is critical for the building life. The right selection of maintenance contractors and professionals can ensure the quality of the building maintenance. The in-house qualified staff of management professionals are critical for the building life.

In the office building maintenance stage, several indicators such as churn rate (number of times employee change work location per year) and maintenance rate are reflected in the maintenance costs. These are mostly the concern of the building managers. Generally, the application of computer in facilities management is not very popular. In addition, the communications between building occupiers and management consultants are relative poor. It appears that the facilities maintenance and management did not get help from the computer application or support from the design consultants.

Computer applications are increasingly used by building occupants and maintenance staff. The communications between building occupants and maintenance staff are also improving. It appears that the facilities maintenance and management did not get help from the computer application or support from the design consultants.

In the office building, the responsibilities at BAS can be divided into three parts: operation, maintenance and developing/ reconfiguring. The BAS operation relies on a house qualified staff. The maintenance and developing/ reconfiguring tasks mostly rely on the contract services, and partly on management professionals.

After building delivery, the responsibilities at BAS can be divided into three parts: operation, maintenance and developing/ reconfiguring. The BAS operation relies on a house qualified staff. The maintenance and developing/ reconfiguring tasks mostly rely on the contract services, and partly on management professionals.

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</table>
### System Integration

#### MBR04
**Air Quality**
- Equipment, Electric Failures and power, Lighting
- Building system effects

**Building systems to meet the design requirements and client expectations**

- The system is suitable for integration
- The building systems to meet the design requirements and client expectations.

**MBR04**

- Floor Plan controls
- Setting the systems to meet the design requirements and client expectations.

#### KMB0401
**For the problem solving procedures for the building management and professional enhancement**

- The building systems to meet the design requirements and client expectations.

#### GB15

- Field Plan controls
- Setting the systems to meet the design requirements and client expectations.

### Problem Solving

#### MBR05
**The problem solving procedures**

- Least / Most
- The surveys have shown that the building management systems are mostly concerned with the effectiveness of problem solving procedures for dealing with the complaints of building occupants, and tracking problems of BAS. It proves that most occupants are due to discomfort, which can be caused by ineffective problem solving, tracking and dealing with complaints. Thus, customer orientation is important as well as sustainable maintenance.

**MBR05**

- The problem solving procedures, dealing with the complaints and tracking problem solving are core issues of the building management.

#### KMB0501
**Making the complaints and tracking problems are basic requirement for ensuring the comfort**

- The building systems to meet the design requirements and client expectations.

### Evaluation

#### MBR06
**Effective problems**

- Yes / No
- The building management systems have obtained the applicable instructions from the designers, vendors or manufacturers, as well as feedback of the problems of building occupants. Consequently they did not relative deliver problems in relation to BAS operation and maintenance to the designers.

**MBR06**

- The problem solving procedures are effective for tracking and dealing with complaints.

#### KMB0601
**Building the service is needed to effectively minimize the life cycle costs**

- The building systems to meet the design requirements and client expectations.

### C. Technical issues

#### MCB01
**Inadequate temperature/ humidity control**

- Least / Most
- The surveys have shown that the building management systems are mostly concerned with the effectiveness of problem solving procedures for dealing with the complaints of building occupants, and tracking problems of BAS. It proves that most occupants are due to discomfort, which can be caused by ineffective problem solving, tracking and dealing with complaints. Thus, customer orientation is important as well as sustainable maintenance.

**MCB01**

- The problem solving procedures, dealing with the complaints and tracking problem solving are core issues of the building management.

#### KMC0101
**Making the complaints and tracking problems are basic requirement for ensuring the comfort**

- The building systems to meet the design requirements and client expectations.

### Complaints

#### MCB02
**Inadequate temperature/ humidity control**

- Least / Most
- The surveys have shown that the building management systems are mostly concerned with the effectiveness of problem solving procedures for dealing with the complaints of building occupants, and tracking problems of BAS. It proves that most occupants are due to discomfort, which can be caused by ineffective problem solving, tracking and dealing with complaints. Thus, customer orientation is important as well as sustainable maintenance.

**MCB02**

- The problem solving procedures, dealing with the complaints and tracking problem solving are core issues of the building management.

#### KMC0201
**Making the complaints and tracking problems are basic requirement for ensuring the comfort**

- The building systems to meet the design requirements and client expectations.
With respect to the security and fire systems, an overall security system is generally required and installed with a secure separate power supply for office buildings. In addition, the security system interface is also needed to integrate with the fire systems and building management systems.

Office buildings are normally accessed by smart card, code or manual ID cards and have CCTV presence detectors in the security systems.

The functions of the sensor. Sensors in relation with BAS are light/temperature/humidity/Smoke/Air/Pressure sensors and are more common in office building applications. Other sensors as humidity, pressure, air and light sensors which are also equipped to increase the occupants’ comfort and decrease energy consumption.

The building maintainers are mostly satisfied with the support of new or up-to-date information, sufficient instruction/ manuals for BAS operation and maintenance, and historic records of BAS operation as well. The current maintenance support. It indicates that the support of maintenance is important as well as the historic records which rely on the maintainers and are gathered by computerised aids.

The maintainers are basically concerned with those factors which minimum energy consumption design in BAS, applicable BAS, applicable BAS integration and adequate operation/ maintenance.

In practice, the evaluation of BAS is carried out over different durations categorised as monthly, seasonally, half-yearly, and yearly periods. Normally, it is often done by monthly or yearly. These periods are considered the necessary inspection and maintenance routines in order to sustain the functions of facilities. Normally, the evaluation of BAS should be scheduled to become the regular tasks.
### BAS Evaluation

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<th>Component</th>
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<td>More</td>
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### BAS Selection

1. **HVAC/Energy management**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

2. **Electrical power/ lighting system**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

3. **Fire/security system**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

4. **Life/rescue**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

5. **Lifts/ escalators**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

6. **Water supply/drainage**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

### BAS Maintenance

1. **HVAC/Energy management**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

2. **Electrical power/ lighting system**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

3. **Fire/security system**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

4. **Life/rescue**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

5. **Lifts/ escalators**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

6. **Water supply/drainage**
   - Low: 6, High: 6
   - Frequency: 4
   - Least: 1, More: 6
   - Total: 7

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**Notes:**
- The BAS evaluation is exclusively the responsibility of the facility manager, or alternatively by the design consultant. The BAS evaluation is the responsibility of the maintenance staff as well as the designers across the whole building process.
- The building systems in HVAC, energy management systems, electrical power/ lighting systems, fire/security systems, and lifts/escalator are more important than other building systems such as parking systems and water supply/drainage systems.
- The results indicate that the awareness and understanding of the importance of the building systems can result in an integrated solution.

**Tips:**
- Application of BAS meeting with the requirement of clients.
- Selections of applicable BAS meeting with the requirement of clients.
- Selections of BAS that meet the requirement of clients, the performance/efficiency of BAS after delivery, the balance of BAS costs between the design requirements and the client’s budget, availability of the evaluation tools for BAS.
- Selections of BAS that meet the requirement of clients.
- Selections of BAS that meet the requirement of clients.
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- Selections of BAS that meet the requirement of clients.
Appendix F

Demonstration of the Pilot System
Appendix F

1. Homepage:

![Homepage Image]

2. Content page:

![Content Page Image]

3. Information retrieval- initial page:

![Initial Page Image]

4. Information retrieval- second page:

![Second Page Image]
5. Information retrieval - third page:

6. Information retrieval - fourth page:

7. Retrieval result: (End of the pilot system)
Appendix G

Demonstration of the
Prototype Decision Support System
(1) General D/M Quiz: It is an initial warm up step to realise the integration concept and learn the evaluation process of the system.

(2) Evaluation: It can be used to evaluate the BAS design and maintenance issues to verify the concept and practical situations to explore the guidance.
Appendix G
(3) Search: It can be used to search the professionals of the design and maintenance, and guidance of the design and maintenance issues.
Appendix G

(4) Update: It can be used to update the knowledge database of the professional and guidelines, which are updateable for the users to add and modify the information.

(5) Hot Topics: It includes the recent issues of the BAS design and maintenance, which provides the information and research findings for the users.
(6) Links: It can be links to intranet and internet of the World Wide Web (WWW) for exploring the wide range information.

(7) Help: It includes the introduction and a demo of video clips to demonstrate the operation procedure.
Appendix H

Prototype Decision Support System

SBASpro

The Integration between Design and Maintenance of Office Building Automation: A Decision Support Approach
**SBASpro**
**Installation Guide**

**First Step:** Install MS.Net framework
1. Click “dotnetfx.exe” to install, then
2. Click “setup.exe” to install

**Second Step:** Install **SBASpro**
1. Click “setup.exe” to install
2. Make and select installation folder: C:\SBASpro\
3. Adjust the screen resolution to 1152 by 864 for the best resolution

**Third Step:** Apply **SBASpro**
1. Click “WindowsApplication1” from C:\SBASpro\
2. Help: provides demo of the utilities.

**Attached CD:** contains

MS.Net Framework1.1 & SDK packages and

Prototype of Office Building Automation Decision Support Pro (**SBASpro**)