Evidence based design in healthcare: Integrating user perception in automated space layout planning

Yisong Zhao

School of Civil and Building Engineering

Loughborough University

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I would like to dedicate this thesis to my loving parents...

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Abstract

Despite significant technological and scientific advances in healthcare provision and treatment in past decades, economies are struggling to address increasing costs while enhancing accessibility to quality health and care services. Globally, around 8.4% of gross domestic product (GDP) is spent on healthcare, with United States spending 17.4% of its GDP. There is, therefore, a growing interest in reducing healthcare costs and improving quality of care in terms of patients outcomes and their perception. Research has found strong association between physical environments and patient outcomes and staff and patient wellbeing. The acknowledgement of this link has led to the postulation of the idea of evidence based design (EBD) of healthcare facilities, in which design decisions are based on the evidence of the impact of environment on healthcare indicators. The key challenges for integrating EBD in healthcare design are the difficulty in disaggregating past research findings (i.e. evidence) from the context and the use of these findings, often hidden behind several behavioural and demographic variables or of the form of multi-dimensional indices, in design decision-making. Another recent development in healthcare is the patient-centred approach of care, in which patients perceptions and needs take the centre-stage in the planning and delivery of their care. Local and regional healthcare authorities are, therefore, interested in incorporating patients views in all aspects of care, including the design and operation of health and care facilities.

Considering the gaps in knowledge, this research was aimed at investigating: users perception of physical environment indicators that had the potential for influencing their wellbeing and care outcomes, and the integration of their perception in the design of healthcare facilities through automated space layout planning. Perceptions of physical environment indicators were investigated using structured questionnaires among three user groups: inpatients, outpatients and healthcare providers. Resulting perception indicators were then used in a prototype automated space layout planning system, developed as part of this research, to aid the optimization process.

The research has identified significant differences in perception between different user groups, in particular between males and females. Analyses of scaled responses indicate that environmental design (e.g. lighting and thermal comfort) and maintenance (e.g. cleanliness) related factors are more important to users than abstract architectural design factors (e.g. aesthetics). Accommodating the variation in perception would require individual approaches for the design of constituent spaces in a healthcare facility. With regard to the integration of user perception in design, the research demonstrates that qualitative indicators such as perception can be integrated in automated design frameworks and, therefore, design decisions can be based on a mix of quantitative and qualitative evidence. The application of automated layout planning system in the design of healthcare space layouts also demonstrates that computer-mediated systems and frameworks are a promising alternative to traditional manual design, if increasing number of design factors and objectives are to be reconciled for decision making.

Key words: Evidence based design, healthcare facilities, automated space layout planning, user perception

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List of Abbreviations

Roman Symbols

AI	Artificial intelligence
ANN	Artificial neural networks
BRI	Building Related Illnesses
BS	Building Sites
CABE	Commission for Architecture and the Built Environment
CLASS	Computerized layout Solutions using Simulated Annealing
CRAFT	Computerized Relative Allocation of Facilities Technique
DLP	Dynamic Layout Problem
DoH	Department of Health
EBD	Evidence-based Design
EDGE	Evolutionary Design based on Genetic Evaluation
EPA	Environmental Protection Agency
EPPIC	Evidence for Policy and Practice Information and Co-ordinating Centre
FLP	Facility layout planning
FSQP	Feasible Sequential Quadratic Programming
GA	Genetic Algorithms

GDP	Gross Domestic Product
GHS	Green House Gas
GP	Genetic Programming
GRAMPA	GRAph Manipulating Package
HAI	Hospital Acquired Infections
HBN	Health Building Notes
HC	Hill Climbing
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
KMO	Kaiser-Meyer-Olkin
MRSA	Methicillin-resistant Staphylococcus aureus
NHS	National Health Service
NP	Non-Polynomial
NPSA	National Patient Safety Agency
ONS	Office of National Statistics
PCA	Principal Components Analysis
PD	Patient Dignity
PR	Patient Recovery
PS	Patient Satisfaction
PSa	Patient Safety
QAP	Quadratic assignment problem
SA	Simulated Annealing
SARS	Severe acute respiratory syndrome

SBC	Simulated Binary Crossover
SBS	Sick Building Syndrome
SD	Standard Deviations
SDU	Sustainable Development Unit
SLP	Space Layout Planning
SP	Staff Productivity
SQP	Sequential quadratic programming
SS	Staff Satisfaction
SU	Space Unit
SUS	Stochastic Universal Sampling
TS	Tabu Search
UK	United Kingdom
US	United States
VOC	Volatile Organic Compounds

Chapter 1

Introduction

This thesis details the research undertaken to explore people's perception of the physical environment of healthcare facilities and utilise the findings into modelling and simulation for better layout design. This chapter presents the context of current research and then leads to an exploration of the purpose of the research by identifying the research problem, research aim and objectives. This is followed by a justification of why this research is carried out. A brief description of research methodology, aligned with the research objectives, is presented, and the contributions to knowledge are summarised. The chapter concludes by outlining the structure of the thesis.

1.1 Background

In the UK, the National Health Service (NHS) is mostly free at point of use and paid for out of taxation, delivering local service by 1.1 million staff in more than 400 organisations and through approximately 8200 GP practice premises, as well as other primary care services (Department of Health, 2012). Over its sixty year span, a large number of healthcare buildings have been built in order to meet the increasing demand of healthcare delivery throughout the UK. As the demand continues to grow, the NHS is under great pressure to reduce energy consumption and the associated costs from buildings, while not sacrificing the well-being and satisfaction from patients and staff.

The NHS in England is responsible for more than 18 million tonnes CO_2 each year from heating, cooling, lighting buildings, powering equipment, procuring goods and commissioning services, sending waste to landfill, and patient, staff and visitor travel. This is 25% of total public sector emissions and 3.2% of total carbon emissions in England. A large proportion of emissions coming from NHS buildings because significant percentage of energy is used for heating and hot water (Figure 1.1). According to NHS Sustainable Development Unit (SDU), the NHS buildings consume over £410 million worth of energy and produce 3.7 million tonnes of CO_2 every year. Although the associated emissions have decreased from 22% in 2004 to 19% in 2010, it is still the second largest carbon emissions from overall NHS carbon emissions. And a further cut of 4.6% (0.9 $MtCO_2e$) is needed for the NHS to reduce its emissions by 10% by 2015 as proposed in the NHS Carbon Reduction Strategy (NHS Sustainable Development Unit, 2009).

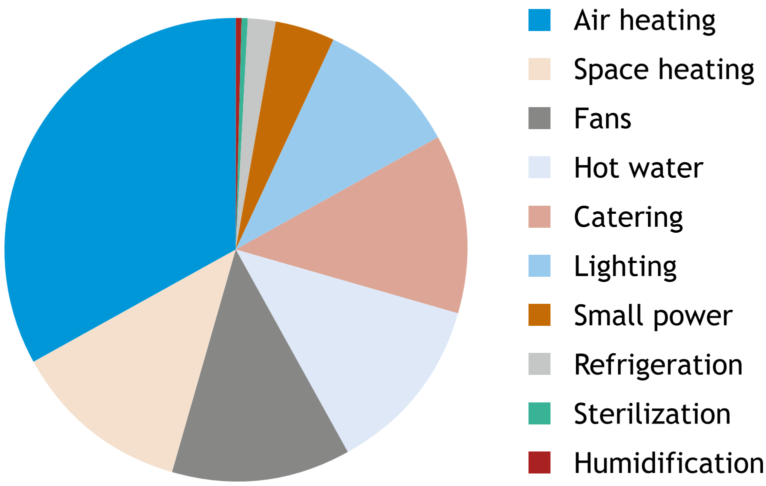

Figure 1.1: Energy consumption in a typical hospital by end use (Carbon Trust, 2010).

The Office of National Statistics (ONS, 2008) has shown that national health expenditure accounts for 8.7% of the country's gross domestic product (GDP), leading to an obvious increase compared with the level of 6% GDP in 2000 (Propper, 2001). Healthcare expenditures have also been increasing in other countries around the world in the last decade. For instance, the US signed the most expensive cheque for healthcare, reaching 15.2% of its GDP in 2008, as compared to Germany (10.5%), France (11.2%), Japan (8.3%) and Brazil (8.4%). The comparative figures for these countries in 2000 were 13.4%, 10.3%, 10.1%, 7.7% and 7.2% respectively (WHO, 2011). It is anticipated that healthcare spending will continue to rise and will outpace the growth in the general economy of some countries (Belohlav, 2010).

Despite record investment over the past decade, problems in the healthcare persist with efficiency improvement, quality management and service delivery, which all affect patient satisfaction. Evidence from recent literature indicates that patients expect more from the hospital in addition to a high quality of health service, such as spacious en-suite single bedroom, pleasant lighting, ability to have outside views, access to phone and television controls, etc. Measuring their satisfaction has become an important and effective outcome for healthcare services (Brian, 1994; McKinley *et al.*, 1997). Most researchers agree that a patient-oriented healing environment should be built to address patient's need and enhance patient satisfaction (Coulter, 2002; Douglas & Douglas, 2005).

Greater budgetary pressure, target to cut carbon emissions, ageing population and increased expectations in quality of care, all call for a rethink in the way care is delivered. In response to these challenges, physical environments in which care takes place, namely buildings and ancillary facilities, are a major part of this healthcare regeneration process. The need for building adaptation in the hospital sector is evident and the hospital designers need to bear in mind the concept of design flexibility; enabling the hospital to run with improved efficiency. Whether in the form of new constructions or building refurbishments, the overall aim of improving efficiency is to achieve not only the lowest possible construction, maintenance and operational costs, but also the highest possible patient/visitor satisfaction, comfort and privacy (Kazanasmaz, 2006a). Against such backgrounds, healthcare design is at a turning point to resolve the potential challenges and provide a better environment for the hospital users.

Traditionally, healthcare building design projects begin when architects are given a set of objectives by clients, stakeholders or others. These objectives/functions are then translated into design goals according to the department requirements (a greater definition of the floor plan) and room adjacencies are defined. Once this information is provided, a detailed design of each room is completed and finally equipment, information technology, building service systems, interior furniture and other components are put together. This conventional process of health building design is typically quite linear, passing over scrutiny of other related issues such as users' opinions and preferences. Once a design has been determined in the early stage, the steps that follow are then taken forward with no back loop of evaluation. Patient safety, staff and patient satisfaction are seldom taken into account during the early design process, as a result, the characteristics of this type of design increases the potential of active failures in existing hospital designs (Norman, 1998).

Many studies have examined the link between the design of healthcare physical environment and patient well-being and outcomes (Ulrich, 2001; Devlin & Arneill, 2003; Douglas & Douglas, 2005; Dijkstra *et al.*, 2006). The acknowledgement of this link has resulted in the postulation of the idea of evidence-based design (EBD), which is a recent trend in healthcare design (Becker & Parsons, 2007; Codinhoto *et al.*, 2009; Ulrich *et al.*, 2008). The EBD is a process adopted by architects, healthcare designers and other healthcare professionals involved in the planning, design and construction of healthcare buildings. It is achieved by a design group with mixed backgrounds that makes decisions based on the best information available from research, from project evaluations, from evidence gathered from different stakeholders and their own knowledge. The EBD results in a significant improvement in the utilisation of resources to fit as many perspectives as needed in the design process. More knowledge relates to EBD in healthcare design could be referred to a comprehensive literature review carried out by Ulrich *et al.* (2008). They have found a large body of rigorous studies to guide the healthcare design, with respect to reduction of hospital acquired infections (HAIs) and improvement of patient outcomes for a range of design characteristics, such as single-bed rooms instead of multi-bed rooms, effective ventilation systems, good acoustic environment, nature distractions and appropriate lighting, better layout design and improved work settings. However, the key challenge for the integration of EBD into planning, design and operation of healthcare buildings is that much of the underpinning EBD research is contextual. Applications of such findings in healthcare buildings are challenging mainly because of the difficulty in disaggregating the findings from the contexts of care and/or physical environment. In addition, the effects of the physical environment in the existing evidence base are hidden behind various physiological and psychological variables, which are difficult to assess and need to be translated into design variables or indicators before being applied in decision-making process. It is therefore necessary that patients' perspectives are considered in all aspects of care–from care delivery and treatment (Robinson & Thomson, 2001) to the design and operation of buildings (Smith *et al.*, 1995).

1.1.1 User perception in hospital design

Healthcare providers and patients constitute of the most frequent user group who spend most of their working and caring time in hospital's indoor environment. Their opinion on the design of a hospital provides valuable information and expertise to hospital designers. On one hand, healthcare providers are familiar with the physical aspects of the environment, as well as its relationship with their working requirements. They can provide comprehensive first-hand resource of information with regards to what they think are necessary and what should be avoided in design. On the other hand, patients' perception and feedback about the physical environment includes what they think is important to them, what matters to them and what supports their healthcare experience. Such sources of information are very significant in screening for problems and in developing an effective plan of action for quality improvement in healthcare organisations (Stern *et al.*, 2003). The participation of care providers and patients are also contributing to the research by meaningful information, enabling healthcare designers and architects to go beyond their own limited experience within the built environment of a particular healthcare facility. Accordingly, they can make an effort to shape and/or reshape the healing environment in order to realise the desired outcomes of perceived service quality (Fottler *et al.*, 2000).

Since patients' outcomes could be influenced by hospital settings, healthcare physical environments have also been found to be linked with staff performance issues such as medical errors, injuries and stress (Ulrich *et al.*, 2008). A rich body of evidence have shown that a well-designed healthcare environment has the potential to increase care providers' productivity, reduce medical errors and decrease the injury rates and stress. However, most aspects related to a well-designed physical environment are determined during early design stages of a building's life-cycle. Subsequent modifications at later stages are expensive and sometimes difficult to achieve due to the multidisciplinary nature of design decision-making (Mourshed, 2006). An understanding of patients and care providers (including staff and nurses) perception of design factors is, therefore, essential for informed decision-making (Kelly, 1955) during early design stages. Past research on physical environments in hospitals focused mostly on user satisfaction and was linked with service delivery. User satisfaction studies such as the ones conducted by (Brian, 1994),(Asadi-Lari *et al.*, 2004) and (Walsh & Knott, 2010), provided an indication of some relevant physical environmental features that could be considered during design. Nevertheless, they were mere proxies, which needed translating into design factors before use and not without the loss of semantics. Moreover, physical environmental factors were not studied in an integrated way in a single study in order to generate a comprehensive evidence base, upon which decisions could be made.

1.1.2 Optimisation of architectural layout design

The architectural design has been defined as the initial phase of the design process (Liu & Hsu, 2000; O'Sullivan, 2002) and the designers will generate several possible solutions according to the specification of the required object. This process could be seen as an optimisation activity as the design aims to find out the optimum solution, satisfying the design requirements by a range of available means (Mourshed, 2006).

One of the key architectural design activities for healthcare facilities is the design of the physical layout that is concerned with finding feasible locations and dimensions for a set of interrelated components in order to meet the design requirements and maximise the design quality (Michalek *et al.*, 2002). Traditionally, architectural layout design depended on the expertise of designers/architects involved and the process is influenced by their prior experience and cultural bias. Due to the nature of optimisation, human designers are only able to choose part of the alternative solutions from a complex potential solution space. Computer based optimisation methods were therefore designed to overcome the deficiency of human factors. The advantages in automatic building optimisation enable the designer to reach an optimal outcome within a reasonable time scale, which brings a significant improvement with regards to accuracy and time consumption compared with the human designers. A typical process of architectural layout design optimisation has been drawn up in Figure 1.2. The optimisation problem is formulated in terms of some design parameters and restrictions, which need taking consideration of expertise knowledge of space layout planning, the defined objectives and building design regulations. The parameters chosen to describe the healthcare design are known as design variables, these variable are usually generated by designers according to the design purpose and regulations. Restrictions are known as constraint conditions, analysing the problem is a process examining the constraints to satisfy the convergence criteria, evaluations will be made to justify the optimisation results and the employed optimisation method will be modified accordingly to improve the results' quality in order to reach the optimum solution.

1.2 Justification of the research

Patient-centred strategy and focus in healthcare facilities presumes patients' and their families' involvement in the decision-making in planning and design process. Patient-centred design requires participation of patients because the non-consumer stakeholders often don't know what matters most to patients during care delivery. However, the pre-condition of the patient-centred healthcare design is that patients' perception of the importance of various design indicators are captured in a usable format. In most countries, patients' views are collected using quality of care questionnaires and are often linked to care or treatment they received beforehand. They concerned more of the quality of care they receive. As a result, patients' perceptions of physical environmental dimensions

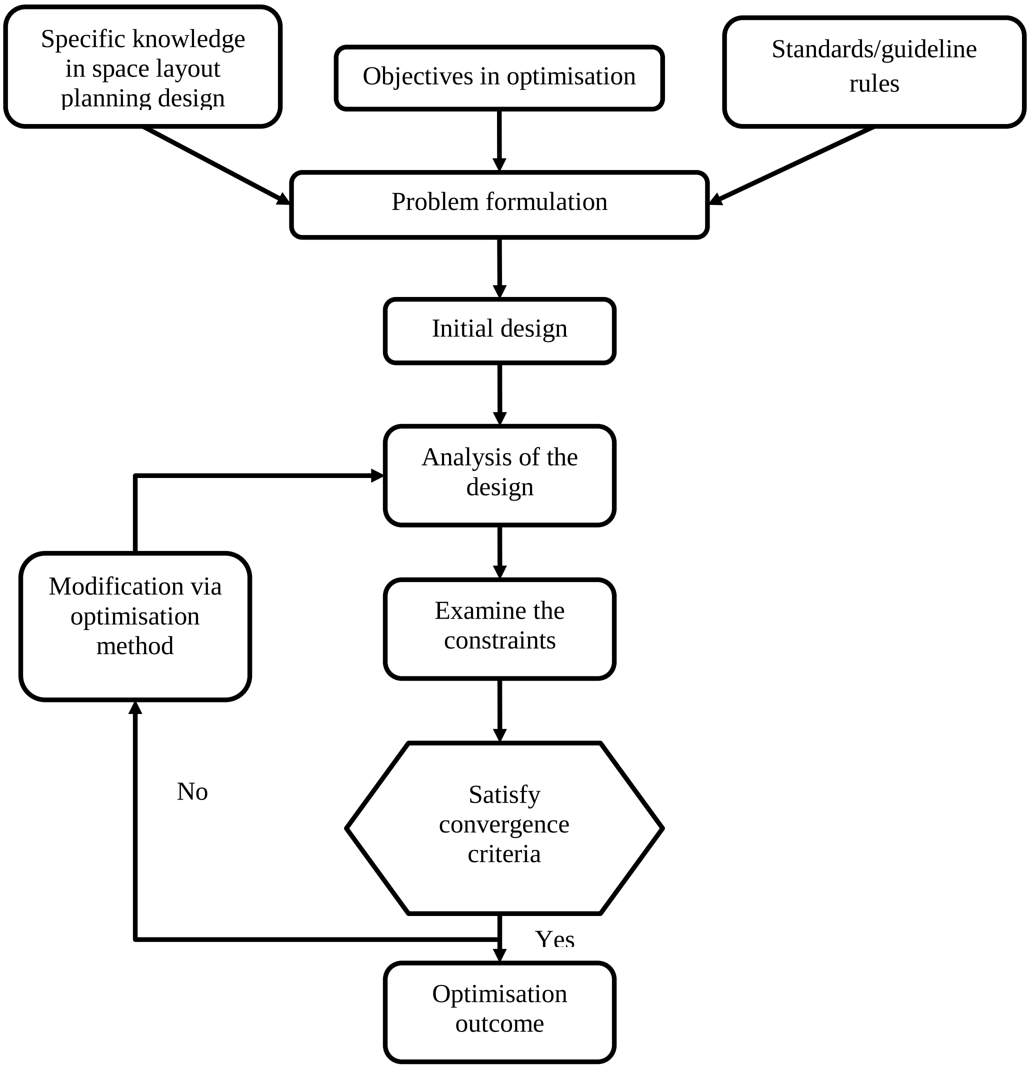

Figure 1.2: Flow chart of the optimisation layout design process.

relevant to the design and operation of buildings are thus less explored in the existing literature.

Another challenge is that the architectural optimisation itself since it is a combinatorial problem that involves minimisation or maximisation of certain design criteria based on predefined objectives (Mourshed, 2006). And it requires computer technology to examine all possible solutions in the search space rather than rely on a human designer. For healthcare buildings, it is even far more complicated than any other type of buildings (Kendall, 2005). This is due to large quantities of different functional spaces and a greater diversity of these spaces with various restrictive requirements in a healthcare building (Tzortzopoulos *et al.*, 2005).

Space is one of the most important elements in healthcare facility design, in order to meet users' requirements and functions of a building. Any activities of an individual or an organization in a building must be carried out in a certain space. Hence, building spatial properties are determined on the basis of user organisation requirements (Ekholm & Fridqvist, 2000). A campaign (Healthy hospitals campaign) led by the Commission for Architecture and the Built Environment (CABE) has obtained views from the public about hospital design (Figure 1.3). 32% of the respondents suggested that space considerations should be prioritised for hospital design. The percentage of space is higher than for any of the remaining design factors investigated by CABE.

Based on these backgrounds, this research investigated users perception of healthcare physical environment in different aspects to contribute to the evidence base on factors (Figure 1.3) related to physical environments in healthcare facilities. The research then proposed a method integrating user perception with spatial layout using optimisation algorithms rather than previous experience without validated search.

1.3 The purpose of the research

1.3.1 Aims and objectives

The aims of the research are to gain an understanding of users' perception of factors related to hospital design and develop a methodology to optimise the space layout of healthcare facilities as an evidence based design. This requires to consider the factors influencing the space planning in the context of hospital design and integrate the user perception with automated layout planning and mathematical optimisation techniques in the decision making process.

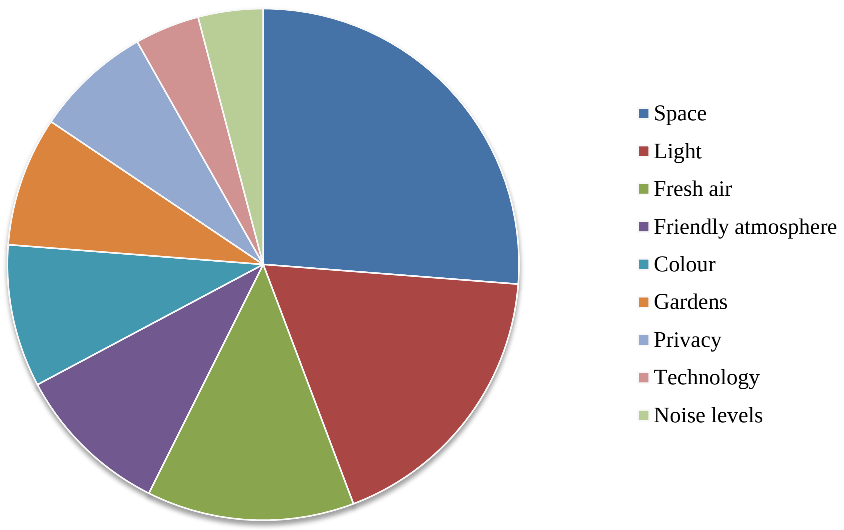

Figure 1.3: Preference for the consideration of factors during healthcare design by the respondents in the CABE Healthy Hospital Campaign survey. (Source of data: CABE, 2003)

Five objectives of this research have been devised. They are detailed as below. Table 1.1 shows the relationship between the research objectives, the methods and the corresponding chapters.

1. Review the state-of-the-art relating to the design of healthcare space and methods for space layout planning.
2. Investigate the factors that affect decision making during layout planning of healthcare facilities.
3. Investigate the user perception on the physical environment of healthcare facilities through questionnaire and interviews.
4. Develop a framework for the integration of user perception of healthcare physical environments in decision making process through the use of automated space layout planning and mathematical optimisation methods.
5. Test the developed framework in solving realistic hospital spatial layout problems using the principles of evidence-based design.

1.4 Research scope

Based on the review of the state of the art in healthcare building design and after discussing with relevant stakeholders, the following questions were designed to guide the research process. The questions are elaborated further in Chapter Four.

- What are the most important factors that drive the need of spatial layout design in healthcare facilities?
- Do users' perception of factors related to healthcare building design vary and if so, can their perception be integrated in the design process?
- What methods can contribute to and/or improve the space layout design in healthcare facilities?

The research scope involves a wide range of literature reviews regarding impact of hospital design and methods of space layout planning. A quantitative survey consists of three questionnaires is designed for patients and care providers as well as interview questions with nurses and other hospital users. Within the research, models and simulations of layout design prototypes are built in order to integrate healthcare users' perception with the spatial layout planning. These are broken down into activities listed below:

- Conduct a "state-of-the-art" review of hospital design, it's affects on patients as well as care providers, mathematical methods for space layout planning, and identifying the suitable modelling method for this study.
- Conduct a review of patient satisfaction survey and other related questionnaires to identify a perception survey that will be utilised in the study.
- Explore the perceptions of the physical environment from patients and care providers, and examining the relationship between the characteristics of the respondents and the findings; and
- Build a prototype [1] to integrate user perceptions with the application of mathematical modelling methods to assist layout planner in the decision making process.

[1] Prototype is a preliminary simulation model used in spatial layout planning.

Table 1.1: Research map

Objectives	Methods	Chapters
To establish research questions, aims and objectives	Literature review of factors influencing the hospital design	Chapter 2: Systematic review of factors affecting the hospital design
Choose the most suitable optimisation method	Review of optimisation methods	Chapter 3: Review of spatial layout optimisation techniques
To explore the importance of aspects of physical environment in healthcare facilities and propose a feasible solution to solve SLP problem	Deliver surveys and gather data; Site visits to hospital; Mathematical programming	Chapter 4: Conduct questionnaire and interview, define spatial layout planning problem and optimisation method
Investigate people's perception of physical environment of healthcare facilities	Investigate the association between different stake-holders' perception with their demographic information by SPSS	Chapter 5: Questionnaire (Users' perception studies) results and discussions
Evaluate the performance of the prototype to solve different scales of spatial optimisation problem	Evaluate the prototype in different case studies	Chapter 6: Implementation of spatial layout optimisation – two case studies of hospital design
Chapter 7: Conclusions and future studies		

1.5 Research methodology

In order to address the research questions identified in Section 1.4, a multi-methodological research design is adopted to provide a richer and deeper meaning of the research questions. A pragmatic mixed-methods methodology, combining both quantitative and qualitative approaches for data collection and analysis, has been identified as the most suitable for the current research, hence this was the method employed (see Chapter Four). Table 1.1 shows the objectives at different stages, the methods employed and the corresponding chapters in the thesis.

The research will begin with a systematic literature review of the factors that may influence the hospital design and the review of automated SLP (Space Layout Planning) optimisation methods. By understanding the impact of design factors on patients and care providers, it leads to the rationale for investigating how people perceive the design of healthcare layout in reality and what aspects the hospital users consider to be most important in the design process, etc. Therefore, a quantitative study will be conducted via questionnaire survey and interviews in two hospitals in order to explore the facility users' perceptions on hospital design from care providers, inpatients and outpatients. The obtained data will be analysed using statistical software package (SPSS), then the next step is to develop a prototype in order to solve the typical SLP problem using evolutionary optimisation method which will be chosen from the literature review. The final step will be to integrate the findings from the questionnaire surveys with the SLP prototype in order to deal with healthcare SLP problems. Based on the results, further analysis will then be carried out in order to evaluate how changing variables will affect the final performance to identify most important factors.

1.6 Overview of the chapters

The thesis is structured into seven chapters with appendices containing additional information. Table 1.1 presents a schematic representation of the thesis indicating how the chapters inter-relate in order to allow the reader to have a clear view of the development of the study.

An overview of following chapters is given:

Chapter Two

This chapter provides a systematic literature review of the factors that influence the spatial layout design in healthcare facilities. The factors include users' satisfaction, patient safety and well-being, organisational aspects, energy consumption, layout spatial configuration, etc.

Chapter Three

This chapter reviews a series of optimisation methods in spatial layout planning, based on the literature review, and the practical optimisation method is identified. The application of genetic algorithms is then discussed.

Chapter Four

This chapter explores the philosophical stance along with research methodology and design. It presents the justification for the questionnaire design and interview. The research sample, data collection methods and analysis are detailed. The selected software package SPSS is used in order to assist the data analysis for the purpose of transparency and credibility of present research. Design of the SLP programme is followed, problem formulations are specified and the application of GA toolbox is discussed in this chapter.

Chapter Five

This chapter presents the results and findings from questionnaire surveys. Descriptive analysis and factor analysis are conducted with data obtained from three types of questionnaire surveys. Results regarding the internal consistency are then presented. Respective discussions are also presented in this chapter.

Chapter Six

This chapter explores the process of developing a feasible SLP optimisation prototype with integration of user perception of healthcare physical environment that is generated from questionnaire survey.

Chapter Seven

This chapter presents the contribution to knowledge made by this research and discusses future directions.

Chapter 2

Systematic review of factors affecting the hospital design

This chapter provides a systematic literature review of the factors that influence the design of physical environment in healthcare facilities. The method of systematic literature review was presented and impacts of the factors influencing the design of the physical environment, in particular the design of space layouts, are categorised in terms of user groups. Other impacts on spatial configuration, energy and environment are also discussed.

2.1 Introduction

Global healthcare expenditures account for around 8.4% of the gross domestic product (GDP). Some developed countries spend more than 15% of the GDP on healthcare such as the United States (17.9%), Germany (15%) and France (16%) (The Henry J. Kaiser Family Foundation, 2012). Given the investment in healthcare, it is important that healthcare professionals understand how evidence-based and facility user-focused design creates a healing environment for users, e.g. care providers, patients and visitors.

Evidence based design of healthcare facilities is focused on the utilisation of proven design features that impact on patient health, wellbeing and safety, as well as the well-being, productivity and morale of staff. When healthcare designers and architects design hospital, more often than not, they concentrate more on the designing of buildings and their architectural appearance and pay insufficient attention to the design impacts on its occupants (patients and care providers). However, understanding such impacts is important in the decision-making process, as patients and care providers consist mostly of facility users, and have a better knowledge, from their experience, of what matters to them, what supports their requirement and how to improve the quality of the healing environment from their perspective. By assessing such impacts on patients and care providers, healthcare professionals can find user-focused design problems and provide solutions. Another rationale addressing design impacts on facility users in the decision making process is the decision regarding the physical characteristics of a building such as layout, shape and form. These are made at an early stage in a building's life cycle and it is difficult to alter or reverse them later without significant financial implications.

Nevertheless, little research has been carried out on determinants of impacts on patients and care providers in healthcare buildings. The following sectors of this chapter describe a systematic literature review regarding the factors affecting the design of healthcare buildings.

2.2 Method of the systematic review

This systematic review of the state of the art on current practices in healthcare buildings, healing aspects of the built environment, advances in space layout design and relevant policies and strategies of the NHS and Department of Health (DoH). Several strategies were employed in order to identify published and unpublished literature for the review. Metalib, an information portal, has been used to identify relevant catalogues, reference databases, citation databases, journals and conferences through semantic meta searches. The literature review process was adapted from a methodology developed by the EPPI-Centre (Evidence for Policy and Practice Information and Co-ordinating Centre), Institute of Education, University of London (Peersman *et al.*, 1997). The process used for this literature review comprises a number of distinct phases:

- Identification: Identify the need for a systematic literature review and formulate the review questions.
- Searching: Carry out a comprehensive search strategy to investigate potentially relevant studies.
- Screening: Apply the predetermined inclusion and exclusion criteria to assess the searched literature.

- Data-extraction: Examine the full-text of the literature to assess the quality of the studies and extract data from each included study.
- Summarise and synthesis: Analyse the results from the reviewed literature to develop a framework of a new idea.
- Reporting: Present the review findings.

2.2.1 Identification of research questions

The main research question seeks to find factors that influence the planning and design of healthcare facilities in the initial design process. The impacts of patient-focused activities on hospital design falls into different categories, which formulate different sub review questions.

Therefore, the main review question is:

What are the factors that may influence the design of the physical environment of the healthcare facilities?

And the sub review questions are:

- *What are the health building designers' considerations upon the design layout for an in-patient hospital?*
- *What aspects in the hospital design will influence patient safety, satisfaction and recovery.*
- *What are the issues to be addressed in the policies regarding the interior hospital design?*
- *How is energy consumption related to the interior design process in healthcare facilities?*
- *What are the issues that need to be addressed when adaptation of healthcare facilities occurs?*

2.2.2 Search strategy

In order to make sure that the literature search performances are consistent and comparable, a search strategy is developed via two types of searches: database searches and web searches.

2.2.2.1 Database searches

Selected electronic databases are shown in Table 2.1. The first round of searches was undertaken by Metalib in order to identify the studies regarding the search terms ‘hospital design’ and ‘layout planning’. These initial searches yielded a total of 81978 references. The number of results were narrowed down using a combination of other search terms. For example, search term 1 (‘hospital design’) was to be paired with search term 2 (‘patient safety’) using a disjunctive manner (OR), some other searches use addition (AND) in order to broaden the search space as well. Related search terms were derived from the research questions including ‘patient safety’, ‘patient dignity’, ‘staff productivity’, ‘patient recovery’, etc. Once the second round of searches finished, the results were placed into categories and at this stage the results were reduced to 1486.

In order to reduce the number of potential papers to a manageable level within the available time-scale, a significant proportion were screened on-line in order to determine the suitability for inclusion in the systematic literature review.

Electronic databases:
Article First (OCLC)
Construction Information Service (CIS)
Emerald
Health and Safety Science Abstracts (CSA Illumina)
Intute: Health Life Science
MEDLINE (OCLC)
OHSIS: Occupation Health and Safety Information Service
PhyclINFO
Science Direct
Zetoc

Table 2.1: Selected electronic databases.

2.2.2.2 Grey literature searches

In order to ensure the research did not overlook any important material regarding the research questions, additional grey literature[1] searches were performed on the world wide web using popular search engines such as Google, Yahoo, Bing and Ask.com. Some key conference proceedings, journals and authors were also searched for based on the references found in the primary studies. Researchers with publications relevant to this research were contacted via email to see if they have any new findings and publications in the pipeline which could be considered.

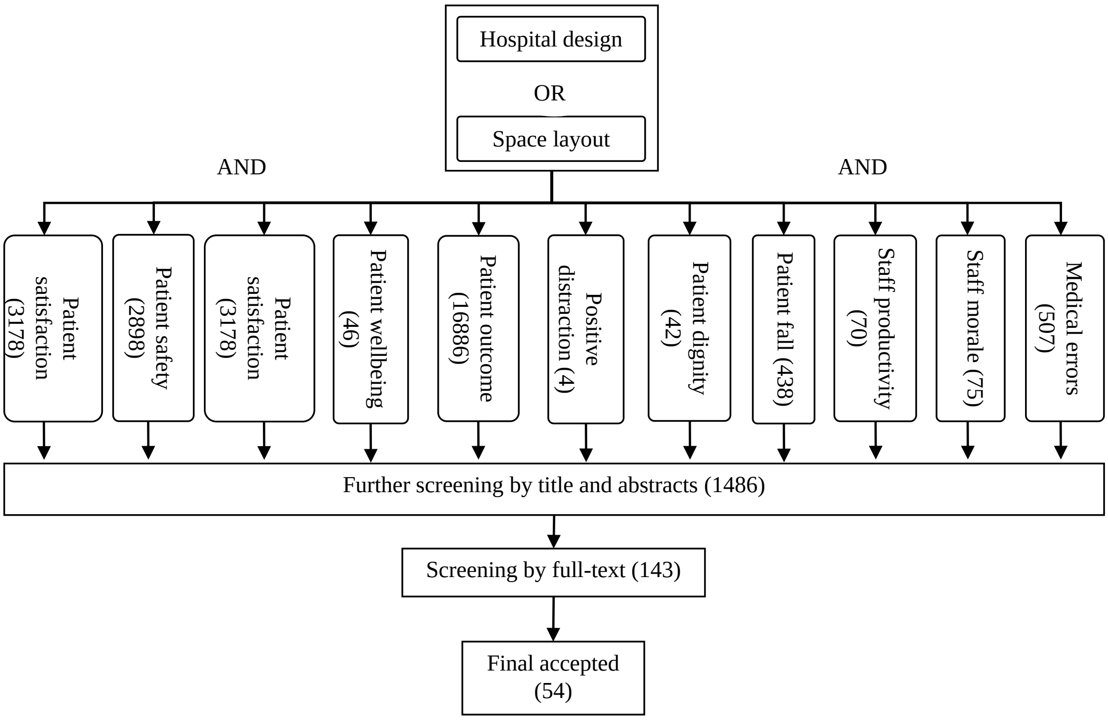

Figure 2.1: Flow chart of the search strategy.

2.2.3 Screening

The search results of each category were evaluated on the screen to ensure that the pre-determined inclusion and exclusion criteria were met for In order to ensure the searched

[1]Grey literature is defined as "literature which is not readily available through normal book-selling channels, and therefore difficult to identify and obtain"(Auger, 1994).

literature's predetermined inclusion and exclusion criteria were met for each source. Inclusion and exclusion criteria were derived from key inherent concepts in the research questions, and were based on three quality assessment criteria; namely, soundness, appropriateness and relevance. The inclusion and exclusion criteria for this review are as follows:

Inclusion and exclusion criteria

Literature are **included**:

- *on hospital design and related patient-centred aspects;*
- *on hospital layout planning;*
- *directly answer any one or more of the research questions;*
- *draw on published and/or unpublished research;*
- *intervention studies and other sorts of literature;*
- *are written in English;*

Literature are **excluded** that:

- not relevant to hospital design and related patient-centred aspects;
- not relevant to hospital layout planning;
- not based on empirical research;
- based on single person's opinion;
- not written in English.

2.2.4 Data extraction

The purpose of the data extraction is to extract the relevant data from accepted papers, which are used to prepare the summary tables and answer the research questions. The data extraction was conducted by the completion of a data extraction sheet, with the following items: author, publication year, study type and contribution to knowledge. (See appendix B)

2.2.5 Limitations of the review

This systematic review had its own limitations. In brief, the limitations include: accuracy, unobtainable material and time-scale restrictions.

Although this review tried to include all the relevant literature in different ways regarding the research questions, some key studies may not have been identified due to the limitation of the chosen database and uncertain results derived from defined search terms. Finally, the 54 obtained articles were considered to have strong relevance to the research questions, although some materials were excluded due to unavailability and access prohibitions of databases. Besides these, not all the references found in the database were available at one time, therefore some of the electronic files were excluded due to unavailability.

This review was limited to a certain time-scale, therefore, only selected databases were searched to get as many results as possible within a reasonable time scale.

2.3 Impacts of hospital design on patients

The design of healthcare facilities had, in the past, concentrated mostly on accommodation of the physical requirements of space and service delivery. The consideration of non-tangible benefits to the users such as patients, staff and visitors was mostly ad-hoc. Recent studies have indicated that the physical environment, dependant on how various activities are laid out, is linked with patient outcomes and well-being. The impacts of healthcare design on patients are considerable and cannot be ignored in the healthcare building design and planning process. Advances in understanding of the therapeutic impacts of the built environment have led to a better appreciation of users' needs and their relevance to patient well-being and recovery. Different factors (see Figure 2.2) have been summarised from the literature to address such impacts in a patient-centred design. In brief, these factors include patient safety and security, prevention of patient falls, improvement of patient satisfaction, patient dignity and privacy.

A table was created including different stakeholders, their expectations from spatial configurations and the impact of the factors on patient outcomes (Table 2.2). Factors that influence the design of physical layouts in healthcare facilities are described in the following sections and summarised in Figure 2.2. Five main factors were categorised as user satisfaction, organisational factors, safety and wellbeing, energy and environment and spatial configuration. Each main factor has several sub-factors reviewed from literature that have influences to the design of space layout planning in the healthcare facilities (Zhao *et al.*, 2009).

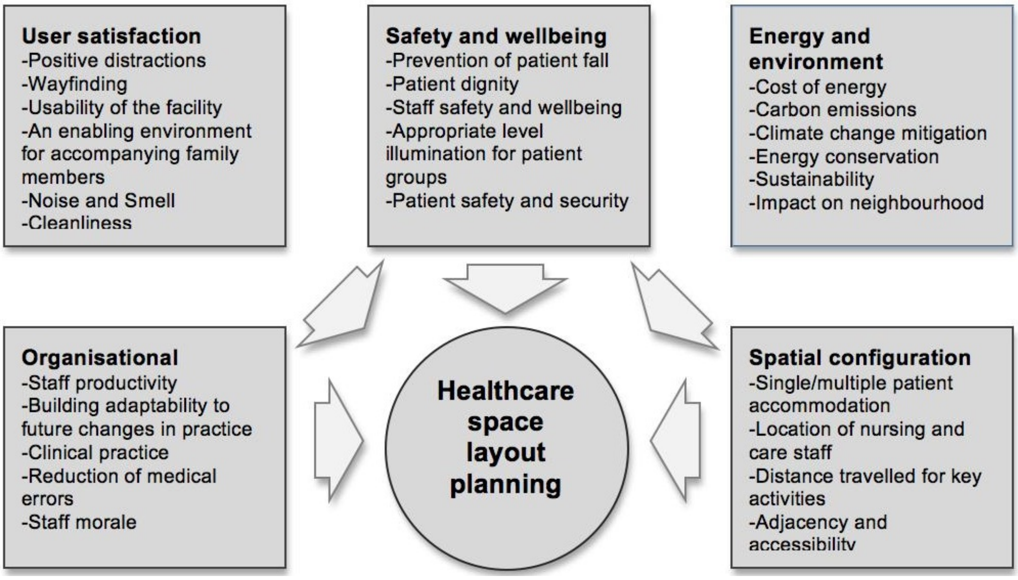

Figure 2.2: Factors influencing the healthcare space layout planning (Zhao *et al.*, 2009).

2.3.1 Patient safety and security

Patient safety is defined as being the protection of patients from direct or indirect harm that may occur as a result within the healthcare system. It has been considered as one of the most important and less understood aspects in the hospital design process because hospital design may affect patient safety directly or indirectly (Joseph & Rashid, 2007). The safety system often runs under acute circumstances since the hospital is a complex organisation where many healthcare professionals work together in order to resolve complicated tasks that relate not only to patients but also affect visitors and care providers themselves. Regarding patients, a safe environment is required for successful recovery. For care providers, safety is associated to their working environment and their well-being. Safety issue related to visitors is the prevention of infections acquired upon accessing the hospital.

There is a growing body of evidence that establishes links between the design of the physical environment and safety outcomes for patients (Reiling, 2006; Rashid, 2006; Hartmann *et al.*, 2009). The issue of patient safety is often raised in the literature in

Table 2.2: Stakeholders' expectations from spatial configurations and impacts.

Stakeholders	Specific requirements	Impacts
Patients	Isolation from other patients (when required)	PD, IC
	Company of other patients (when appropriate)	PS
	Easy access to lighting, bed and television controls	PS
	Easy access to phone	PS
	Interesting area for ambulation	PS
	Outside view	PS, PR
	Easy access to nurse's call signal	PS, PR
	Access to bathroom and shower	PS, PSa
	Pleasant indoor light	PS, PR
	Aesthetic, pleasing environment	PS, PR
	Ability to accommodate differing approaches to staffing	SP
	Ability to deal with shift in severity index	SP
	Ability of all care providers to confer in privacy	SP
Care providers	Ability to work effectively in day or night shifts	SP, SS
	Access to office and conference space	SP, SS
	Access to information retrieval and input	SP, PR
	Access to high-urgency/frequent-use items	SP, PR
	Access to supplies and disposal of used supplies	SP, PR
	Access to equipment storage in designated spaces	SP, PR
	Access to medication	SP, PR
	Staff lounge facility	SS
	Security- personal and for property items	SS, PR
Visitors	Easy access to patient's room	PS
	Private space for communication with staff	PD
	Accommodation with patients	PS, PR

Legends:
SP: staff productivity, SS: staff satisfaction, PS: patient satisfaction
PSa: patient safety, PR: patient recovery, PD: patient dignity IC: infection control

terms of medical errors, patient security and other negative issues that can happen to patients (Joseph & Rashid, 2007). In general, there are two types of adverse events in the hospital: active and latent failures. Reason (2000) distinguished these two types of events as active errors and latent errors. The active errors are those obvious errors that can occur at the interface between care providers and patients, such as violations, mistakes, etc. While the latent errors are outside the direct control of operators, meaning that unlike the active errors, the effects are less apparent failures. The latent errors are usually the results of poor system design and poorly structured organisations (Hickam *et al.*, 2003) that contribute to the occurrence of active errors. For instance, staffing decisions made for fiscal reasons will increase the likelihood of error. Comparing these two types of safety issues, active errors are fairly easy to be targeted and prevented while latent errors pose greater threat to patient safety, because they are often unrecognised and in the future they are prone to result in multiple types of active errors.

Birnbach *et al.* (2010) found that the evaluation of the healthcare facility design mainly came from the criticism of design drawbacks from the post-construction phase, which negatively affected patient safety. In order to enhance levels of patient safety, a great deal of innovation has taken place in the patient room and the integration of technology in hospital-wide to avoid the errors. Safety systems have been implemented to ensure that potential causes of adverse events are anticipated and prevented. However, they can't promise to prevent all kinds of adverse events in hospital since the safety systems will be compromised by special circumstances acting in combination with human factors.

Security is also associated with patient safety, which is of particular importance in the design of healthcare facilities, as discussed by Sine & Hunt (2011). It is summarised in the following five-levels:

- Level 1: Restrictions on accessibility; e.g. staff and service areas where patients are not allowed;
- Level 2: Highly supervised areas; e.g. corridors, counselling rooms, interview rooms and smoking rooms where patients are highly supervised and not left alone for periods of time;
- Level 3: Generally supervised areas; e.g. lounges and activity rooms where patients may spend time with minimal supervision;
- Level 4: Minimal or no supervision areas; e.g. patient rooms (semi-private and

private) and patient toilets where patients spend a great deal of time alone with minimal or no supervision; and

- Level 5: Administrative or initial assessment areas; e.g. admissions rooms examination rooms and seclusion rooms where staff interact with newly admitted patients that may present potential unknown risks and/or where patients may be in a highly agitated condition.

The levels of safety described above depend on the amount of supervision that the patients get from the staff during their stay. Recommendations are given that designers should group the functional areas (outpatients, intensive care, accident and emergency, radiography, operating theatres, etc.) together in order to ensure patients who visit hospitals are able to find the required treatment with easy access from one area to another. Hospital layout designs based on an assessment of staff and patient safety will aid the staff, offer better supervision and reduce potential medical errors. The aspects of health and safety legislation and the management's desire to minimise risk from litigations also contribute to the safety aspects of design.

2.3.2 Patient falls

Patient falls usually occur during a patients' stay in the hospital and can often result in serious injuries, which extends the patient's recovery and drives up patient costs significantly. It is a common phenomena and has become a major concern during the design of healthcare facilities. Early evidence shows that inpatient fallings range from 1.9% to 2.8% of hospital admissions (Mahoney, 1998) and the frequency of falls by patients varies considerably in different hospital areas. Patient rooms have been suggested to be the place where most of patient accidents take place according to some findings from literary sources. For example, Hendrich *et al.* (1995) discovered, through a case study at a teaching institution, that most of falls occur on the way from patient rooms to the bathrooms. Miller & Elliott (1979) further identified that 55% of the falls occurred in bedrooms and 19% in the recreation and dining areas. Pullen *et al.* (1999) also reported that 74 out of the 444 patient falls in their study happened when the patients were alone in bathrooms. In addition, furniture was involved in nearly 50% of all the falls, for instance, chairs and wheelchairs are accounted for 30%. Further investigation of the possible accident locations suggests the issue of patient falls implacable in the desired occupancy of patient areas. Multi-occupancy areas have higher concentrations of staff visits and therefore are safer with regards to patient falls, although this finding may conflicts with other design goals such as patient satisfaction, privacy needs, etc. Another way to approach the issues would be increasing the monitoring of patients by staff members (Hendrich *et al.*, 1995), however, this may not necessarily be preferred by the hospital due to the desire to drive down the costs of service delivery. Allowing family members to accompany the patient has also been suggested by (Ulrich *et al.*, 2005) in order to reduce the risk of fall.

The physical environment was cited as a root cause in nearly 50% of patient falls in the United States. Unstable furniture, elevated bed positions, slippery floors, dim lighting in rooms and corridors have been identified as contributing to patient falls (Whedon & Shedd, 2007). Besides, different types of healthcare environment also lead to variance in patient falls. Krauss *et al.* (2007) conducted a research to determine the relationship between patient falls and the hospital circumstances. According to their research, they found that the rate of patient falls are associated with different hospital circumstances; urban and suburban hospitals have higher fall rates than rural hospitals and the academic hospitals have more assisted falls and fall related injuries.

Some patient falls can be avoided through a systematic layout design with well-located patient rooms and bathrooms and, by placing decentralized nursing stations to allow nurses' easy access to patients (Ulrich *et al.*, 2005; Chang *et al.*, 2004). However, there is no clear evidence to show any single traditional design measurement that is thoroughly effective in order to prevent patient falls, but some combinational measurements have proved to be effective.

Recent literature also suggests the success in fall prevention programmes to reduce the number of patient falls (Kostopoulos, 1985; Hernandez & Miller, 1986) through a combination of interventions based on environmental factors, patient and organisational characteristics. Hendriks *et al.* (2005) evaluated a multidisciplinary intervention programme, testing whether it is more effective than usual care in preventing patient falls from both practical and economical points of view. After implementing the programme, Innes & Turman (1983) noted a 50% reduction in patient falls when compared to the previous year. This programme utilised a risk assessment tool, a specialised nursing care plan, colour coding on the nursing desk and patient call box to alert staff to the at-risk patients. A similar approach was conducted by Fife *et al.* (1984), who found a 61% decline in patient falls over a year.

2.3.3 Patient satisfaction

In addition to a high quality of health service, patients usually expect more from the hospital, such as spacious single bedrooms with a bathroom, pleasant lighting, external views, access to telephone and television controls, etc. Meeting these increasing demands have been found to have positive impacts on patient outcomes by many researchers (Ulrich *et al.*, 2005; Lawson & Phiri, 2000; Asadi-Lari *et al.*, 2004). Some features found in the literature are discussed below.

2.3.3.1 Accommodating visits from family members

Patient's interaction with family or family members' involvement during a patient's hospitalisation can affect patient outcomes (Powers & Rubenstein, 1999), because family members' visits always provide social support to the patient, which is helpful to alleviate patient's physical pain and stress. Evidence shows that patients are more satisfied with their care when given adequate space for interaction with their families. Considering family members play a very important role in patients' recovery process, it is necessary to provide adequate space for family members for their convenience in participation in the healing process, and sometimes it is suggested to supply them comfortable accommodation to let them have good rest overnight (Stern *et al.*, 2003). Although there are no studies directly providing links between hospital design and family or visitors' needs, some researchers have indicated that interaction with family members is enhanced in private rooms (Hill-Rom, 2002; Ulrich, 2003).

2.3.3.2 Occupancy environment

Barlas *et al.* (2001) argues that the noise disturbance slows down patient recovery by increasing stress levels and disturbing patients' sleep patterns. To avoid this, single inpatient rooms are preferred new healthcare facilities as they provide patients with a quieter environment compared with multi-bed wards. Patients' privacy and confidentiality are also boosted in single patient rooms. In addition, as discussed above, frequent family interactions are more acceptable in single rooms to avoid interfering with other patients. A more detailed discussion on spatial arrangement will be given in Chapter Two, section 2.5.

2.3.3.3 Positive distractions

Positive distractions have been defined (Ulrich, 1991) as "environmental-social conditions marked by a capacity to improve mood and effectively promote restoration from stress". Such effects of positive distractions have been found from various design factors, including pleasant lightings, odour, external views, music and art, etc. Some researchers have found the evidence that these positive distractions are able to enhance patient well-being:

- Keep *et al.* (2007) conducted a questionnaire survey and found that patients treated in the ICU with windows with external views remember their admission more accurately after their discharge and experienced less sleep and visual disturbances.

- Lehrner *et al.* (2000) diffused a room with orange oil within a group of patients, and those women patients reported much less anxiety before the treatment and their mood was also improved.

- Ulrich (1984, 2001); Ulrich *et al.* (2008) indicated that attractive recovery surroundings that included views of nature, art, room furnitures, etc. had substantial beneficial effects on the recovery rate of hospital patients. Patients that had access to positive visual stimulation recovered three quarters of a day faster and needed less pain medication than patients that did not have such similar visual stimulation.

- Joye (2007) in his paper reviewed a large body of literature and reported that humans are aesthetically attracted to things found in nature and some particular landscape configurations which can help reduce stress and have a positive effect on human function.

- Studies by Staricoff *et al.* (2001) indicated that the contribution of art can improve patient well-being. One of the three report shows that the concept of integrating arts into healthcare received overwhelming support from patients, staff and visitors.

2.3.3.4 Way finding systems

Healthcare facilities have inherently complicated environments. Patients often find themselves navigating through different zones/units/ to their final destinations. A poor wayfinding system can increase anxiety, confusion and dissatisfaction with regards to a person's hospital experience. Patients often feel frustrated of their inability of navigating to the right destination if they are disoriented, stressed or getting lost (For example, getting lost is ranked among the top complaints by visitors to healthcare facilities). As a result, they will very quickly redirect their frustration to the healthcare facility and generate negative impacts on their hospital experience.

On the other hand, a poorly designed way-finding system also represents a significant hidden cost to a hospital. According to Ulrich *et al.* (2005), the annual cost of a way-finding system is more than $220,000 per year in a study conducted at a 604-bed hospital. Such hidden cost is often associated with the lost time from staff members giving directions to visitors and appointment delays. Therefore, an improved way-finding system will not only help the hospital reduce the hidden cost but also address patients' varied mobility and cognitive needs due to the complexity of the hospital sites. However, a good way-finding system is not just about better sign-age or coloured lines on floors. It is an integrated system that includes coordinated elements, recognition of a comprehensive set of spatial relationships and a well-planned physical setting. Carpman *et al.* (1984) explained that a way-finding system usually consists of three main elements: design-related elements, operational elements and user behaviour.

Design-related elements: Exterior building cues, are very important components of a way-finding system. When people arrive at a hospital, they need signs and cues to direct them to their destinations. This is particularly important at the parking lot, for instance, a video simulation study was conducted by Carpman *et al.* (1985) and they found that the presence of the entrance to the deck from the drop-off circle did make a significant effect with regards to turning behaviour.

A sign-age system has been considered as the major way-finding design element by many researchers (O'Neill, 1991; Gargiulo, 1994; Carpman *et al.*, 1985). From a design perspective, interior sign-age and exterior sign-age should ideally consistent within one system to reduce confusion and enhance way-finding. Some key elements include elimination of unnecessary sign-age, location of sign-age, colour and shape, avoidance of complex array of signs, etc. Other related elements also include landmarks, way-finding-related lighting system and landscaping design.

Operational elements: Terminology is a major operational element in way-finding (Carpman *et al.*, 1984). Once patients find their way into the building, they are faced with the prospect of identifying their destinations. It is very likely that they get confused by some medical terms because some are difficult to understand such as 'Otorhinolaryngology'. Information leaflets at the reception would be helpful to patients and logical room numbering for department is also suggested by researchers (Carpman *et al.*, 1984).

In addition, some healthcare facilities may expand, relocate or move departments during a refurbishment, it is necessary to keep signs and maps up-to-date and ensure the whole way-finding system consistent with the relevant information.

User behaviour: Different people have different behaviours regarding way finding in hospitals. They use different strategies depending on the situation which usually fall into four categories (Carpman *et al.*, 1984)

- Some people are cognitively focused, they mainly rely on maps and written direction on the way.
- Some need explanation of the direction from verbal communication, e.g. from reception.
- Some use signs and visual landmarks along the way to their destinations.
- Some get their direction through interaction with other people while they are on their ways.

A book by Carpman & Grant (2001) on health care design which reviewed research and design recommendations for way-finding in the healthcare environment is recommended for readers who are interested in more about way-finding.

2.3.4 Patient privacy and dignity

Patient privacy refers to a 'quality or state of being honoured or esteemed' (Hofmann, 2002) and 'a socially recognized sense of worth' (Caygill, 1990). In a large number of literature, patient privacy has been identified to be a primary concern in healthcare facility planning and design (Bck & Wikblad, 1998; Mlinek & Pierce, 1997; Karro *et al.*, 2005; NHS Estates, 2001). Patient privacy and confidentiality is an essential guiding principle of the staff-patient relationship (Flegel & Lant, 1998). Healthcare providers are responsible for treating patients with respect and autonomy. And it is their duty to protect patients as well as their personal data from the invasion of privacy. In some particular healthcare departments (e.g. emergency department), patients perceive overheard conversations by staff or other patients which are considered to be a breach of privacy (Karro *et al.*, 2005).

Most of patient privacy related literatures focus on the research of the planning and design of patient wards, where patients spend most of their time in hospital. Different types of patient accommodation are considered to be associated with patient satisfaction of privacy, such as single-sex accommodation and single-bed accommodation.

2.3.4.1 Single-sex accommodation

Being with other patients of the same gender is an important component of privacy and dignity. This type of accommodation is usually achieved by the design of single-sex wards, single-sex bedded bays and single rooms. A combination of these different types of accommodation is suggested in the current hospital design. Improvement in patient privacy could be achieved by the provision of individual clusters of single and multi-bed areas for each sex and separated by doors, clinical spaces or a nurse base (NHS Estates, 2001). Recognising the importance of this aspect, the Department of Health (DoH) has been slowly replacing mixed wards with single-sex wards over past years. 97% of NHS trusts provide single-sex wards with segregated bathroom facilities. Although single-sex accommodation is the easiest way to separate male and female patients, in some situations, due to the limited availability of wards, it is difficult to represent all types of wards by single-sex only (NHS Estates, 2001).

2.3.4.2 Single-bed accommodation

The use of single rooms permits maximum bed occupancy levels to be achieved without compromising privacy and dignity issues. In a single-bedded room, the isolation from other patients also contributes to the reduction in nosocomial infections, compared with multi-bedded ones (van de Glind *et al.*, 2007). Other benefits of single-bed wards include the reduction of ambient noise levels, better hygiene provision, convenience of family chaperones, etc. Nevertheless, the impacts of single-bed accommodation on patients' well-being and recovery are not well explored. Few studies were found to be thoroughly evaluate the effects of single-bed rooms. It is hard to justify the argument in 100% favour of single rooms in the future trend of hospital design, since multi-bed rooms also have their own advantages, such as promoting interactions or communications with patients. van de Glind *et al.* and his colleagues (2007) have reached a similar conclusion in a recent review from the Netherlands.

2.3.4.3 Dignity on the ward

In addition to segregation based on sex, patients prefer to have the ability to make their personal space private as and when necessary. However, a lot of wards fail to provide the essential levels of privacy to patients, this is particular taking place in those wards featuring a line of beds with no physical separation between them. In such ward, physical touch, the need to undress and the patient's lack of control over their environment all contribute to patients' perception on the lack of privacy (Leino-Kilpi *et al.*, 2002).

2.3.5 Patient well-being and health outcomes

An enhanced therapeutic environment will improve patients' experience and help them to recover in better outcomes with shorter bed-stays and greater throughputs (NHS Estates, 2005). The same opinion was shared by Gross *et al.* (1998) who considered that hospital design could have a huge impact on a patient's well-being and outcomes. In his study, he proposed that the staff and patients would be affected positively if the big structural ward was designed into smaller units. This trend has already been implemented by the NHS when they design new wards (NHS Estates, 2005). A three-year research programme was conducted in an acute hospital in order to establish the minimum space requirements around the bed and examine the benefits of single rooms. The benefit of single rooms has been discussed in the last section that they are beneficial to patient privacy and confidentiality. There are other advantages over multi-bed rooms and open bays that contribute to patients' overall well-being, such as better control of infection, reduction of the risk of adverse clinical errors, better communication between staff and patients, and more flexibility with the potential for increased capacity (NHS Estates, 2005; Ulrich *et al.*, 2005).

Some researchers have found the impacts of the hospital environment on several patient/health factors by means of environmental psychology studies. Back to 1972, Wilson found that patient delirium after surgery was twice as high as in a windowless intensive care unit. Goffman (1961) described in more details of the detrimental effect on psychiatric patients from a warehousing type of healthcare design. And he extrapolated that the hospital environment had a crucial influence on the mental health and well-being of all patients. Like every coin has its two sides, patients can be affected negatively by some hospital environments, their well-being and outcomes can also be enhanced by good environment designs. Hospital stay has been proved that it could be shortened for those in sunny hospital rooms (Beauchemin & Hays, 1996). A well-designed experiment was undertaken by Ulrich (1984) in order to compare the effects of the view from their hospital window on the patients who had just undergone surgery, and the findings appear to suggest that patients who had a view of a number of deciduous trees in foliage from the window experienced more positive outcomes than those whose view was that of a plain brick wall. The difference of geographical locations make patients feel from isolated to less “shut in”, which contributes to an effect on the patient’s psychology. Other design factors are also considered to have positive associations with patient well-being, for instance, displaying some art work in the healthcare buildings is able to reduce patient’s feelings of stress and worry and effectively improve their mood. Patients are also benefited psychologically from going out into the fresh air on the ward balcony that is proved in Campbell’s research (1999). Winkel & Holahan (1985), psychologists, also suggested that the patients’ well-being and outcome of treatment involves more than clinical interventions and emphasized that“care delivery is embedded within the hospital’s broader physical and social environment whose organization and characteristics may be expected to affect the course of treatment”.

2.4 Impacts of hospital design on care providers

There is also a significant impact of hospital design on staff, adding to their stress and error levels and influencing their career choices as well as their working performance. Research co-commissioned by the Commission for Architecture and the Built Environment (CABE) and PricewaterhouseCoopers LLP (2004) in the UK has investigated the role of hospital design in the recruitment, retention and performance of NHS nurses in England. The research consists of focus groups with nurses throughout England and a questionnaire survey (479) from nursing directors. The results of this study suggest that healthcare design matters to nurses and brings influence on their working performance and the choice of the working place. Internal hospital environment is found to be the most important factor related to nurses’ performance, other contributing factors include the space and building layout and interior design features. 78% of nursing directors support that the hospital design impacts on the recruitment of nursing staff, 39% of survey participants consider the external space ‘very important’ and another 37% rate the internal space ‘very important’ in the recruiting process. Although it is believed that hospital design is a less important factor with regards to nurse retention, compared with management attitudes and relationships with colleagues. Nurses express that they are more likely to stay where they feel safe and secure, which could be ensured by a good hospital design. A similar study in the US also found that noise, chaotic and unwieldy environments and a lack of patient contact all contribute to low retention levels of nurses (McCarthy, 2004). In addition, reduction of medical errors, staff morale and productivity and the configuration of their working environment are also beneficial from hospital design.

2.4.1 Reducing errors

When considering studies on medical errors, a definition of medical error is given by The National Patient Safety Agency (NPSA) as: *". . . any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of health professional, patient or consumer"*. Research has shown that people are likely to make mistakes when they are busy, tired or at worse body conditions. And those mistakes always take place at locations such as ill-designed nursing stations, disorganised and/or filled storage rooms. For instance, in Cortvriend (2005)'s research, he found that the nursing staff is likely to pick up the wrong bottle or to put a bottle back in the wrong place because of non-distinguishable storage design for medicines. Other than mistakes of manipulations in storage room, in some departments, medical errors may occur during patient surgery, leading to very serious accidents. Typical healthcare errors and adverse events include surgical injuries, adverse drug events, transfusion errors, hospital-acquired infections, falls, burns, and pressure ulcers (von Laue *et al.*, 2003). And these medical errors have been observed as the eighth towards leading causes of death in the United States (McFadden *et al.*, 2004).

2.4.2 Staff morale and productivity

A number of organisational shifts have been taken place on hospital nursings, from functional nursing in the 1940s to team nursing in the 1960s, and then to the primary nursing in the 1980s (Eastaugh, 2007). Changes of such staffing patterns have increased costs of hospitals as task delegation and the allocation of nurses have became major medical economics issues(Eastaugh, 2007). However, staff morale and productivity can not be sacrificed to improve service quality. Although it is quite difficult to evaluate the efforts of organisational changes in healthcare (Axelsson, 2000) due to its subjective characteristics, considerable organisational supports improve staff working satisfaction and mental energy (von Laue *et al.*, 2003), and decrease the feeling of depression in their working environment. Their research also found evidence that good organisational supports will decrease staff turnover rate as already discussed.

Nurses' work has strong association with patient well-being, especially for the outcomes of inpatients. Higher productivity often means nurses are able to save more time and more concentrate on patients. A representative research that aims to determine their attitudes towards hospital design was commissioned by CABE (a telephone survey of 500 nurses) and they have found the following results:

- 22% of nurses surveyed stated that hospital buildings, setting and interiors were very significant in their job selection desiccation.
- 48% of nurses surveyed agreed strongly that working in a well-designed hospital would help them do their job better.
- significantly, 41% of nurses surveyed disagreed strongly that the design of a hospital makes no difference to staff morale.
- 56% of nurses surveyed strongly agreed that working in a poorly design hospital contributes to increased stress levels.

The majority of nurses believe a well-designed hospital would enhance their productivity for a good job, while poorly designed environment will affect their morale negatively. Quality of their working environment therefore becomes essential to guarantee a better morale and higher working productivity.

2.4.3 Nursing stations

The nursing station (also called nursing unit) is the organisational hub of the patient's ward where nursing calls are registered, paperwork is prepared and where staff go to report at the change of shifts (Figure 2.3). It has been considered as the primary determinant of the architectural form and character of hospital buildings (Kazanasmaz, 2006b).

As a nursing station is part of the ward layout, it cannot be designed in isolation and it need to be evaluated in the context of ward layout design process. Over the years, different nursing units and ward designs have evolved, each having distinct features (Chaudhury *et al.*, 2005). Some think that the 'Nightingale' type ward should be replaced with more single rooms which can reduce patient transfers and increase patient privacy (Haggard & Hosking, 1999). Others found that the majority of gynaecological patients preferred the bay ward to the Nightingale ward (Pattison & Robertson, 1996). However, the evidence does not clearly support the use of one particular type of ward over another. Each type of ward has its advantages and disadvantages, which are considered as trade-offs in the design stage. For example, a good observation of patient ward from nurses is very likely to let patients feel they have lost their privacy (Miller & Swensson, 1995). Therefore, evidence based design is welcome adopted by designers to consider more design factors when designing a ward, such as, bed needs, budget, privacy needs and intensive care levels (Catananti *et al.*, 1997).

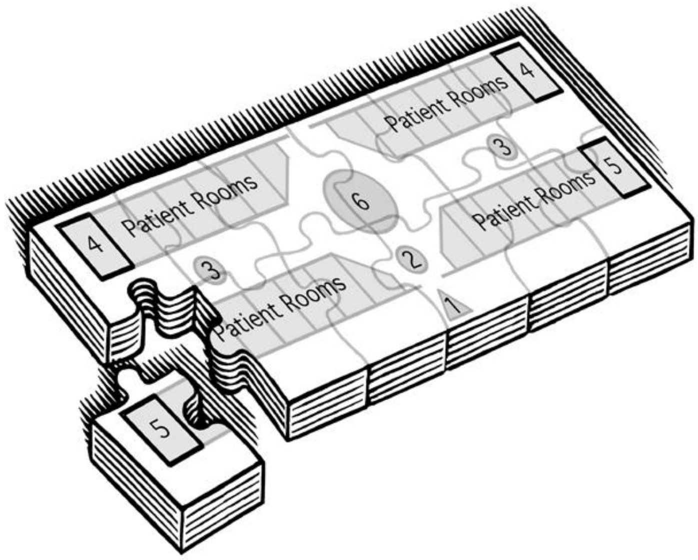

Figure 2.3: Typical centralized and distributed nursing station and patient rooms.

(*Note* 1: Entry 2: Reception 3: Distributed nursing stations 4: Staff informal meeting room 5: Family room 6: Centralized nursing station and staff meeting place)

A good design of the nursing unit will help to improve patient care and staff satisfaction (McCarthy, 2004). The impacts of a well designed station usually consist of patient observation, efficiency of material delivery and nurses' travelling time. Some experts have indicated that the decentralised nursing station can improve patient safety by reducing the proximity of the nurses to the patients, which can both improve nurses' observation and shorten their response time. They also reduce distraction, because they allow nurses to start immediately and to complete their charting. Evidence shows that each nurse has to walk an average of five miles for each shift. Decentralised workstations are welcome by most of the nurses because they no longer need to walk long distances for phone or computer access, and they can communicate directly with one another.

Visibility of the nurses' station to the patients has been found to be important in maintaining a good level of service. Table 2.3 depicts popular types of nursing stations and their impact on the layout and architectural form. Since different types of nursing units may fit different types of wards, it is difficult to illustrate which type of the nursing unit is the optimum one without consideration of the ward type.

Table 2.3: Various types of nursing units.

Types of nursing unit	Advantages	Disadvantages
Radial design unit	Centralise patient care and provide immediate access to the patient, reduction in travelling time	Lateral expansion is difficult; awkward leftover spaces in the centre, irregular shapes of patient rooms (Stichler, 2001; Cawood, 1993; Verderber & Fine, 2000).
Square nursing unit	Better observation to the patients; less walking time, turnover is low	Not suitable to multi-occupancy room (Fisher, 1982).
Cluster design unit	Reduce patient travel, increased visualization of patients	Decentralization and more social needs of nurses (Tradewell, 1993; Jones, 1995; Stichler, 2001).
Triangular design unit	Reduce travel distance; multiple nursing units are possible and storage space is centralized	Limited visibility of patients, difficulty of unit expansion (Stichler, 2001).
Rectilinear design unit	Less costly, centralized storage	Increasing travel distance, minimal visualization of patients, more space requirement

2.5 Impacts on spatial configuration

2.5.1 Infection control

Good hospital design should ensure the inpatients, especially those vulnerable and weak, are away from sources of infection within the hospital. Some nursing staff working in the emergency department are also exposed to a burden of infectiousness (Escombe *et al.*, 2010). To protect the people in the hospital from healthcare-associated infection (HCAI), spatial patient rooms in the healthcare facility are designed with extra caution with good installation of ventilation system. Several studies indicate the effectiveness of frequent hand washing after healthcare activity to prevent associated risks of infection. Spatial configuration with single-patient accommodation have also been found to be effective in infection control and elimination of the spreading risk (Chaudhury *et al.*, 2006; Dowdeswell *et al.*, 2004; Ulrich *et al.*, 2005). However, it needs to be mentioned that the degree of effectiveness of single-patient accommodation in reducing levels of hospital infection is not based on any large scale longitudinal study. Contrasting findings also exist; Vietri *et al.* (2004) investigated the effects of MRSA infection rates in moving from a hospital with open bay wards to a new facility with single or double rooms. No significant change of MRSA infection rate was found in these two types of rooms. This is an example but it covers only one hospital that includes a relatively small group of patients. Other evidence concerning the efficacy of patient treatments in single rooms mainly focus on quite specific categories of patients such as SARS infected patients (McManus *et al.*, 1994; Thompson *et al.*, 2002; Farquharson & Baguley, 2003). Lawson & Phiri (2000) argue that it is easier to detect and manage infection outbreaks at single-patient rooms because:

- Single-patient rooms act as isolated units in the hospitals;
- It is relatively easy to carry out deep cleaning in single-patient rooms;
- Monitoring of single patients with infection is more manageable.

2.5.2 Space considerations

Bed space is the provision of sufficient space in clinical areas, in particular around each bed. It is one of the most important aspects of the design of acute inpatient accommodation in order to allow for key activities as well as to reduce infection risks. The relationship between the bed spacing and infection carriage has been examined by many researchers (Kibbler *et al.*, 1998; Williams, 1966; Saxon, 2004). They argue that if adequate space around a single bed is not provided, the equipment may become contaminated and may lead to cross-infection if they are relocated elsewhere. Lawson & Phiri (2000) recommended that the minimum area of single-patient rooms should be $20m^2$, with dimensions of 5m by 4m, excluding en-suite facilities; similar to what has been suggested in the Health Building Notes (NHS Estates, 1997).

2.6 Impacts on energy and environment

Energy consumption cannot be overlooked from the early design stages because health care sector is one of the largest energy consuming sectors in public, with an annual energy bill of £400m and carbon dioxide emissions of 3.3MtCO_2/yr. The sector has mandatory energy targets for new and existing buildings, which seek to deliver a 15% reduction in energy consumption from 2001-2010 and 60% of NHS carbon emissions by 2050 (NHS Estates, 2008). The NHS Carbon Reduction Strategy for England has set an ambition for the NHS to reduce the required carbon in order to slow progress towards climate change. It will be proved as a balancing act to ensure that the NHS research effort is not hampered by energy conservation efforts, and simultaneously guarantee that the majority of the public would benefit from the carbon reduction action.

Changes in the layout will not only produce a different interior space but also lead to other changes in the building, such as HVAC system, thermal comfort, etc. A well thought-out layout design may prevent unreasonable energy consumption and enhance the overall sustainability of the building, contributing to climate change mitigation. In recent years, attempts have been made by the NHS to decrease the amount of energy consumed within their premises and, and consequently, to decrease greenhouse gas (GHG) emissions.

Old hospital design seems to have become costly and inefficient, by wasting energy, depleting natural resources and endangering the environment. The solution to these problems has been suggested to be focused on designing more efficient "green buildings", especially for use in healthcare facilities. Green buildings are designed specifically to reduce the impact of their construction and operation on the natural environment and for the comfort and health of its occupants. Healthcare faculty design is beneficial from this concept as thermal comfort is important to all the patients and staffs in the hospital, since a standard indoor temperature is influential to patients' mood and well-being. Allow appropriate amount of day lighting in the patient rooms is another important criteria in designing a good hospital layout, which may influence to other design process in the healthcare facilities, for example, the installation of different external and internal blind, interrelated mechanical system delivery and different internal load configuration alternatives. By optimising the shading of peak external load, solar loads can be reduced by decreasing the supply of mechanical system and operation savings achieved simultaneously, providing a thermally comfort indoor environment. Other methods such as free cooling is also promoted to enhance energy savings, by utilising outdoor temperature to manage indoor temperatures.

2.7 Summary

The influence of a hospital's design on patient well-being has been widely debated throughout the past 150 years (Gidney, 2008). Along with an increasing number of patient-centred healthcare facilities have been built in recent years, a guarantee of patients' well-being is not the only standard to evaluate a successful modern hospital. some authors have stated that a modernised, well-planned healthcare environment can have a positive effect on patient's well-being, behaviour and attitude, a decrease in patient falls and an improvement in morale for patients and staff. Some also suggest that even minor changes such as the rearrangement of furniture or redecoration could have an impact on the patient. Whilst these findings have their limitations (e.g. the patients in for a short stay and in specific wards), they nevertheless indicate that hospital design should take into account physical and social environmental issues such as those discussed earlier, however insignificantly they may appear to be at present. A key element of care should take the form of primary emphasis on patient safety through the designing of a hospital environment which is patient-centred. A set of guidelines supported by the previous literature are summarised for an effective hospital design aiding to increase therapeutic value and performance:

- Patients are not overcrowded or over concentrated;
- Patients are given the opportunity to retreat if they need to but also the opportunity to form beneficial social interactions;

- A variety of spaces should be provided such as a big day room, a dining room that is well lit and ventilated and a spacious lobby and corridors;
- Provision of furniture that is residential in nature rather than institutional;
- An open nursing station that generally is found to result in more staff leaving the station and spending more time in patient contact and being able to observe patients easily;
- Attention needs to be given to lighting, both natural and artificial.

Besides the provision of a location for medical service, the healthcare environment also plays a very important role in both patients' recovery process and affects care providers' working patterns. In particular, some issues that are of importance in the design from the nurses' perspective are summarised as follows:

- provision of some facilities such as banks, shops and cafs;
- public spaces that encourage interaction so that nurses feel part of the bigger picture rather than a discrete unit;
- visible security;
- designing for flexibility so that as changes in patient care are made, one space can easily be converted into another;
- sufficient workspace and wide enough doors etc.

The factors of hospital design affecting the staff's performance include but are not limited to:

- Flexible working spaces, layout and distance to be travelled between tasks;
- Having dedicated spaces for staff rest and relaxation, including attractive areas outside as well as adequate staff facilities such as lockers, showers and so on;
- Provision of space for confidential discussions with patients and other staff;
- Sufficient and functional storage space;

- Quality of fixtures and fittings such as door frames, locks and sink fittings that do not facilitate good infection control.

This chapter provides a basis for further research into consideration of factors that influence the healthcare design. There are a number of aspects identified through the report, reflected in wider literature. A good understanding of these factors will assist the healthcare builders in order to design an optimum layout from the initial status of a hospital's life.

Chapter 3

Literature review of spatial layout optimisation

This chapter introduces the work that are carried out to solve spatial layout problems and optimisations. Historical overview of different layout problem formulation methods is given including Genetic Algorithms (GA), Simulated Annealing, Neural Network, etc. The purpose of presenting various methods to solve the spatial layout problem is to understand their capacities, advantages and limitations. Implementation issues related to using GA tool box are discussed. At the end of this chapter, a brief overview of some commercial packages for spatial layout planning is given.

3.1 Introduction

Space within the architectural layout is recognised as a resource as important as other resources such as time, material, facility, etc. A well designed layout can contribute to enhancing the whole performance by minimising the travelling distance, decreasing the time and efforts spent on the material handling, increasing productivity and improving safety. However, the concept of a proper space layout planning (SLP) is often ignored in the design phase of the construction (Sadeghpour *et al.*, 2006). Although SLP cannot be defined as an independent problem in the whole design process (Nassar, 2010), it is necessary to consider SLP within the broad context of the architectural design from the conceptual to the detailed stage and make necessary collaboration between designers. Michalek *et al.* (2002) defined SLP as a multidisciplinary task, finding arrangements for a set of rooms fitting to the inter-relational and geometrical requirements while maximising design quality in terms of design preferences. However, in practice, SLP problems are often ill-defined or over constrained (Jo & Gero, 1998; Yoon, 1992) since there are many design elements selected while considering a wide range of quantifiable as well as non-quantifiable criteria simultaneously (Choudhary & Michalek, 2005). The objects are independent themselves while the relationships and requirements are not specified and clarified enough, which make it more difficult to describe formally. Before the advent of computer design phase, the architects tend to describe the space relationships by using the adjacency matrix (Figure 3.1) or a space bubble diagram (Figure 3.2) for the client or themselves to understand (White, 1986), and the consultants are likely to mark their opinions of the design on the plan drawings, as the development and evaluation of the alternative solutions basically depend on the judgement, intuition and experience of the layout analyst (Chintala, 1994). It utilised an trial and error design concept to come up with a satisfactory diagram, and eventually the bubbles are converted into room size rectangular to complete a formal representation to the client. However, when the size and number of different spaces to be allocated increase and the typical case being having number of ill specified spatial requirements, the problem becomes too large and complicated for a human designer to handle (Liggett & Mitchell, 1981).

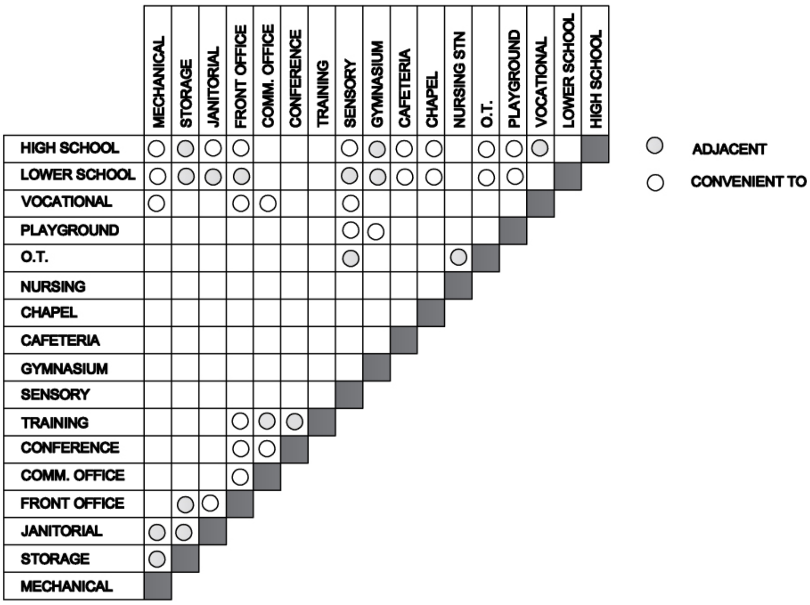

Figure 3.1: Traditional adjacency matrix (Liggett & Mitchell, 1981).

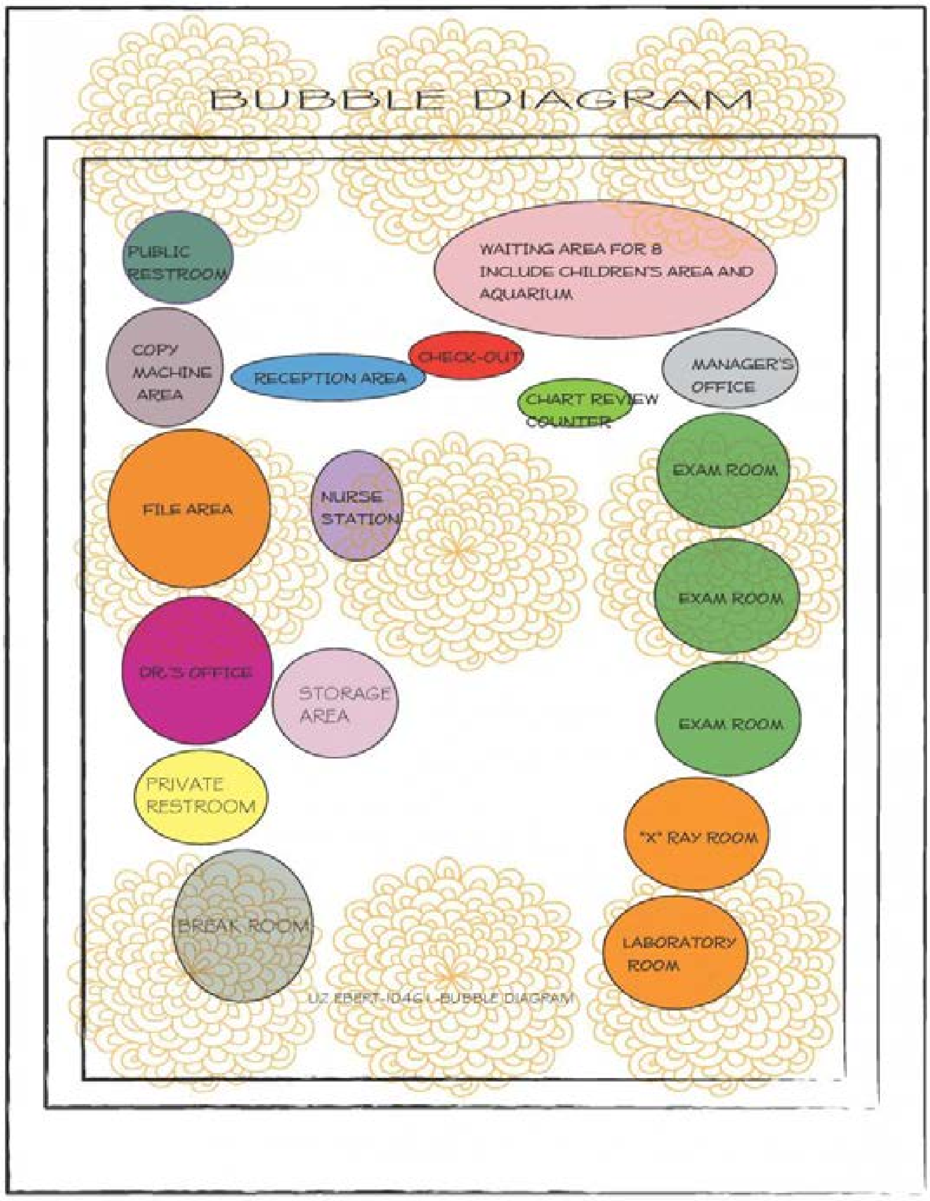

Figure 3.2: Space bubble diagram (Liggett & Mitchell, 1981).

3.2 Automated of space layout planning

Traditionally the architectural layout deign is strongly relied on the expertise of designers/architects, depending on the individual's experience and cultural influences. However, this could not compromise to find out the optimum solution since the solution space is complex involving a large number of variables (Mourshed, 2006). Doulgerakis (2007) also argued that the space layout problem is very complex and even a small number of spaces give rise to a vast search space as the possible solutions increase exponentially. The increasing complexity of the problem with a number of factors involved, the computing time is hard to get handled by human beings. With the aid of computer, researchers tried to use the automated method to get over such design barriers to find good solution from various possible solutions in a reasonable time scale and are able to make continuous modification of the design constraints to refine the problem definition, since computation made possible the development of search algorithms and optimization strategies.

Over the past four decades several computer models have been developed to help solve the space layout planning (SLP) problems, although the objectives and the scope of the problems largely varied, Liggett (2000) concluded two main researches focusing on floor plan layout problem to arrange physical space on a plan and the spatial allocation problems. A detailed review of recent SLP approaches will be given in the next sections.

3.2.1 Space layout problems

There are different types of layout problems that have been studied in the previous literatures: variations in the shape and size of components and the constraints between them. But generally, the space layout problems can be broken down into two sub-problems: topological/qualitative problems and geometric/quantitative problems (Jo & Gero, 1998; Flemming, 1988; Arvin & House, 2002). The layout topology covers the interrelations between the individual spaces (spatial units) such as non-overlapping, adjacency and accessibility. The geometry determines the physical dimensions of building elements, such as the shape, size and location of spatial units. Some layouts have same geometry but different topologies (Figure 3.3), which increases complexity of the planning problems. Therefore, the problem of space layout planning is to arrange the spatial units according to a required topology and geometry (Jo & Gero, 1998).

Since there are a number of different ways to arrange spatial units (SUs) within a defined space, it is difficult to find out the optimal solution from them. A small number of space elements will easily generate a large solution space that result in unaffordable time consuming and calculation demand. The space elements therefore partially define the size of the SLP problem, other variables like the constraints will also affect the size of the SLP problem. SLP problems belong to the category of "very hard to solve" or non-polynomial time complete (NP-complete) problems (Jagielski & Gero, 1997). Jo & Gero (1998) said this Non-Polynomial (NP)-completeness of space layout planning problem makes it difficult to guarantee finding the optimum solution within a reasonable time. Usually some strategies are adopted to avoid this unacceptable result by reducing the number of variables, setting constraints to the formulation of problem and etc. In addition, combinatorial behaviour of the problem limits the number of spatial units that can be handled by a particular search method. Therefore, the quality of solutions found depend on three strongly interrelated aspects: method of representation, problem formulation and solution strategy (Jo & Gero, 1998).

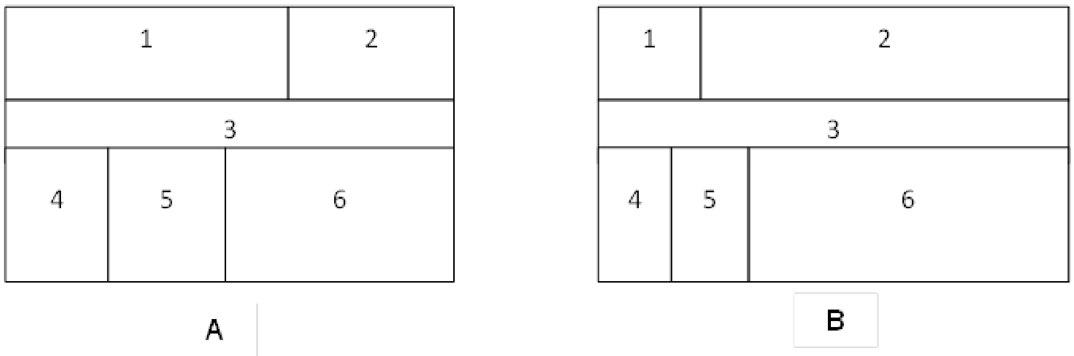

Figure 3.3: Two different geometrical solutions with a same topology.

3.2.2 Space representation

There are mainly two mechanisms to represent the space in the SLP from previous literature: rectangular spaces and space modules. According to Steadman (1983) (quoted in (Damski & Gero, 1997)), it is the most common representation to place the rectangular SUs on a plan in dimensionless form. Many researchers used this type of space representation to interpret topological relations and symmetries among the SUs as well as dimensional concerns of constraints on area, width and length of each space (McManus *et al.*, 1994; Michalek *et al.*, 2002; Flemming, 1978). Most existing algorithms handle rectangular components. Rectangular components may have: fixed area with discrete allowed aspect ratio and variable area with (upper and lower bounded) continuously variable aspect ratio. Nevertheless, using rectangular elements in SLP may constrain the shape of the spaces, irregular shapes can be generated by combination of a set of rectangular elements (Grason, 1971).

Modular space allocation is another common method used for space representations (Jo & Gero, 1998; Gero & Kazakov, 1998; Liggett & Mitchell, 1981). This method divides the spatial areas/located activities with a set of square grids (modules) in equal size. These modules can be located to where the spatial area/activities need to be represented. Compared with the rectangular representation, this small module representation can well handle the formulation of irregular shaped areas. However it increases the complexity of the SLP problem with more elements.

3.2.3 Problem formulation methods

Method of problem formulation determines the specific advantages and limitations of searching the solution space (Michalek *et al.*, 2002). Popular methods are relationship graphs, quadratic assignment problem (QAP), sequential quadratic programming (SQP), simulated annealing, physically based modelling and methods of artificial intelligence (AI) such as evolutionary methods and neural networks. It can be observed by reviewing recent literature that, methods of AI such as, genetic algorithms (GA), genetic programming (GP) and artificial neural networks (ANN) are becoming popular optimisation methods (Caldas, 2008; Jo & Gero, 1998; Damski & Gero, 1997; Jagielski & Gero, 1997; Yeh, 2006).

3.2.3.1 Exact procedure

Exact procedure, also called optimal procedures, can guarantee the optimality of a solution for a given problem (Belin, 2007). The basic procedure in layout planning is the attempt to come with a number of possible arrangements of space plans for a range of selected rooms. The designer can therefore choose the most appropriate layout plan from the generated alternatives for a given project. However, the approach is generally unsolvable to guaranteed optimality (Bozer *et al.*, 1994), this is due to the mathematical complexity of the problem, an increasing number of design parameters will rise up the number of possible solutions dramatically (Table 3.1). It becomes time consuming for a computer to solve the large number of possible solutions if the n $\geq$ 16, even if a powerful

Table 3.1: Numbers of space elements 'n' and their possible solutions (Liggett, 1980).

n	Number of solutions	n	Number of solutions
Feasible to solve by hand		Feasible to solve by computer exhaustively	
1	1	7	5040
2	2	8	40320
3	6	9	362880
4	24	10	3628800
5	120	11	39916800
6	720	12	479001600

computer can handle a large instance of the problem, no layout designers has time and energy to review all those solutions.

Quadratic Assignment Problem (QAP) Approach

The Quadratic assignment problem (QAP) is widely used in automated facility layout planning (Kusiak & Heragu, 1987), which was introduced by Koopmans & Beckmann in 1957 as a mathematical model for location problems of equal areas. "The QAP is concerned to find out optimum location for a set of interrelated objects" (Liggett, 2000). The arrangement is predefined by a one-to-one correspondence (Figure 3.4) and every object is assigned to one location and at most one object to each location (Meller & Gau, 1996). The QAP has been widely used to model the facility layout problem; however this doesn't mean all the FLP problems can be formulated by QAP. Once the distance between the locations cannot be determined or the distance depends upon other arrangements, the QAP will fail to formulate the problem. Koopmans and Beckmann further described that due to the inherent combinatorial nature of the SLP problem, QAP does not provide sufficient flexibility and computation difficulties when the QAP with moderate sizes of problems is insurmountable. Earliest attempt of employing QAP for solving SLP is made by Armour & Buffa (1963) for a manufacturing facility (Kusiak & Heragu, 1987).

According to Liao, Kusiak and Heragu, and others, the unequal-area facility layout problem could be modelled as a modified QAP by breaking the departments into small grids with equal area, assigning a large artificial flow between those grids of the same department to ensure that they are not split, and solving the resulting QAP. However, due to the increase in "departments", it is not possible to solve even small problems with a few unequal-area departments.

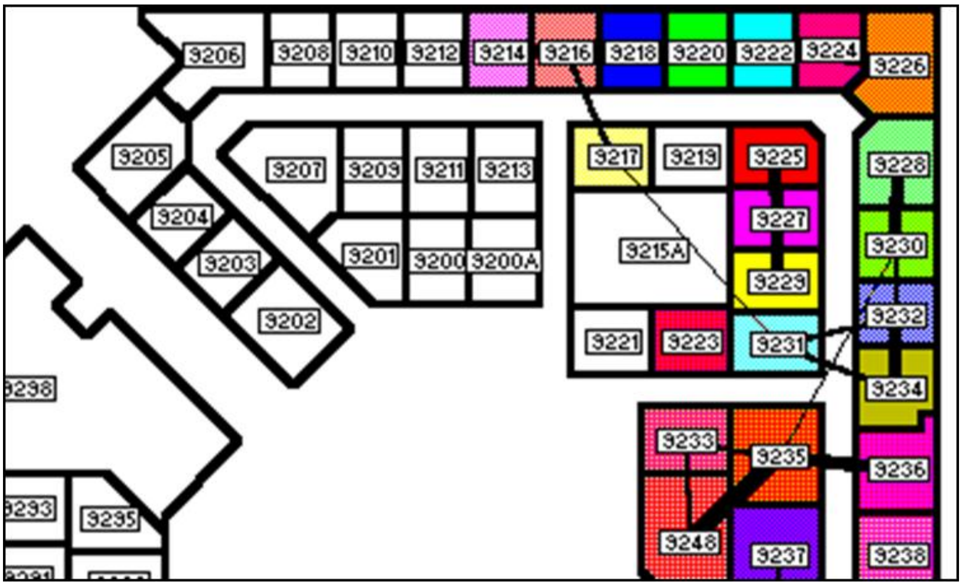

Figure 3.4: One-to-one assignment (Liggett, 2000).

Graph-Theoretic Approaches

The application of graph theory was first suggested by Levin (1964) for architectural layouts. It has been applied to SLP for a number of years (Ruch, 1978) because of the advantages it provides: it doesn't consider infeasible solutions. Since all layout diagrams that are generated using graph theory by definition must be planar, they therefore are feasible solutions. In the past two decades, Graph theory has been demonstrated as an effective tool for solving space problems/floor planning (Grason, 1971; Medjdoub & Yannou, 2000). The Graph theory involves the representation of vertices as layout SUs in the graph and the adjacency relationships are represented as a set of edges between any SUs. These edges are weighted according to the measurement of the relationships that are of interest within the SLP. Advances in graph theory have been made in three main areas: adjacency matrix, dual graphs and rectangular dissections.

Adjacency Matrix: Although it is fairly easy to formulate a graph with nodes and edges, such representation is not suitable for computer storing and processing (Wu *et al.*, 2004). One way of storing a graph is to represent a list of all the adjacent nodes of the graph by a matrix, which is often called Adjacency Matrix. Miller (1970) uses a matrix to represent the adjacencies between SUs implemented in a software called MATRAN III. The principle is quite simple, a N×N matrix ADJ is formulated by given N nodes, the value in ADJ[x,y] indicates whether y is an immediate successor of x or not. The value can be either 0 or 1, or true or false for unweighed graph. For weighted graphs, value ADJ[x,y] is a numeric value and a depth-first search algorithm can be used to find all the possible edges for two given nodes (Tarjan, 1972). Given a set of nodes, this relationship represented graph can be interpreted into a number of different geometric feasible layout solutions, which may hinder designer find out better optimum solutions, therefore this approach act poorly in reaching optimality.

Dual graphs: Grason (1971) uses graph theory to computer space planning based on an experimental computer program–GRAMPA (GRAph Manipulating Package). The methods of solution depend on a special linear graph representation for floor plans called the dual graph representation. The general idea of this approach is to set down four nodes and four edges of the dual graph which represent the four external walls of the building. Therefore the created space is considered to be adjacent to four exterior spaces on N, S, E and W directions. Then nodes and edges could be added to the dual graph according to adjacency requirements and other considerations from users until a completed graph is created. It is very easy to generate the various possible geometric representations of dual graphs (Figure 3.5) and compared with other methods, this approach is very fast and its computation time increases only linearly with the size of the graph. However, it has more emphasises on the weighted relationship of spaces and is unable to consider more than adjacency objectives such as circulation or accessibility. This hampers the utility of the program to other specific types of buildings (e.g. schools, warehouses) (Homayouni, 2007).

Rectangular dissections: Flemming (1978) used a heuristic approach to create rectangular dissections to generate space topologies. In his method spaces are represented using their boundary walls. His heuristic starts with an empty space consisting only of external spaces and one by one fills in the internal spaces by drawing the walls as specified by the client. This method is capable of generating space layouts if all the relations are specified along with the sequence the walls need to be placed which hardly occur in real layout specifications. Accessibility and circulation spaces are not considered.

3.2.3.2 Gradient based method

Gradient based method is considered as a hill-climbing method which relies on the information about the gradient of the function to determine whether the search has reached the peak point in the search space. By calculating the gradient of the objective function and searching in negative direction, the method could be distributed into a specific direc-

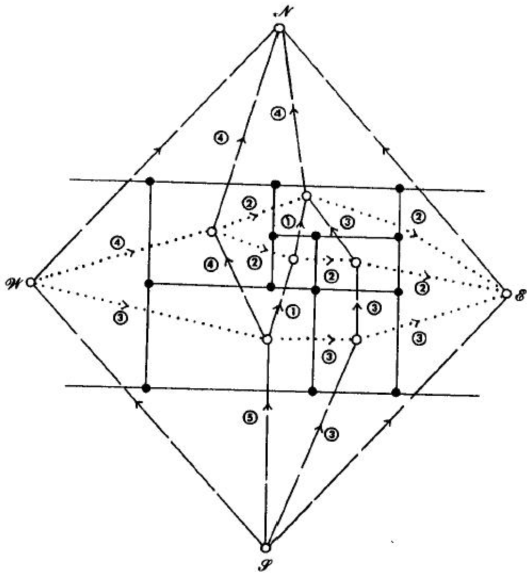

Figure 3.5: Floor plan graph with dual graph (Grason, 1971).

tion. Because of its discontinuous, the method is not suitable for multi-peaks function, it will stop searching at the first peak that will be climbed, however, this may not be the highest peak.

Gradient-based algorithms can significantly reduce the computation time which is required to reach an optimal solution by limiting the search directions. However, this optimal solution is barely the nearest local optimum (single peak) developed from one gradient solution. Since the objective function could be 'multi-peaks', the method needs to restart a new direction at a new gradient of search space and the process to be repeated a number of times, otherwise the highest peak (global optimal) cannot be reached if the search space is limited to local areas. Once the analytical gradient information is not available, usually some finite-difference approximations will be used (Cagan *et al.*, 2002), which may not be accurate and hence may have misleading effects on the search.

3.2.3.3 Genetic algorithms (GA)

Genetic algorithms (GA) were first introduced by Holland at the university of Michigan in 1975. As a simple and powerful stochastic search technique, GA has been popularised in many disciplines such as constrained or unconstrained optimisation (Michalewicz, 1996), scheduling, SLP/FLP (Gero & Kazakov, 1998; Li & Love, 2000; Jang *et al.*, 2007; Jo & Gero, 1998), transportation (Ho & Ji, 2005; Gen *et al.*, 2006), reliability optimisation

(Mukuda & Tsujimura, 2006; Mutawa *et al.*, 2009; Coit *et al.*, 1996) and artificial intelligence (Moore, 1995). Genetic algorithms are based upon the principles of natural selection and the survival-of-the-fittest, trying imitate the development of natural evolution of biological species (Goldberg, 1989; Jahagirdar *et al.*, 2010). Jo & Gero (1998) clarifies the primary concept of GA, which is involved in the natural evolution process, is that the combination of characteristics of different individuals can produce offspring whose fitness is greater than that of either parent. The characteristics evolve during the generations and produce new and better populations consisting of a subset of individuals, i.e. solutions. Each solution is associated with the fitness value, which is the objective function value of the solution. According to Goldberg in his book 'Genetic Algorithms in Search, Optimisation and Machine Learning' there are four main factors affecting the efficiency of GA: The representation of the solution; selection of the individuals; genetic operators and evaluation function (Figure 3.6).

Genetic representation: Genetic representation uses the terminology based on natural genetics terms. A potential solution is called an individual or a chromosome. Each chromosome is made up of a string of units called genes (genotype) that represent the design variables. A set of chromosomes are called a population. Performance of behaviour of chromosomes is called phenotype which is the decoded genotype at the physical/structure level (Jo & Gero, 1998).

Selection: Selection is performed among the individuals of current population to choose the better solutions to participate in reproduction. Individuals are selected according to their quality (as measured by a fitness function), the better they perform (fittest) the higher probability to survive and reproduce themselves. Selected individuals will recombine their genetic materials and propagate into the next generation. The recombination and propagation process are executed with the genetic operators.

Genetic operators: A number of genetic operators are used to evolve an initial population, these generators are reproduction, cross-over and mutation. Cross over allows selected individuals (parents) to swap their information with each other to produce new individuals (offspring) with better performance/features. There are two main crossover operators: asexual and sexual. The difference of two operators is the mechanism of creating offspring, during asexual crossover, offspring is created from a single parent. While during sexual crossover, two or more parents produce their offspring. Mutation is an alteration of the value at a random position in the genotype string. Slight changes in genes are made during mutation to have new offspring. Figure 3.7 illustrates a sample

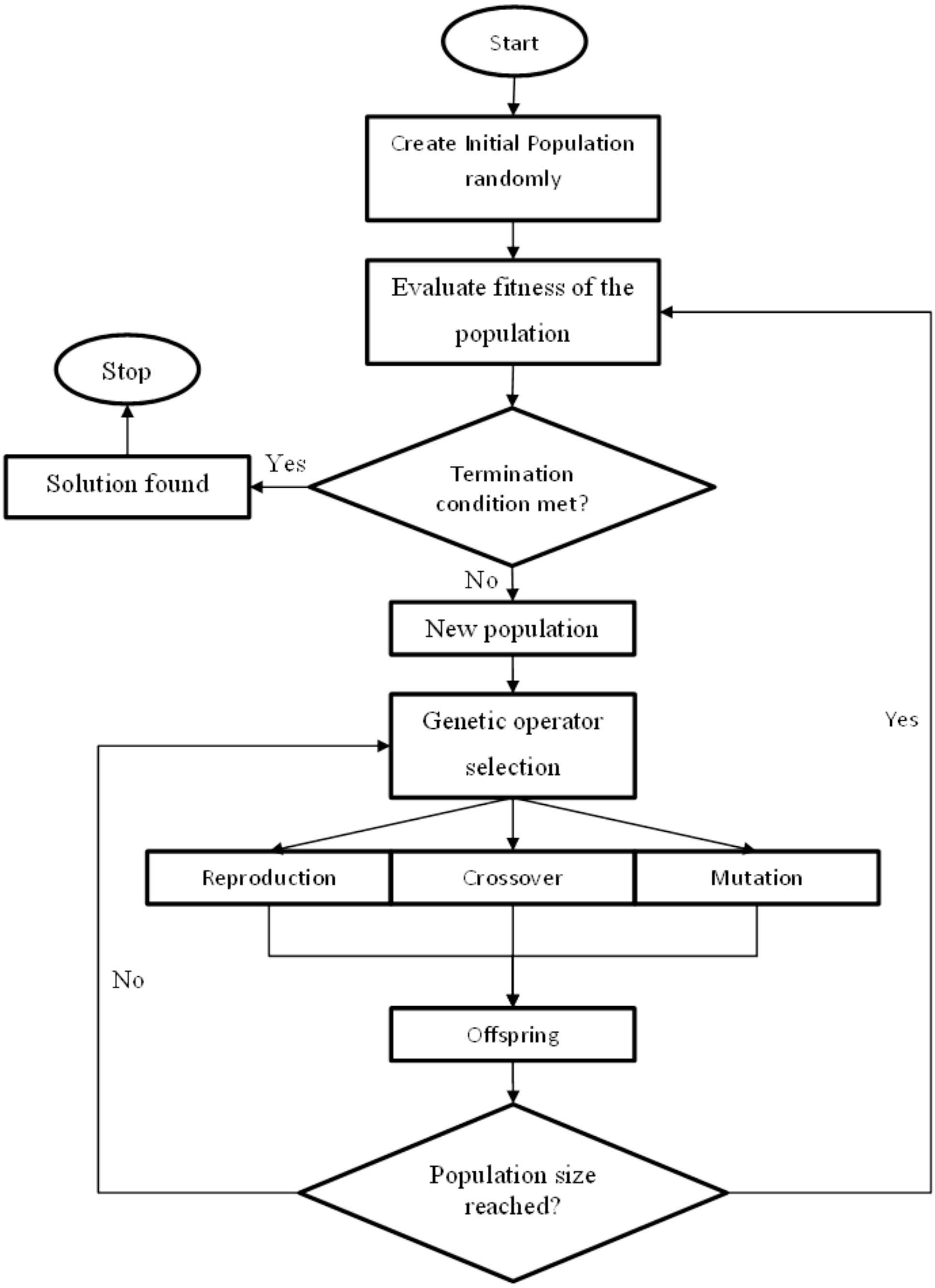

Figure 3.6: Flow chart of Genetic Algorithms adopted from Goldberg (1989).

process of crossover and mutation.

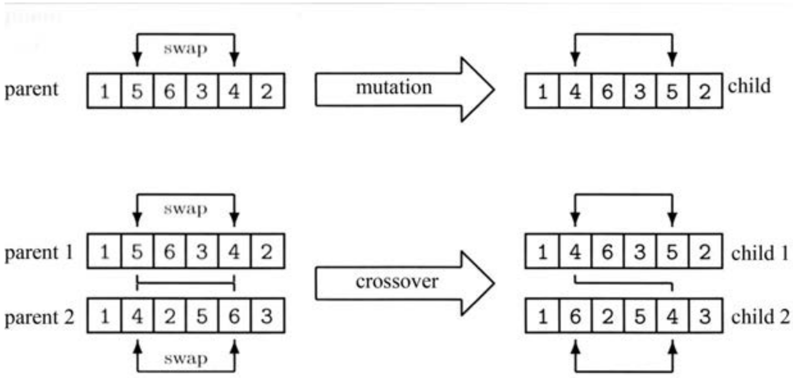

Figure 3.7: Genetic operations Flake (2000).

Evaluation function: Evaluation function evaluates the quality of each individual and is designed to ensure the optimum solutions will be given the optimum evaluation. Fitness of an individual is determined by its value of quality.

Genetic algorithms search space by climbing multi-peaks in parallel to avoid getting stuck in local optima. It can therefore handle a large solution space to settle on (or near) a global optimum solution. Compared with conventional approaches, GA is quite unique due to its genetic operation mechanism (crossover and mutation) that designers can work with a set of possible solutions to evolve toward one or more feasible solutions. However, seeking for a preferred solution may take a long time to converge, control mechanisms are introduced within GA by manipulating the population size and number of generations to control searching time and solution space.

A brief review of related GAs optimisation research in SLP is provided in the following.

Jo & Gero (1998) outlined a GA based algorithm for solving the SLP problem drawn from previous literature. They applied the method by using a GA pro-gramme named EDGE to allocated space modules, followed by a set of rules that defines a binary string giving the sequence to fill the space with modules. Generated layouts are evaluated based on Pareto optimisation technique and selection is based on a simple weighted roulette wheel. The result indicated that the EDGE allows the optimisation process to be much more economical computationally.

Michalek *et al.* (2002) use gradient-based algorithms and GA for topological optimisation (discrete decisions and global search). They use SA to find a feasible initial solution, combining with FSQP for global search and use GA to generate feasible solutions. They integrate a mathematical optimisation and subjective decision into a solution-finding process, which allows the designer to change the constraints and objectives during the design process. However, it seems complex to the users that how variables work and respond to each other.

Caldas & Norford (2002) use a GA based design tool (GENE-ARCH) for optimising location and sizing of windows in an office building. In their research, the optimiser (GA) is coupled with DOE 2.1 Energy simulation software for evaluation of the generated solutions. A further investigation of this research (Caldas, 2008) shows that applications of GENE-ARCH in designing faades and constructing systems for a case of fixed building design and design of layouts for optimum energy performance for a building for known adjacencies. The research shows the importance of using an energy simulation software as well as the capability of GA in SLP optimisation. What is still needed is to generate meaningful layouts for ill-defined requirements in the real world concerning circulation area requirement.

Rodrguez & Jarur (2005) present a method to search spatial configurations using genetic algorithms that combines a direct approach to treating binary constraints. The novelty of their work is the definition of a new genetic operator that combines randomness with heuristics to guide the reproduction of new generations. They compare this new genetic performance with a deterministic approach and a local research approach. The result shows the assisted GA is quite good at searching spatial configurations while the deterministic approach is intractable due to the complexity of the database.

3.2.3.4 Genetic programming

Genetic programming (GP) paradigm provides a way to search for the fittest individual computer program from a set of populations of possible programs (Koza, 1990). The GP hires the Darwinian principle of survival of the fittest, which is the same as described in GA. Bentley & Corne (2002) classify GP as a special kind of GA , treating the computer programs as individuals and modifying genetic operations that GA implement. Koza (1992) proposed the arrangement of solutions in hierarchical tree-structures, Figure 3.8 presents the process of crossover and mutation in Genetic programming, the crossover swaps sub trees that may be of different sizes and positions in the programs and GP mutation create entire new sub trees (Sean & Lee, 1997).

Both GAs and GP are evolutionary algorithms and they execute similar heuristics

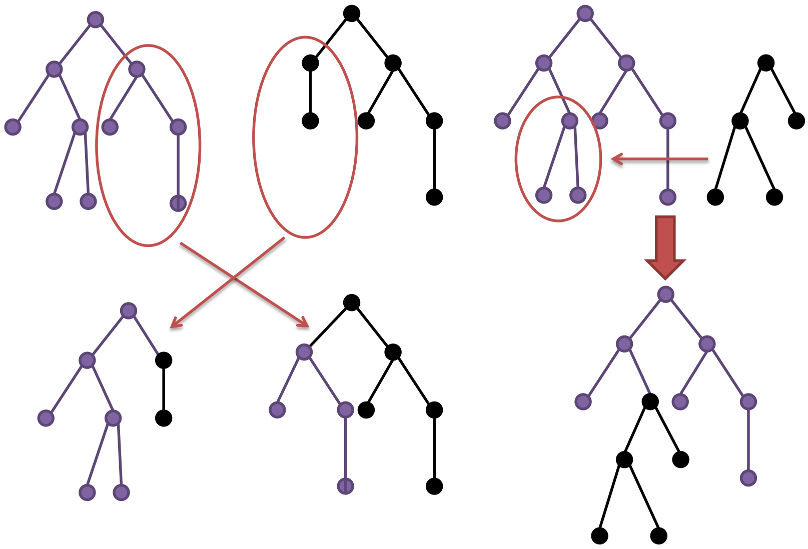

Figure 3.8: Crossover and mutation in GP (White & Poulding, 2009).

in the solution's induction process. However, the major difference between these two algorithms is the distinct types of solutions they are involved in. GAs articulate the problem in terms of values required, whereas GP focus on rules describing a method to solve the problem. GAs explore the search space defined by a specific problem in search of a specific optimal solution (data). On the other hand, GP explores the search space defined by a general set of problems in search of a general solution (algorithm) that responds to the requirement set by such problems. Hence, the selection for the implementation of the appropriate algorithm, either GAs or GP, depends on the objectives of the research. When a problem is explicitly defined as a single case problem and the desired result is the final values of the variables, the GAs should be implemented. Whereas, when the input that defines a specific problem [e.g. environment values and objectives] is unknown, GP can provide a general set of instructions (algorithms) that adequately solve such problems.

3.2.3.5 Simulated annealing

Simulated Annealing (SA) is a stochastic optimisation algorithm inspired by the way that molecules in metals minimize energy state during the annealing process (Metropolis *et al.*, 1953). This algorithm was first introduced by Kirkpatrick *et al.* in 1983 (Szykman & Cagan, 1995). SA has been used as one approximate solution to combinatorial optimisation problems (Takaaki *et al.*, 1999) that utilise the connection between the statistical mechanics (behaviour of systems having number of degrees of freedom in thermal equilibrium at a finite temperature) and combinatorial optimisation (finding the minimum of a given function depending on many parameters) (Kirkpatrick *et al.*, 1983). Takaaki *et al.* (1999) compared SA with another layout design simulations using Hill Climbing (HC) to deal with optimal layout design problems and found that the value of cost evaluated by SA was lower than that of HC. The same idea was shared by other researcher who clarified that simulated annealing techniques eliminate many disadvantages of hill climbing methods since SA depends no more on the choice of starting point and is more likely to achieve convergence of global optimum (Liggett, 2000).

Sharpe & Marksj (1986) applied SA to solve a large scale facility layout problem with up to 200 locations. A major advantage of SA is the insensitivity of the final solution to the initial conditions which is shown by a program called CLASS (Computerized Layout Solutions using Simulated annealing) (Jajodia *et al.*, 1992). The findings are based on the comparisons with other approaches for layout planning such as CRAFT, etc. Baykasolu & Gindy (2001) showed how the implementation of SA provide an approach to Dynamic Layout Problem (DLP).

As it has been discussed by many researchers, SA has advantages compared to traditional improvement methods; however, it is not guaranteed to reach a local or global optimum in a limited time scale. In other words, SA is unable to find a feasible solution even the program is running for several days on a trivial problem (Michalek, 2001). In order to obtain better solutions, SA is combined with other global optimisation methods such as GA and SQP (Mavridou & Pardalos, 1997; Ku *et al.*, 2011; Michalek *et al.*, 2002; Shi, 2009). Michalek (2001) used SA to search a good starting point, and SQP is used to find the local minimum near each starting point (Figure 3.9) to take advantage of the global qualities of SA and the efficiency of SQP to generate local optima of global quality.

3.2.3.6 Hybrid approach

As a trade-off exists in terms of randomness, reliability and computing time for the global optimisation algorithms, (e.g. GAs and SA), new hybrid methods are designed to combine principles from constructive and improvement approaches. The constructive approach sets the tone of the generated solutions while the improvement procedures refine the details. This will decrease searching time for GAs and SA starting with a reasonable solution rather than a randomly generated one, at the same time, promise the

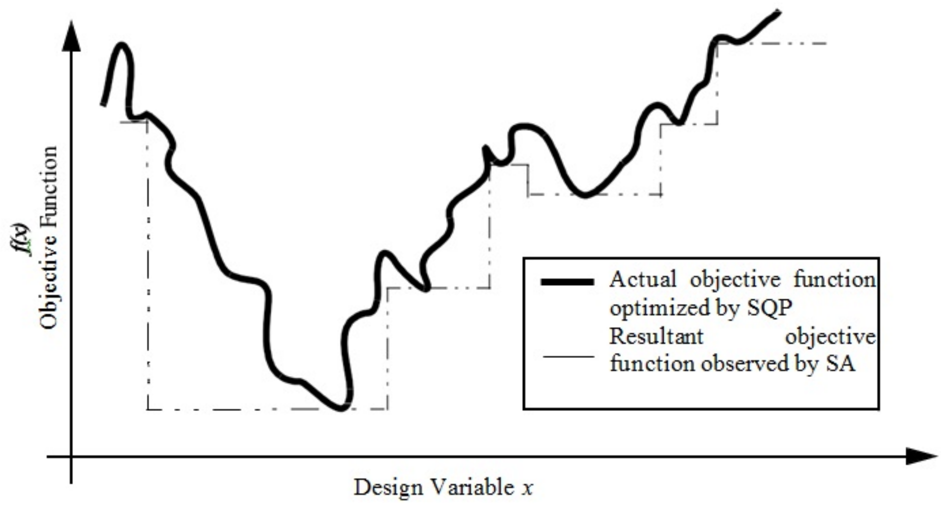

Figure 3.9: Hybrid approach of SA and SQP.

reliability of the solution. Michalek (2001) combined SA and SQP as discussed earlier, Renders & Flasse (1996) design a hybrid methods coupling the 'hill-climb' methods of genetic algorithms for global optimisation. Dai & Cha (1994) presented a hybrid approach of heuristic rules and neural network algorithms to solve the two-dimensional rectangular layout. Smith *et al.* (1996) described an application using a combination of simulated annealing algorithm and a knowledge-based system technique for spatial layout. The knowledge-based method could formulate the problem specifications and evaluate potential solutions, and the SA algorithm is used to generate initial layout for later manipulation. Jo & Gero (1998) improve Liggett's solution (1985) to solve a layout problem by using a genetic search algorithm which is called Evolutionary Design based on Genetic Evaluation (EDGE) (Figure 3.10).

3.2.3.7 Physically based modelling

Physically based space planning (Figure 3.11) is a method applying the physics of motion to space plan elements in the layout design process (Arvin & House, 2002). Designers create a layout plan by specifying graphic design objectives, which are modelled as physical objects and forces used in a dynamic physical simulation. SLP is formulated as a spring-damper physical system by Arvin & House (2002), the spatial units are simulated as point masses and the adjacencies between spatial units are modelled as springs connecting the

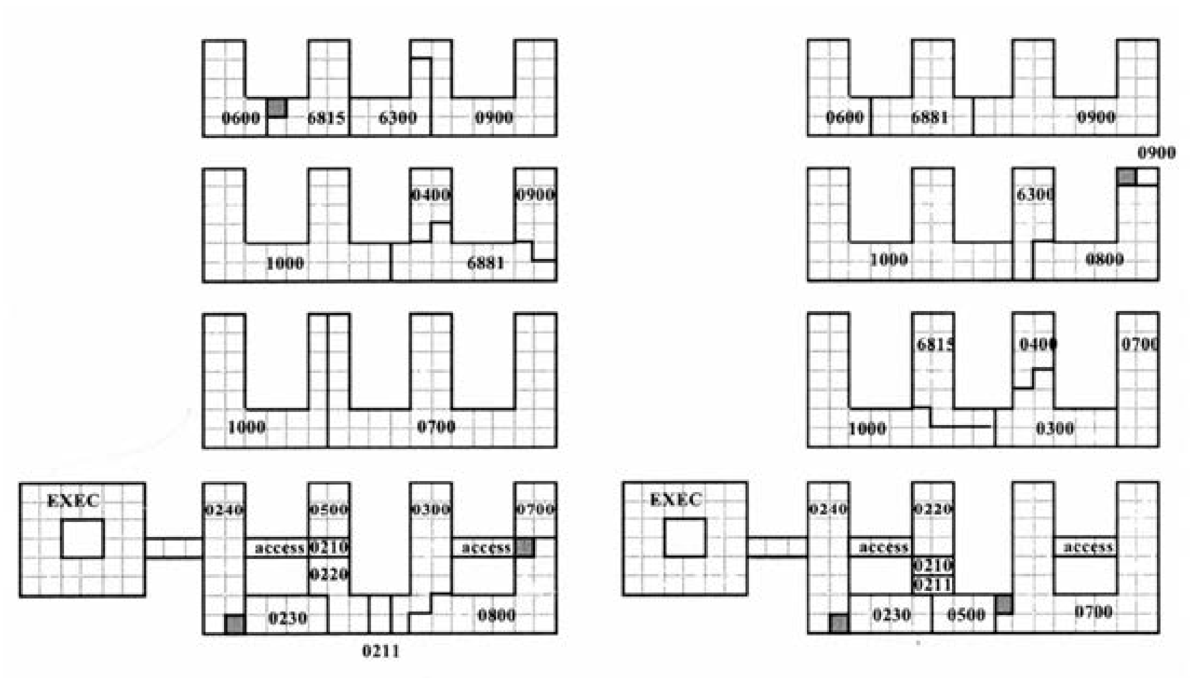

Figure 3.10: Transformed final solutions after 500 generations where (a) is one of the solutions evolved from the randomly seeded initial generation, and (b) is a solution evolved from using Liggett's solution as the initial population (Jo & Gero, 1998).

masses. There are three steps in the methods, the first is to specify topological objectives that apply force to the centre of a space, and the next step is to run the dynamic simulation until the system is in equilibrium and resolve the geometric objectives afterwards. Once the geometric simulation reaches equilibrium, designer is able to move to the last step to interact to modify the topological and geometrical objectives. It is sometimes risky if the problem is ill-defined in the SLP, since the physically based model would be difficult formulated the spring-damper physical system.

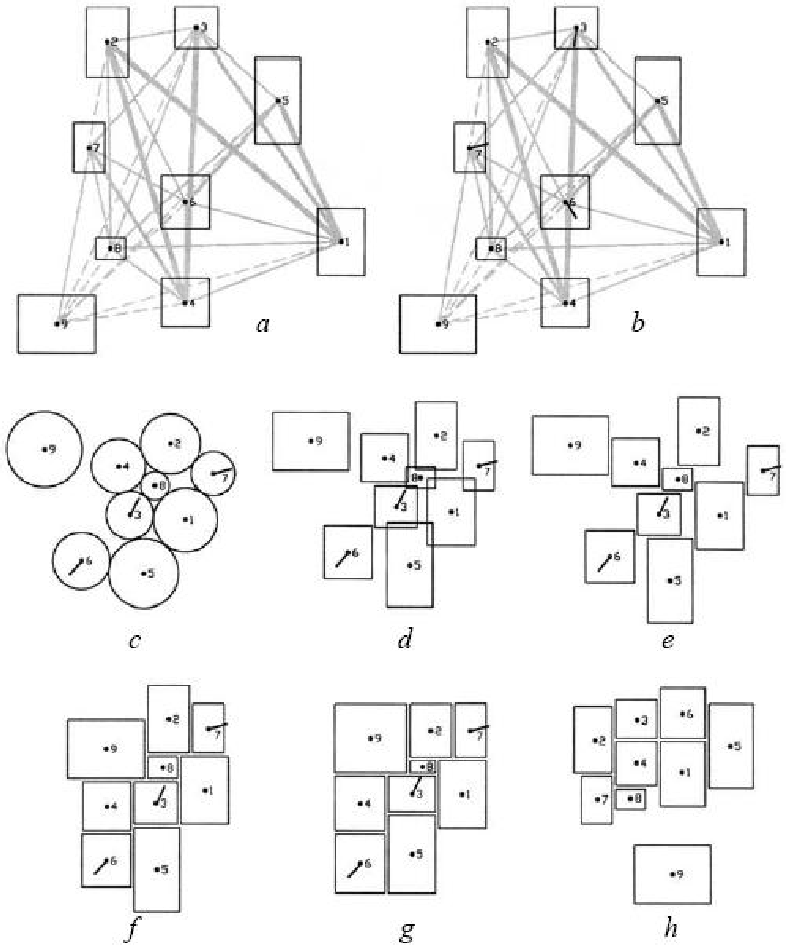

Figure 3.11: Physically-Based Modelling Techniques (Arvin & House, 2002).

3.2.3.8 Tabu search method

Tabu search (TS) is similar to simulated annealing in that both traverse the solution space by testing mutations of an individual solution. However, these two methods can be differentiated by that simulated annealing generates only one mutated solution, while tabu search generates many mutated solutions and moves to the solution with the lowest energy of those generated. In order to prevent cycling and encourage greater movement through the solution space, a tabu list is maintained of partial or complete solutions. It is forbidden to move to a solution that contains elements of the tabu list, which is updated as the solution traverses the solution space.

Tam (1992) discussed a slicing tree based tabu search heuristic for the rectangular, continual plane facility layout problem by incorporating the facilities with unequal areas and integrated the possibility to specify various requirements regarding (rectangular) shape and dimensions of each individual facility by using bounding curves, which made it possible to solve problems containing facilities of fixed and facilities of flexible shapes at the same time. This paper presented a procedure that calculated the layout corresponding to a given slicing tree on the basis of bounding curves and integrated the tabu search to find the better results.

3.2.3.9 Neural networks

Artificial Neural Networks (ANN) is another heuristic approach in evolutionary methods which formulate from the research on the biophysical properties of neurons and their organisation combine in producing impressive high speed computation power as observed in human brain (Hopfield & Tank, 1986). ANN is a structure composed of a number of interconnected units (artificial neurons). Each unit has an input/output (I/O) characteristic and implements a local computation or function. The output of any unit is determined by its I/O characteristic, its interconnection to other units, and external inputs. The network topology, the individual neuron characteristics, the learning strategy, and the training data determine the functionality achieved. The main features that make ANNs advantages over computational techniques are that, information is distributed over a field of nodes, their ability to learn and allow extensive knowledge indexing, and their suitability for processing noisy, incomplete, or inconsistent data and mimic human learning processes. Although ANNs can perform tasks that a linear problem cannot, they also have some drawbacks where, once it deals with large neural networks, a high processing time is needed. In addition, there is no definite way to access the internal operation of the network (Jahagirdar *et al.*, 2010). Other disadvantages also include difficulty in network parameter adjustment and hard to predict future network performance.

Yeh (2006) presented a novel research on the use of Annealed Neural Networks for construction site layout. Yeh formulated the problem as a discrete combinatorial optimization problem. This formulation is identical to what is presented by Li & Love (2000). Similarly, the model aimed at assigning a set of predetermined facilities on a set of predetermined locations while satisfying a set of layout constraints. Thus the system's method of assignment is classified as a facility to location assignment.

3.2.4 GA toolbox

The Genetic Algorithm Toolbox is a graphical user interface that enables the user to use the genetic algorithm without working at the command line. One can apply the genetic algorithm to solve a variety of optimisation problems that are not well suited for standard optimisation algorithms, including problems in which the objective function is discontinuous, non-differentiable, stochastic, or highly non-linear. The important advantage of the genetic algorithm over the standard techniques is that it is able to find the global optimum, instead of a local optimum, and that the initial attempts with different starting point need not be close to actual values. Another advantage is that it does not require the use of the derivative of the function, which is not always easily obtainable.

3.2.4.1 Main operators used in GA toolbox

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population:

1. Selection rules:

Select the individuals, called parents that contribute to the population at the next generation. Selection of the fittest population is the cornerstone of the GA genetic operation (Osman *et al.*, 2003)). There are four selection mechanisms dealt with the GA toolbox:

Roulette Wheel

The population is mapped onto a roulette wheel (Figure 3.12), in which each individual is represented by a space that proportionally corresponds to its fitness. By repeatedly spinning the roulette wheel, individuals are chosen using 'stochastic sampling with replacement'. The principle of this selection method is to stochastically select from one generation to create the basis for the next generation, which requires the fittest individual (solution) have a greater chance of survival than the weaker individuals. The roulette wheel is weighted by the fitness values, higher fitted strings have more areas assigned to the wheel and have a higher probability of ending up as the choice.

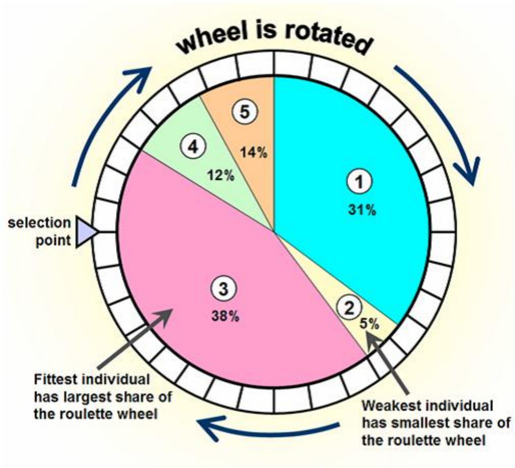

Figure 3.12: Working function of a roulette wheel.

Stochastic universal sampling

Introduced by Baker (1987), SUS is also known as Stochastic universal sampling (Figure 3.13), which is a single-phase sampling algorithm provides zero bias and minimum spread. Unlike the single selection pointer applied in roulette wheel, SUS is analogous to a spinning wheel with N equally spaced pointers (Baker, 1987). The population is shuffled randomly and a single random number pointer1 in the range [0, 1/N] is generated. The N individuals are then chosen by generating the N pointers, starting with pointer1 and spaced by 1/N, and selecting the individuals whose fitness spans the positions of the pointers (Pencheva *et al.*, 2009). This method ensures a selection of individuals that are closer to the optimum than roulette wheel selection.

Tournament WOR/WR

In tournament selection (Goldberg *et al.*, 1989), a number S of individuals is chosen randomly from the population of size N. And the best individual out of S is selected as parent and gets a copy in the mating pool (Sastry & Goldberg, 2001). Selected parents produce uniform at random offspring. The tournament size S takes values from 2 to N

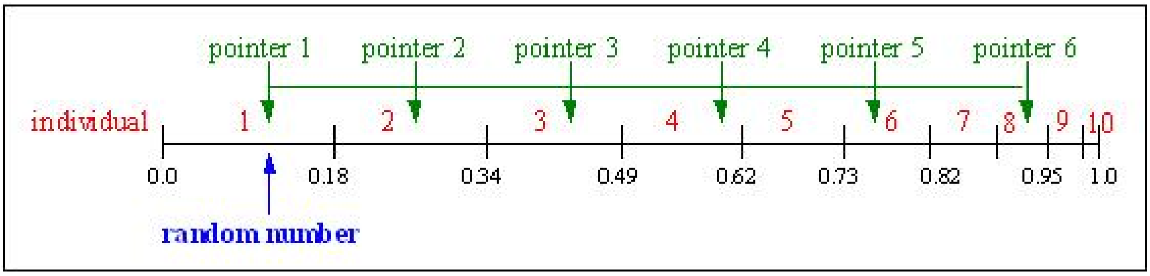

Figure 3.13: Stochastic universal sampling (SUS).

Table 3.2: Relation between tournament size and selection intensity.

Tournament size	1	2	3	5	10	30
Selection intensity	0	0.56	0.85	1.15	1.53	2.04

(population size). Table 3.2 shows the relationship between tournament size and selection intensity. Increasing tournament size increases the selection intensity, however, a high selection intensity could lead to premature convergence and thus to a poor quality of the solutions.

The selection of s individuals can be performed either with replacement or without replacement. In the tournament with replacement the selected individuals are also candidates for other tournament rounds, while without replacements the individuals will be selected only for the current tournament. Effect of such difference was found by Sastry & Goldberg (2001) that tournament selection performed with replacement need larger population size than without replacement to attain the same level of accuracy.

Truncation

Truncation selection is an artificial selection method which is used for large populations. In truncation selection, individuals are sorted according to their fitness. Only the best individuals are selected for parents. These selected parents produce uniform at random offspring. The parameter for truncation selection is the truncation threshold Trunc. Trunc indicates the proportion of the population to be selected as parents and takes values ranging from 50%-10%. Individuals below the truncation threshold do not produce offspring. The term selection intensity is often used in truncation selection. Table 3.3 shows the relation between both.

Table 3.3: Relation between truncation threshold and selection intensity.

Truncation threshold	1%	10%	20%	40%	50%	80%
Selection intensity	2.66	1.76	1.2	0.97	0.8	0.34

2 Crossover rules:

Combine two parents to form children for the next generation. Four types of crossover are provided by GA tool box:

OnePoint

One crossover point (Figure 3.14) is randomly selected. String from the beginning of the chromosome to the crossover point is copied from one parent, the rest are copied from the second parent.

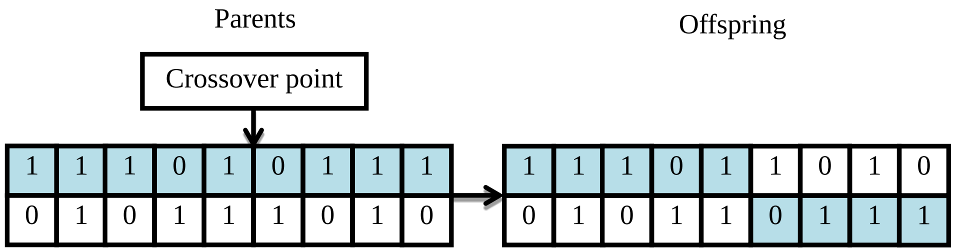

Figure 3.14: OnePoint crossover with a binary encoding.

TwoPoint

Two crossover points are randomly selected. This method (Figure 3.15) copies string from the first parent, starting from the beginning of the chromosome to the first crossover point and from the second crossover point to the end of the chromosome. The rest are copied from the second parent.

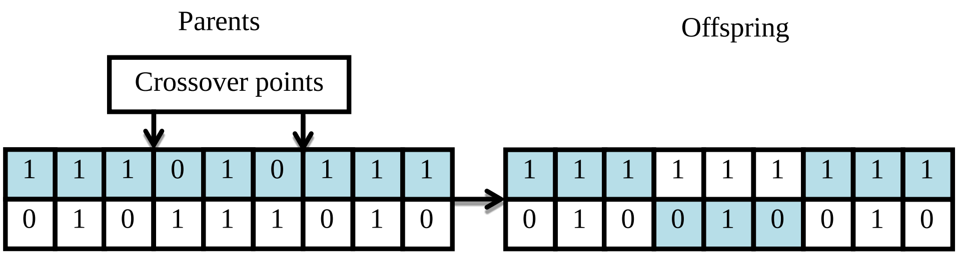

Figure 3.15: TwoPoint crossover with a binary encoding.

Uniform

Crossover bits are randomly selected from both parents to create the offspring (Figure 3.16), compared with one point crossover and two points crossover, this crossover type increases the diversity of offspring that are created from parents.

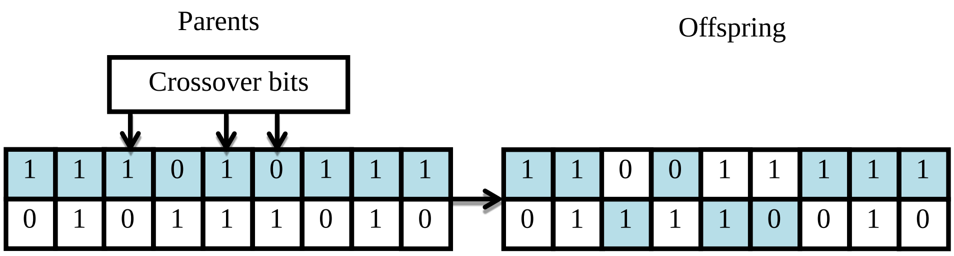

Figure 3.16: Uniform crossover with a binary encoding.

SBX

Simulated Binary Crossover was proposed by Deb & Beyer (2001), it was designed with respect to the one-point crossover properties in binary-coded GA.

SBX operator uses a probability distribution around two parents to create two offspring. The probability distribution of β spread factor is defined as the ratio of the spread of offspring points to that of the parent points as shown in the equation below:

$$\beta = \left|\frac{y_1 - y_2}{x_1 - x_2}\right| \tag{3.1}$$

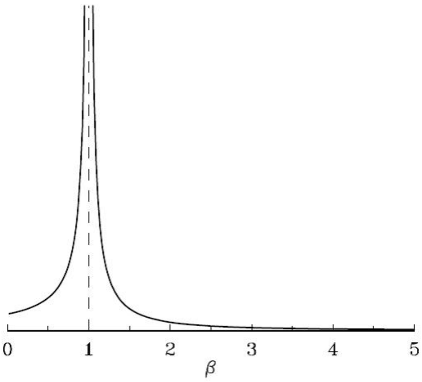

Figure 3.17: Probability distributions of contracting and expanding crossovers on two extreme binary strings.

where x_1 and x_2 are variables of two parent solutions and y_1 and y_2 are the computing children solutions. According to Deb and Goyal (1996), a random number u is created between 0 and 1. Then from a specified probability distribution function a value of β is selected so that the area under the probability density curve from 0 to β equals to the randomly created value u, which β is calculated by the equation below:

$$C(\beta) = \begin{cases} 0.5(n+1)\beta^n & \text{if } \beta \leq 1; \\ 0.5(n+1)\frac{1}{\beta^{n+2}} & \text{otherwise} \end{cases} \tag{3.2}$$

They also indicate that a large value of n has higher probability to calculate solutions that are close to parent solutions, and the smaller the value of n allows distant points to be selected as children solutions (Deb & Goyal, 1996). If the solutions after cross over are away from the parent solutions, the optimisation may lose its direction of convergence. On the other hand, if the children solutions get close to the parent solutions, it may tend to get trapped in a local optima. Previous literatures suggest a value '3' preforms better in optimisation. In addition, many researchers have stated that crossover should occur in a genetic process by a probability of 70%-90% to guarantee good solutions. Practically, this is a subject of trial and error and testing.

3. Mutation rules:

Apply random changes to individual parents to form children. Three types of mutation are provided by GA tool box:

Selective

As explained in the GA toolbox manual document, selective mutation, where a randomly selected gene is replaced by a uniformly distributed random value in the interval $[x_{i,min};\ x_{i,max}]$ with probability p_m.

Polynomial [order of the polynomial]

Polynomial mutation (Deb and Goyal, 1996) is used with a small mutation probability p_m. Where, a polynomial probability distribution function having its mean at the current value and its variance as a function of the distribution index n is used to define a perturbance factor δ as in the equation below:

$$\delta = \frac{c-p}{\triangle max} \tag{3.3}$$

where $\triangle$ max is the maximum permissible perturbance, value x and y is the mutated value (Deb and Goyal, 1996). The mutated value is calculated using the probability distribution factor δ as shown in the equation below (Deb & Goyal, 1996):

$$P(\delta) = 0.5(\eta_m + 1)(1-\delta)^{\eta_m} \tag{3.4}$$

Similar to the SBX operator, a random number h, is generated between 0 and 1, and the value of δ is calculated using the following equation (Deb & Goyal, 1996):

$$\delta = \begin{cases} (2h)^{\frac{1}{\eta_m+1}-1} & \text{if h} < 0.5; \\ 1-[2(1-h)]^{\frac{1}{\eta_m+1}-1} & \text{h} \geq 0.5 \end{cases} \tag{3.5}$$

Genewise

Every gene is mutated using Gaussian mutation with probability p_m, where each variable is modified by adding a random number sampled from a Normal distribution with zero mean.

3.2.4.2 Effectiveness of optimisation of GA toolbox

In GA toolbox, it applies method of Elitist Replacement to improve the effectiveness of optimisation. Both the old and new population is sorted according to their fitness and constraint violation. Top individuals are retained, with a user defined proportion rate, p_r, with the rest n(1-p_r) individuals are replaced by the top individuals in the new generated population. Where 'n' is the population size.

3.2.4.3 Stopping criteria of GA toolbox

After the whole optimization process the algorithm stops when one of the stopping criteria is met, GA toolbox provides 13 criteria for the termination of the algorithm, including: Number of Function Evaluations; Fitness Variance; Best Fitness; Average Fitness; Average Objective; etc. Different stopping criteria could be selected according to different solving problems.

3.3 Challenges in layout planning in healthcare facilities

Medical equipment manufacturers continuously collaborate with healthcare facilities in understanding their needs of newer medical equipment. Advances in medical electronics and instrumentation have enabled design of multifunction equipment. This has made the provision of healthcare facilities easier at many top hospitals across the world. Such collaboration has unintentionally created space redundancy issues in hospital layouts that broadly include, but are not limited to, the equipment used for diagnostics and treatment, patient treatment areas, clinician/technician areas and other storage/waiting areas that the initial designers neither planned for nor anticipated. Problems arising out of a collaboration that is highly favourable to the patients and clinicians can be addressed by adopting a BPM based approach in conjunction with an algorithmic technique to solve the issue of space redundancies.

3.4 Commercial packages for spatial layout planning

A number of commercially available layout design packages are listed in alphabetical order below:

- Flow Planner by Proplanner
- Layout-iQ by Rapid Modeling Corporation
- Plant Design and Optimisation by Siemens PLM Software
- Simulation
- VIP-PLANOPT by Engineering Optimisation Software

The layout algorithms presented in the chapter are basically research-based algorithms, most of them are not available in commercial layout design packages. In many commercial software which consist of CAD systems, the layout function is usually provided with a graphic interface for the user to layout a plan manually with little or no access to information concerning the layout criteria (Liggett, 2000). One of the reason these commercial packages were not adopted in this research is due to its incapability of manipulating the design of constraints and objectives which are research orientated. On the other hand, a layout designer should be able to make trade-offs between constrained design criteria and converge on an optimum solution whilst the commercial layout packages only provide a single least costly plan. The listed software can be used for engineers in solving some particular layout planning problems, but they can't satisfy layout designer's search of an optimum solution in exploring a highly constrained search space. Such limitations prohibited the adoption of commercial layout packages in this research.

3.5 Summary

To conclude, automated space layout planning has been broadly studied in the past several years. The focus of this type of research have moved from the period when SLP problems were handled as finding a satisfactory arrangement of rectangular units to form a layout into searching global optimisation solutions via heuristic methods such as Simulated Annealing, Genetic Algorithms, Artificial Neural Networks, etc. Different types of program, each of which has its own domain and ability to help designers in the layout planning process. It is therefore important to identify and employ different programmes to solve the correspondingly different problems. E.g. GAs are good solvers when NP-hard SLP is treated as single criterion decision problem. On the other hand, the hybrid approaches are promising method for intelligent systems as the weakness of some algorithm could be offset by the strengths of other algorithms.

However, most of these programs are still at a research prototype stage, some programs still have bugs and thus need further improvements. One big obstacle to these programs is the excessive runtime that increases dramatically by increasing the objectives and/or problem variables. Moreover, none of current programs is able to deal with designs in all architecture aspects.

Chapter 4

Methodology

This chapter describes the methodology adopted in this thesis. The user perception needs to be integrated for layout design and an automated optimisation process enables the integration of patients' and staff's point of view so that it translates to 'evidence based design'. Two main steps are taken to accomplish the objectives in this research. The first step is the development of a structured questionnaire to investigate users' perception, the findings of which are used to develop an index of preferences which are described from section 4.1 to 4.5. The second step is to develop an automated layout planning system that integrates the indices of users' preferences for decision making and for driving the search for an optimum design in section 4.6 and 4.7.

4.1 Questionnaire development

The questionnaire development followed four phases. First, the items of the questionnaire were generated based on a review of literature and industry guidelines, conducted in the period from January to May 2009. The purpose of the review was to determine the followings:

- Factors related to the design of the physical environment in healthcare facilities;
- Users' perception of the physical environment; and
- The physical environment factors that affected care providers' performance and patients' outcomes.

Secondly, the author visited the two participating hospitals four times and carried out interviews with 10 outpatients to explore their perceptions of the waiting environment when they were waiting for doctors' calls.

Thirdly, a draft questionnaire was developed by incorporating the findings from the first and second stages. The questionnaire was first produced in English and then translated into Chinese for respondents' convenience. The draft was reviewed for accuracy and validity of content by two administrators and four outpatients from the participating hospitals. The draft questionnaire was then evaluated in a pilot study to analyse the comprehensibility and clarity of the items and attributes related to the psychometric properties of the instrument. The participating outpatients and care providers of the pilot study were asked to state any deficiencies of the content of the questionnaire, other potential sources of perceptions and significance of each item. The pilot study resulted in an amended final questionnaire with improved content validity.

Fourth, the final structure of the questionnaire included three types of questionnaires to rate the perception of the importance with regards to the dimensions of the physical environment in healthcare facilities. Respondents were asked to rate their perception of an item on a Likert type response scale ranging from least important, unimportant, neutral, important and most Important, transformed into a scale going from 1 (Least important) to 5 (Most Important), a higher score indicates a higher level of perception of the item. The questionnaire also contained an open question to enable the respondents to communicate their ideas to improve the design of the waiting environment. Demographic and clinical information such as age and gender were obtained from the participants. Data regarding times to the hospital and types of the appointment were recorded as well.

4.2 Study sample and ethical approval

The study was conducted among outpatients, inpatients and care providers in two Chinese hospitals in Qingdao, a coastal city in East China. The hospitals were chosen for this questionnaire survey because of their size, reputation, world-standard facilities and the relatively large number of staff and patients. One of the hospitals is affiliated with a medical college and the other is the largest general hospital in the city. These two hospitals employ a total of approximately 5900 staff and have around 4000 beds. Respondents were selected to participate in the survey at random sampling. All participants were over 18 years old and they were communicated in writing through an 'introduction to the survey' section, which this survey was voluntary and the confidentiality of the data would be retained.

A two-stage ethical approval was obtained for this survey. First, an ethical approval was obtained from the UK academic institution where the author was based at. Secondly, the research committees of the two participating hospitals gave approval to the study. Specifically, written consent was given for each interview carried out and anonymity of respondents has been preserved except when explicit permission was given to use titles or names. Before photographs were taken at both hospitals, permission was sought and given by the hospital administrative office and no individuals can be identified in any photograph taken by the researcher.

4.3 Data assessment

As some particular holidays in China will create potential bias in the use of the health-care facilities and bring bias in user perception to physical environment, data for this study were collected between August 12th 2009 and 26th 2009, a time period in which there were not any special holidays in China to avoid such situations. The surveyed respondents were randomly selected from each floor in both hospitals, from 8am to 5pm, Monday to Friday, during the two-week study period, in order to capture all time stages of user performance. The researcher distributed the questionnaires to the sampled respondents and explained the purpose of the survey. Informed consent was obtained from each participant in the study. In addition, the author explained the meaning of the questions when the respondents could not understand the survey items, and the author also verified the questionnaires for completeness and correctness for completion. These completed questionnaires were collected on spot when finished. Other questionnaires for care providers and inpatients were mainly distributed and collected by hospital staff. A total number of 928 respondents (including 304 care providers, 337 outpatients and 287 inpatients) from the two Chinese hospitals completed the questionnaires effectively out of 1200 distributed and the results were included in the study. The outpatients response rate was 84.3%. And this figure for care providers and inpatients are 77.3% and 71.75% respectively.

4.4 Statistical analysis

Most statistical analyses have been performed with PASW Statistics version 18.0 for Windows (SPSS Inc, 2010). Nevertheless, the researcher has carried out the test for differences in dependent correlations. Descriptive statistics on the item and scale frequencies, percentages, means and standard deviations (SD) were computed. Demographic and other related data were also analysed descriptively by computing frequencies and percentages. Internal consistency reliability was assessed via Cronbach's coefficient alpha (Cronbach, 1951), with an alpha ≥ 0.70 as the recommended value as this study involved the comparison of groups of respondents (Nunnally & Bernstein, 1994).

As questionnaire of multi-item scales were suggested by (McIver & Carmines, 1981) and (Nunnally & Bernstein, 1994) to reduce random sources of errors to represent the theoretical concept. This study employs Principal Components Analysis (PCA) to identify the underlying structure characterizing a set of highly correlated variables. The PCA analysis showed that fewer items in the main study had a factor loading ≥ 0.40 in more than one factor, compared to the pilot study. The factors from the main study were easier to label and had good correspondence with other studies. After this stepwise development phase good construct validity and internal consistency were established for the questionnaire. Bartlett's test of sphericity was used to identify significant correlation between items. Kaiser-Meyer-Olkin procedure for measuring sample adequacy was applied.

To analyse statistically significant differences in perceptions between genders and appointment types, Mann-Whitney U-test was used. For the outpatient questionnaires, differences between the age groups 18-25 (yr), 25-35 (yr), 35-50 (yr), older than 50 (yr) and visit times 1-2, 3-4, 5-10, more than 10 times were analysed using Kruskal-Wallis test with a p-value<0.05 taken as statistically significant. Same analysis was conducted in the other types of questionnaires. Mann-Whitney U-test with a reduced p-value ($p<0.01$) was used as a post hoc test to avoid the risk of finding significant differences by chance (Bland & Altman, 1995).

4.5 Interviews to validate research findings

Interview questions were initially designed to obtain nurses perception of design factors in one of the above mentioned hospitals. These questions evolved from the literature review, the initial survey findings and through discussions with members of staff at the surveyed hospitals. In order to ensure that the questions were directed, simple and specific while avoiding ambiguous questions, a senior nurse was asked to answer all of the questions and give feedback for improvement. Finally, seven key questions were formulated for the interview of six nurses who were selected at random from survey participants. The interview questions focused on the assessment of the nurses perception of building design factors and their impact on patients and healthcare providers. General demographic information was requested from the interviewees including their age, gender, work experience, work position and job responsibilities. The interviewees were informed beforehand that the interview would be recorded and the confidentiality of the information would be maintained.

4.6 Development of spatial layout planning prototype

There is a limit to the amount of information a designer can process while the range of information which can be brought to bear on a problem is limitless in theory. Practicality dictates that a strategy from selecting the most relevant and useful information is available. There is therefore a need continuing development of a framework to help select the most relevant parameters of the problems a particular building is meant to solve.

It can be seen that conceptual design is an iterative process during which the designer generates a set of alternative solutions for an object based on a design specification. The design specification will contain a set of requirements that the object to be designed must satisfy. Based on these requirements, the designers begins, an iterative process of solution generation. During this process he will develop a solution that is intended to satisfy the design specification. This solution is then evaluated and compared against any solutions that have already been developed. Based on this comparison, the designer will choose to accept, improve or reject a particular solution. The process of solution generation will be repeated many times in order to ensure that a sufficiently large number of solutions have been considered.

The healthcare space layout problem is presented as a process of finding the best location of several medical rooms (represented as Spatial Units), satisfying a predefined relationship among them, including adjacency, accessibility and travelling distance requirements. In the meanwhile, the objective of the optimization is defined to obtain as compact layout as possible. Adjacency defines which rooms are directly connected while a corridor was placed to make the rooms are accessible. The corridor will be treated as a special spatial unit during the optimization. A realistic problem was implemented to test the scalability of the automated space layout planning algorithm. The example involves a small clinic with 7 spatial units (rooms and corridor). Specifications and rooms are shown in Table 4.1.

Table 4.1: Specifications of spatial unit for space layout problem.

No.	Spatial Unit	Area	Length	width	Adjacency requirement
1	Nursing station	3000000	2000	1500	Ward1
2	Reception	2400000	1200	2000	Corridor
3	Ward 1	5000000	2500	2000	Nursing station
4	Ward 2	3740000	1700	2200	Operation
5	Operation area	3600000	1800	2000	Ward 2
6	Waiting area	3000000	1500	2000	Reception
7	Corridor	NA	800	1500	NA

As the design space is combinatorial, multi-modal, and highly constrained, therefore it must be searched with a global scope. For this reason, evolutionary algorithms were selected. Evolutionary algorithms search heuristically, and they can be stopped at any point during the optimization process to return a population of best designs so found. This heuristic search method can often find quality feasible designs to large problems that are intractable for systematic search methods.

An evolutionary algorithm for healthcare space layout was implemented using the GA tool box optimisation package. A SGA method was selected for single objective. A Roulette Wheel selector was used to select high quality designs with greater probability than low quality designs. When crossover is used (randomly), two parents are selected from the population, and two new children are produced using mixed room connectivity from both parents. After crossover, new layouts are mutated slightly (varying according to mutation rate). The evolutionary algorithm implementation is able to generate quality feasible layouts for medium-sized problems.

4.6.1 Spatial unit representation

In general terms, this research approach attempts to model a user-defined space layout using a two-dimensional reference system. For the purposes of clarity, geometric definitions of the layout within the optimization process are introduced here.

4.6.1.1 Space

This space layout problem is posed as a search for the best location of a group of interrelated Spatial Units into a two dimensional space. Generally, space can be of any shape, the space defined here as a rectangular space to perform a specific architectural function. Visualised in a planar coordinate X-Y system, the boundary of the space can be identified as a straight line from the following equation,

$$y = ax + b \tag{4.1}$$

A space boundary composed of a set of n straight edges interpreted as a number of walls, where n gives a particular number of walls. In this research, the value of n is fixed to 4 to form a rectangular spatial unit. In reality, a spatial unit can represent any types of building components, such as rooms, corridor or open areas, etc.

4.6.1.2 Room

A room is defined as a rectangular space element which is used as a living or working purpose. Such as the ward, washing room, office room, etc. In the healthcare space layout planning, it is up to the designer to decide which space could be rooms. For some other research, the utilised room and un-utilised space will be treated differently in the optimisation objectives.

4.6.1.3 Corridor

The corridor is a space with no physical walls to connect different rooms in the layout. Generally, the corridor is used like a room, but function differently. It only provides the pathway between other rooms. In this research, the corridor's function is to promise the accessibility of specific rooms.

4.6.1.4 Boundaries

Boundaries are used to group the spaces, defining the interior and exterior of the building. Because the spaces are located on the building site, the exterior walls therefore define the boundaries of the building. The size of the building boundary varies according to different types of formulated layout.

4.6.1.5 Windows

Windows are a means to let the daylight come into the building interior. Windows are generally added to the spaces and corridors, the size of the window varies according to designers. Spaces that have exterior walls will have windows for natural lighting which will be considered in evaluation of energy performance of the whole layout.

4.6.1.6 Doors

Doors are a means of accessing spaces. Location, number and size of doors on a space boundary is decided by the user, and specified in the accessibility requirements.

4.6.2 Mathematical formulation

4.6.2.1 Spatial unit variables

There are several ways to represent the spatial unit in a two dimensional coordinate system. Figure 4.1 shows some alternative representations of spatial units used in previous researches.

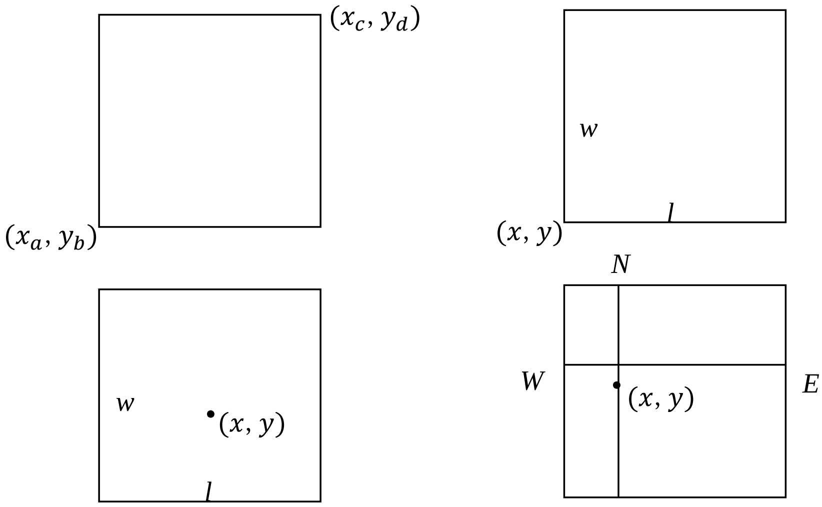

Figure 4.1: Representation of spatial units.

Michalek (2001) has concluded the pros and cons of the above four SU models,

- Model a, can move each wall of the SU indecently with a single variable, may have trouble satisfying area constraints if the SU needs to be moved.
- Model b, unbalanced, the south and west walls cannot move directly without affecting north or east walls.
- Model c, can move the SU without affecting its size; however cannot move any wall independently without changing two variables simultaneously. And when moving the walls it may have trouble violating adjacency constraints.
- Model d, allow the optimization move the SU independently without affecting the size, however, this model have more variables than others, which may increase the complexity of the optimization.

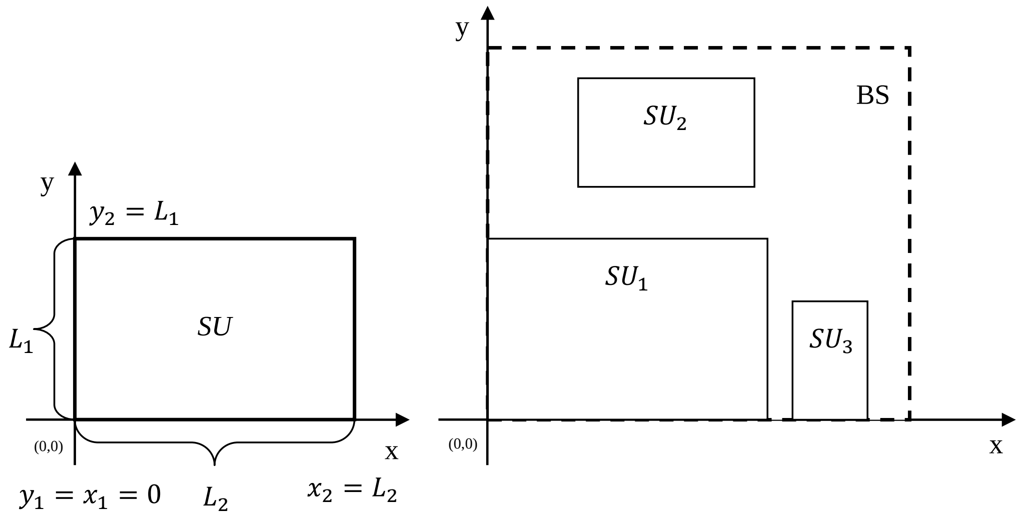

Figure 4.2: Representation of spatial units in coordinates system.

In this research, the spatial units are represented in Figure 4.2 as the area of the SU is constant throughout the optimization process. The Lower left corner of rectangular is set as the origin of the coordinate system, the figure also represents a set of spatial units locating in a layout (building site) within the coordinate system.

The edges of the SU in Figure 4.2 are represented by x_1, x_2, y_1, y_2, the width of the SU equals to L_1 and the length of the SU equals to L_2 . All four vertices of the SU can determined by using the length and width of the SU.

$$x_1 = 0 \tag{4.2}$$

$$x_2 = 0 \tag{4.3}$$

$$y_1 = 0 \tag{4.4}$$

$$y_2 = 0 \tag{4.5}$$

In this research, an oriental variable is needed to adjust the orientation of the SUs, as shown in the Figure 4.3, two situations will be considered, either the orientation equals to 0 or 90.

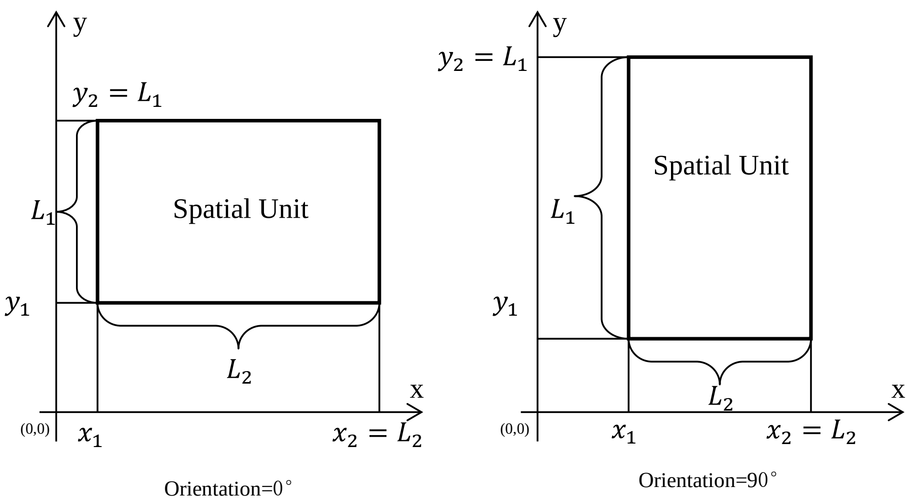

Figure 4.3: Orientation of spatial units.

4.6.2.2 Corridor design

Step 1. In the initial design phase, the area of corridor is set to the 20% of the SU area.

$$A_{corr} = 20\% A_{SUs} \tag{4.6}$$

Unlike the spatial units, the corridor is designed to have changing shape and size. The design process goes in four steps below:

Step1. Set minimum and maximum depths of the corridor as well as the lengths (Figure 4.4).

$$D_{min} = 2m \tag{4.7}$$

$$D_{max} = 5m \tag{4.8}$$

$$L_{min} = A_{corr}/D_{max} \tag{4.9}$$

$$L_{max} = A_{corr}/D_{min} \tag{4.10}$$

Step 2. Here we introduce a concept of corridor break C_{br} to set compartments in the corridor, the number of C_{br} is calculated as,

$$C_{br} = (NumberofSUs)/2 - 1 \tag{4.11}$$

if number of SUs is larger than 2 Or C_{br}=1, if there are only two SUs in the designed layout.

Step 3. A random length L_ram is defined as the value is between the minimum and maximum lengths.

$$L_{min} < L_{ram} < L_{max} \tag{4.12}$$

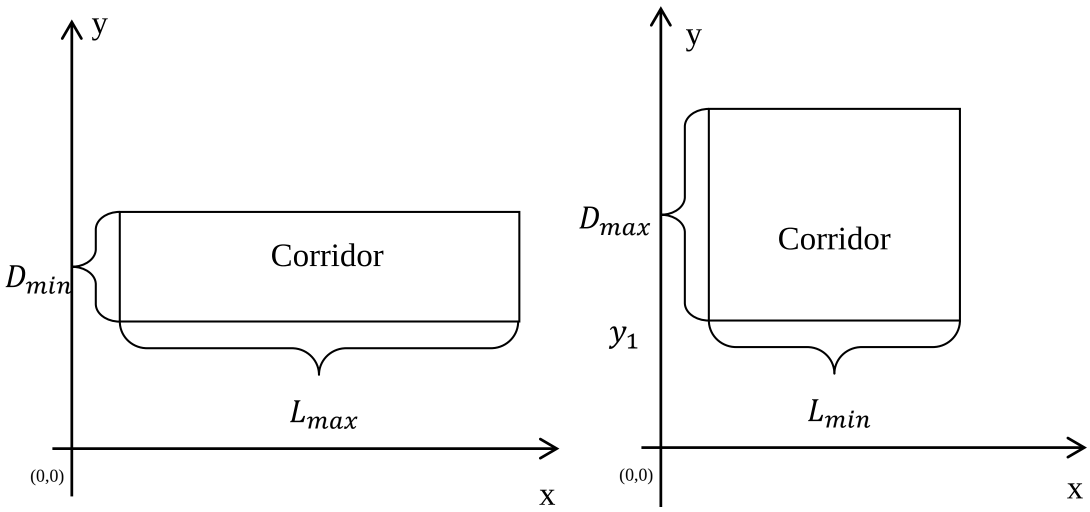

Figure 4.4: Corridor construction.

Similarly, a random depth D_ram is defined as between the minimum and maximum Depths (Figure 4.5).

$$D_{min} < D_{ram} < D_{max} \tag{4.13}$$

Step 4. Then compartments of the corridor can be formulated, for example, if the C_{br}=4, we shall have 4 breaks of compartments in the corridor.

The area of the first compartment is determined by its length and depth, L_{ran1} and D_{ran1},

$$A_{ran1} = L_(ran1)D_{ram1} \tag{4.14}$$

If $A_{ran1} < A_{corr}$ then we continue to formulate the second compartment using the same method. Unless the

$$\sum_{n=1}^{C_{br}}(A_{ran1} + A_{ran2} + A_{ran3} + A_{ran}) = A_{corr} \tag{4.15}$$

It has been assumed that a corridor comprise of compartments and therefore without compartments there cannot be a corridor. A brief explanation of how to construct the corridor compartments is giving below, which employs four main operations.

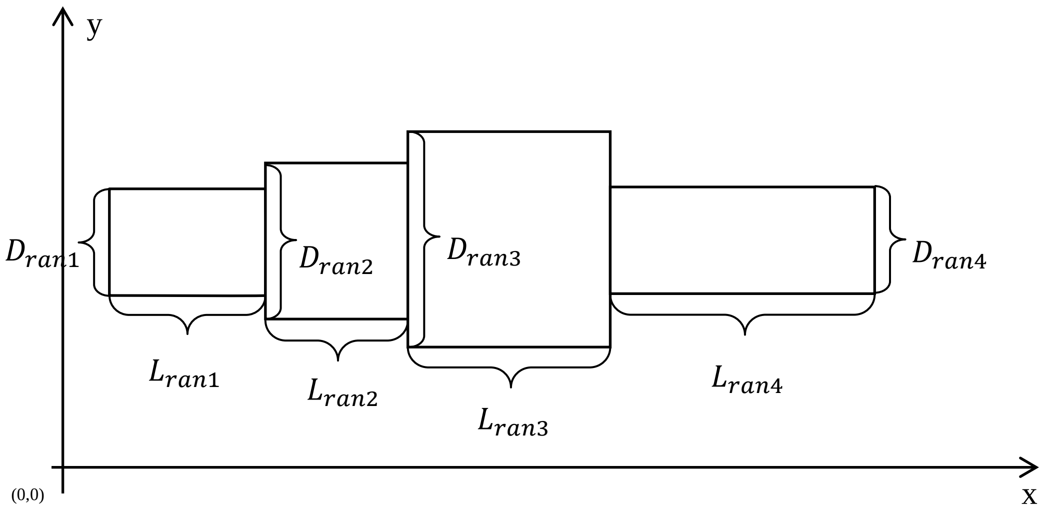

Figure 4.5: Constructed corridor.

for each compartment **do**
  Generate random width and random length
  Calculate area
  if calculated area is less than or equal to maximum compartment area **or** calculated area is less than or equal to remaining area **then**
    Update remaining area of corridor by deducting calculated area
    Store compartment information in a vector
  else if remaining area is equal to total corridor area **and** calculated area is greater than maximum compartment area **or** remaining area is equal to maximum compartment area **then**
    Set calculated area to maximum compartment area
    Reduce original width to half
    Calculate length by dividing calculated area by width
    Update remaining area of the corridor by deducting calculated area
    Store compartment information in a vector
  end if
end for

- *The comp:Compartment[*]* is a vector that will hold compartment information which is cleared using *resetCompList()* operation after each generation in order to store new information. Most of the operations within 'corridor' class are self-explanatory and easy to understand. However, few operations in both classes could be a little confusing to understand and they will be explained briefly below.

- *buildCompartment(corArea)*- This operation in 'Corridor' class is responsible for building compartments. The operation takes a total area of corridor, calculates maximum area for a compartment (50% of the total corridor area) and then builds a compartment by generating random width and width.
- *calculateCentre(maxX,maxY)*- This operation in 'Compartment' class calculates centre point of each compartment in order to adjust the X-coordinate of succeeding compartment.
- *adjustPosX(x1,x2)*- This operation in 'Compartment' class is used for adjusting the position of a compartment on X-coordinate so that the centre point of all the compartments matches.

4.6.2.3 Optimisation objectives

In this research, only geometrical objectives are considered for optimisation, the program attempts to minimise the dissatisfaction of adjacency and accessibility respectively. The objective of this healthcare space problem is to minimize the compactness value of the layout. The optimisation problem can be stated as below

- Minimise

Compactness of the layout

- Subject to

1. Within building site constraints
2. Non-overlapping constraints
3. Adjacency constraints
4. Travelling distance constraints

All the SUs in the layout should be located as compact as possible. The objective function is described below,

$$min f_{compactness} = \frac{\sum_{n=1}^{SUs} A_{SUs}}{A_{spread}} \tag{4.16}$$

Where $A_S Us$ is the total area of all the spatial units, A_{spread} is the spread area of the generated layout (Figure 4.6), the spread area is bounded by the dashed lines, it gets smaller if the SUs are more compact while increases if SUs are located far from each other. However, it won't have more compact layout only minimise the spread area, because the SUs may get overlapped with each other which violating the non-overlapping constraint. Therefore, a ratio between total area of SUs and the spread area is utilised for the objective function.

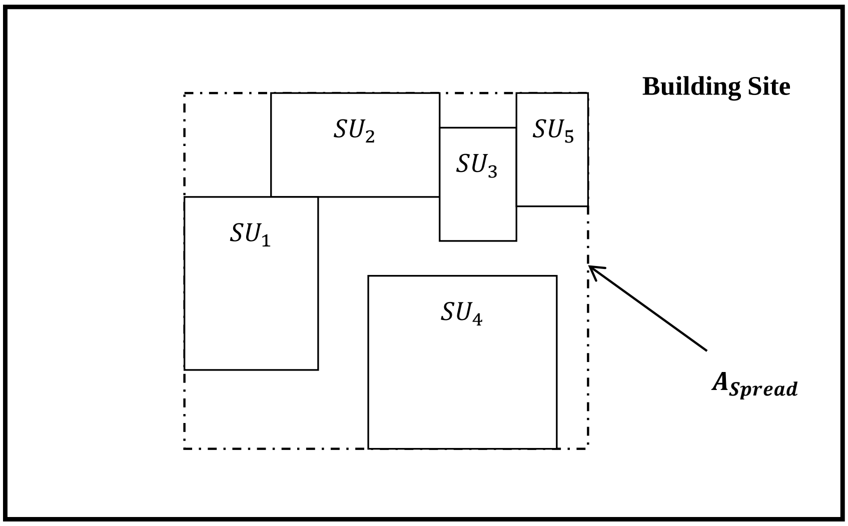

Figure 4.6: Area of spread layout.

4.6.2.4 Problem constraints

Two types of constraints are considered in this healthcare layout problem, geometrical constraints and topological constraints. Each constraint is detailed below and a brief demonstration of the constraints is listed in the Table 4.2.

Table 4.2: Specifications for layout demonstration.

Constraint type	Constraints
Overlap	No two SU can occupy the same space
Adjacency	Ward 1 must connect to the operation area
Adjacency	Ward 2 must connect to the nursing station
Adjacency	Waiting area must connect to the nursing station
Accessibility	From ward 1 to the reception, there must be a route via the corridor
Accessibility	From ward 2 to the reception, there must be a route via the corridor
Accessibility	From operation area to the reception, there must be a route via the corridor
Within the building site	All the spatial units must not exceed the layout plan

Geometrical constraints

Geometrical constraints considered in this research are within building site constraint and non-overlapping constraint. These are the hard constraint that a practical solution must fulfil such requirements.

1: Within building site constraint

All SUs must be located within the building site including all the vertices that construct each spatial unit. Following method is used to determine whether a point P is inside the building site or not. Therefore whether a SU is inside the BS can be determined by applying the method for four vertices of the SU.The twice area of ABP is given as,

$$\begin{vmatrix} x & y & 1 \\ x_A & y_A & 1 \\ x_B & y_B & 1 \end{vmatrix} = 2A \tag{4.17}$$

Where the equation returns a positive value meaning the point P is within the BS. If returns negative value by the equation, it means the point P is outside the BS (Figure 4.7).

The constraint equation is shown:

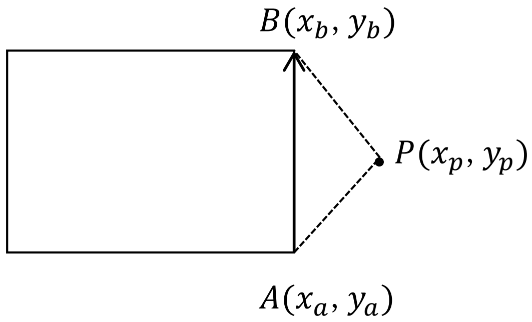

Figure 4.7: Judge whether a point P is within BuildingSite.

$$C_{WBS} = \sum_{AllSUs} \frac{A_{offsite}}{A_{SUs}} \times 100\% \tag{4.18}$$

Where C_{WBS} is the infeasibility value of the constraint, $A_{Offsite}$ is the SU areas falling off the BS. A_{SUs} is the total area of spatial units (Figure 4.8). The worst case will be all the SU are falling off the BS where make the infeasibility value equals to 1, while the best situation would be all the SUs are within the BS, making the infeasibility value equals to 0.

2: Non-overlapping constraints

A non-overlapping constraint means that the spatial units cannot overlap with each another; this constraint promises the area of each single SU not overlapped by other SU or corridor. Four possible scenarios of overlapping constraints is shown in Figure 4.9.

The Overlap constraint ensures that no two rooms occupy the same space.

$$|x_i - x_j| + |y_i - y_j| \geq 1 \forall i \neq j \tag{4.19}$$

Whether two SU are overlapping is tested by considering whether any two lines representing edges of the two SUs cross each other between the end points of both edges considered. However, an orientation as shown in the lower right corner in Figure 4.9, escapes this test. Therefore, method of cross product of vectors explained above is also

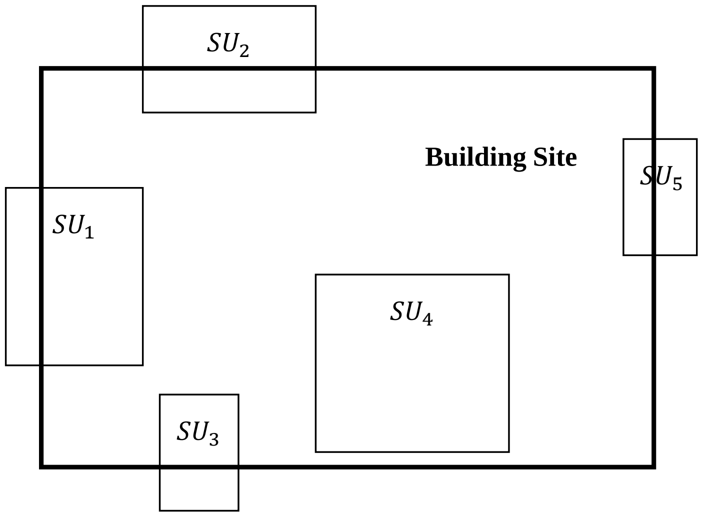

Figure 4.8: Calculate the areas of SU falling off the building site.

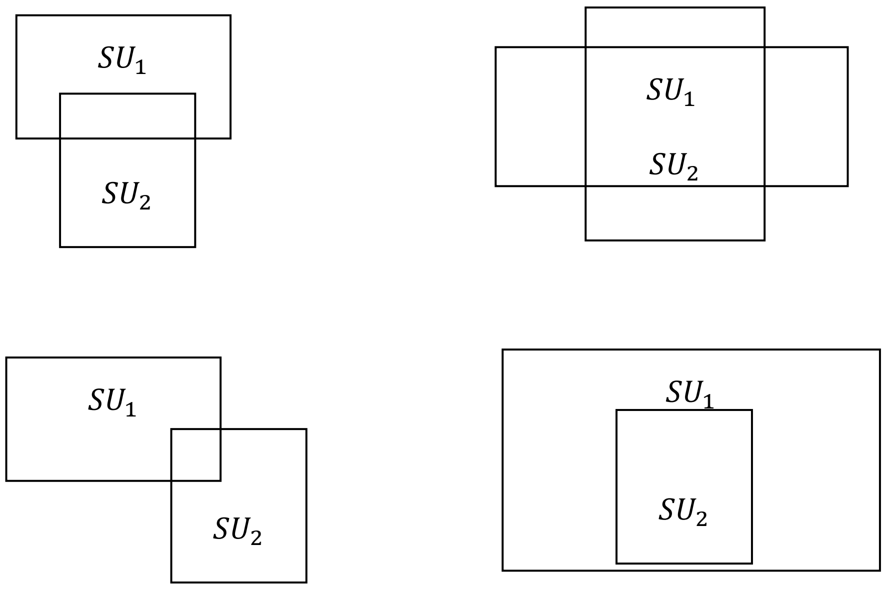

Figure 4.9: Possible cases of overlaps between spatial units.

used. Vertices of overlapped area are computed based on the type of overlap. Therefore, area of overlap is computed solely for SUs. It is derived from following general equation;

$$2Area(p_0, p_1, p_n) = \sum_{i=0}^{n-1}(x_i y_{i+1} - y_i x_{x+1}) \tag{4.20}$$

Where n is the number of vertices of overlapped area and $(x_i\ y_i)$ is the i^{th}vertex of overlapped region. The equation for non-overlapping constraint is expressed as,

$$C_{NOLP} = \sum_{AllSUs} \frac{A_{olp}}{A_{SUs}} \times 100\% \tag{4.21}$$

Where C_{NOLP} is the infeasibility value of non-overlapping constraint, A_{olp} is the overlapped area of one SU, A_{SUs} is the area of the SU.

Topological constraints

Topological constraints allow to specify adjacency, non-adjacency or proximity of a space with another space or with the corridor. Here we will discuss adjacency constraints and travelling distance as accessibility constraint is transformed as a special adjacency constraint.

3: Adjacency constraints

A large part of the work in building layout design is to find ways fixing the adjacencies between the rooms and the circulation or to fix a distance between two rooms (Medjdoub & Yannou, 2000). There are two important parameters in this constraint: The actual adjacency length l and the required minimum adjacency length h between two SUs.

As adjacency is defined as a existence of a common portion shared by two boundaries of the SUs (Figure 4.11). A similar judgement to the non-overlapping is introduced here, the first equation of the line is given as:

$$ax + by = h \tag{4.22}$$

Then a point P is on the line AB if it satisfies the equation, that $ax_p + by_p = h$. If the coordinates of A and B is given rather than given the equation, then an equation for the line segment can be derived as,

$$\begin{vmatrix} x & y & 1 \\ x_A & y_A & 1 \\ x_B & y_B & 1 \end{vmatrix} = 0$$

This gives the following coefficients for the equation: $\begin{vmatrix} x & y & 1 \\ x_A & y_A & 1 \\ x_B & y_B & 1 \end{vmatrix} = 2A$

$$a = y_A - y_B \tag{4.23}$$

$$b = x_A - x_B \tag{4.24}$$

$$h = x_B y_A - x_B y_B \tag{4.25}$$

Therefore only if the point P is on the line AB, then the area of A,B and P equals to zero. Then testing whether coordinates p_X, p_Y are between $x_a y_a$ and $x_b y_b$ (Figure 4.10).

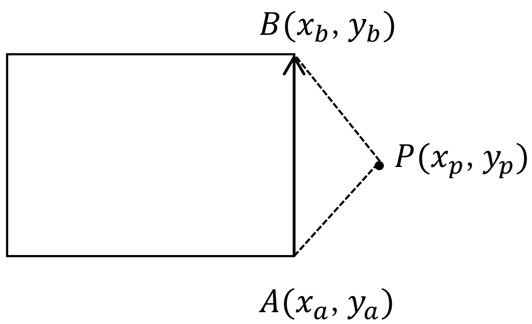

Figure 4.10: Judge whether a point P is on the line AB.

As defined earlier, there are two parameters in this constraint, h and l, which represents the actual adjacency length and the minimum required adjacency length respectively (Figure 4.11), the constraint infeasible function is expressed as,

$$C_{adj} = \sum_{AllSUs} (\frac{l-h}{l}) \times 100\% \tag{4.26}$$

Where the actual adjacency length is shorter than or equals to the required adjacency length, making the returned value between [0,1]. Once the actual adjacency length is longer than the minimum required adjacency, the returned negative value will be set into zero because it has met the adjacency requirement.

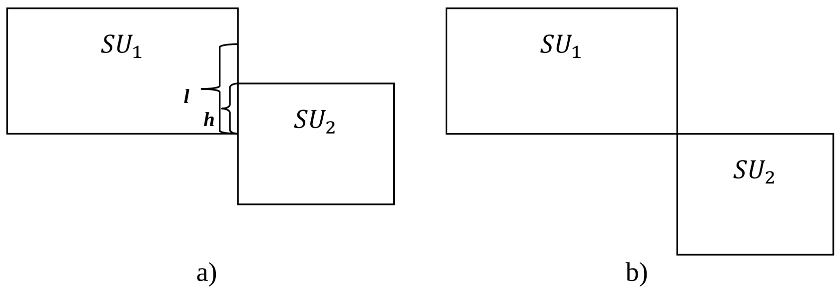

Figure 4.11: Adjacency lengths (actual and required).

Note that in this research we utilise a corridor to access different SUs, the corridor is treated as a special spatial unit with minimum length and width, and accessible requirements are predefined in the XML input file, all the SUs which have accessible requirements have to go via the corridor to other SUs, it is not considered as two adjacent SUs have accessibility property.

4: Travelling distance constraint

In the real optimisation problem, one question is to reduce the travelling distance, especially for the healthcare facilities (Evidence shows that nurses spend nearly half of their working time on the travelling among different rooms). Type of connection depends on required proximity between spaces. Level of proximity is measured in terms of travelling distance from one space to other. Liggett & Mitchell (1981) defined two ways calculating the travelling distance, one is sum the whole distance through the hallways and the other is sum of the direct distance from centre of one space to the other one. As we have defined the corridor property, occupants have only access other SUs along corridor, therefore we employ the first method. The travelling distance is measured from centre of one SU along straight line to the corridor then to the centre of the destination SU (Figure 4.12).

There are two parameters in the travelling distance constraint, one is the actual travelling distance D_h and one is minimum required travelling distance D_l which is predefined

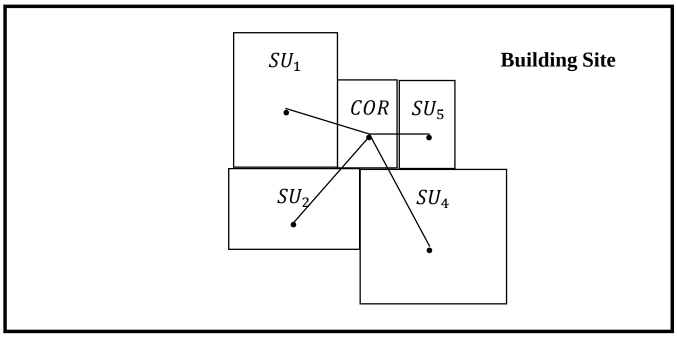

Figure 4.12: Calculating the traveling distance between SUs.

in the XML input file. The constraint infeasible function is expressed as,

$$C_{trd} = \sum_{AllSUs} (\frac{D_l - D_h}{D_l}) \times 100\% \tag{4.27}$$

Where the actual travelling distance is shorter than or equals to the required travelling distance, making the returned value between [0,1). Once the actual travelling distance is longer than the minimum required distance, the returned negative value will be set into zero because it has met the distance requirement.

4.7 Implementation of genetic algorithms/Suitability of GA application

Genetic algorithms has been applied by many researchers to solve optimization problems from a wide discipline (Ho & Ji, 2005; Jang *et al.*, 2007; Zouein *et al.*, 2002; Kochhar *et al.*, 1998; Rodrguez & Jarur, 2005). In this research, genetic algorithms are used as a functional optimizer seeking to improve performance by searching solution space that are likely to lead to optimum ones. In many optimization algorithms, they search better solutions by moving from one point in the decision space, using some transition rules to determine the next point (Osman *et al.*, 2003). This kind of method is dangerous due to the possibility for locating the wrong peaks in a multi peaks search space. In the contrary, GA has its primary advantage compared with conventional methods lies in its capacity to move randomly from one single solution to another, meaning that the algorithms simultaneously search widely separated peaks of the solution space in parallel to avoid getting stuck on local optima (Figure 4.13). This is due to the random elements in genetic operation and the fact that the algorithms search from a population of solutions rather than just a single one. These optimization qualities make the GA a robust problem solving method.

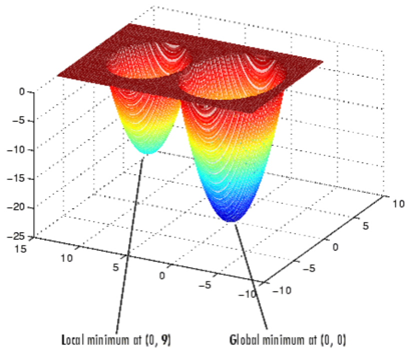

Figure 4.13: Local optima VS global optima.

And this is the main reason why we employ GA as the optimization method. The performance of GA is dependent on the SLP problem because the variable and objective setting and the representation scheme depend on the nature problem (Singh & Sharma, 2005).

Al-Tabtabai & Alex quoted in (Osman *et al.*, 2003) suggest that the use of GA in optimization is appropriate in the following circumstances

- Conventional statistical and mathematical methods are inadequate.
- The problem is very complex, because the possible solution space is too large to analyse the finite time.
- The additional information available to guide the search is absent or not sufficient, so conventional methods are no practical.
- The solution to the problem can be encoded in the form of strings and characters.
- The problem is large and poorly understood.
- There is an urgent need for near-optimal solutions to use as starting points for conventional optimization methods.

Three of the aforementioned points make the utilization of GA in solving this SLP problem very applicable. Firstly, when modelling a spatial layout with a number of SUs, the search space in quite immense due to the number of defined variables. The more SUs a layout constitute, the larger the feasible solution space becomes. Secondly, the solutions to this SLP problem are easily encoded in form of strings. Thirdly, finding a comprehensive solution to the SLP problem is a complex process, have many parameters taken into consideration. The variables, constraints make the optimization approach much complex to undertake and hard to get close to the optimum solution.

4.7.1 Adopting the genetic algorithm toolbox

The Genetic Algorithm Toolbox is a graphical user interface that enables one to use the genetic algorithm without working at the command line. One can apply the genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non-differentiable, stochastic, or highly non-linear. The important advantage of the genetic algorithm over the standard techniques is that it is able to find the global minimum, instead of a local minimum, and that the initial attempts with different starting point need not be close to actual values. Another advantage is that it does not require the use of the derivative of the function, which is not always easily obtainable.

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population:

1. Selection rules select the individuals, called parents that contribute to the population at the next generation.Selection of the fittest population is the cornerstone of the GA genetic operation (Osman *et al.*, 2003).There are four selection mechanisms dealt with the GA tool box: Roulette Wheel, SUS, Tournament WOR/WR and Truncation.

2. Crossover rules combine two parents to form children for the next generation. Four types of crossover are provided by GA tool box: OnePoint, TwoPoint, Uniform and SBX.

3. Mutation rules apply random changes to individual parents to form children. Three types of mutation are provided by GA tool box: Selective, Polynomial and Genewise.

To create the next generation, the genetic algorithm selects certain individuals in the current population, called parents, and uses them to create individuals in the next generation, called children. Typically, the algorithm is more likely to select parents that have better fitness values. The genetic algorithm creates three types of children for the next generation:

- Elite children are the individuals in the current generation with the best fitness values. These individuals automatically survive to the next generation.
- Crossover children are created by combining the vectors of a pair of parents.
- Mutation children are created by introducing random changes, or mutations, to a single parent.

The algorithm begins by creating a random initial population. The algorithm then creates a sequence of new populations, or generations. At each step, the algorithm uses the individuals in the current generation to create the next generation. To create the new generation, the algorithm performs the following steps: Scores each member of the current population by computing its fitness value. Scales the raw fitness scores to convert them into a more usable range of values. Selects parents based on their fitness. Produces children from the parents. Replaces the current population with the children to form the next generation. The algorithm stops when one of the stopping criteria is met.

The genetic algorithm uses the following five conditions to determine when to stop:

1. Generations – The algorithm stops when the number of generations reaches the value of generations.
2. Time limit – The algorithm stops after running for an amount of time in seconds equal to time limit.
3. Fitness limit – The algorithm stops when the value of the fitness function for the best point in the current population is less than or equal to fitness limit.
4. Stall generations – The algorithm stops if there is no improvement in the objective function for a sequence of consecutive generations of length stall generations.
5. Stall time limit – The algorithm stops if there is no improvement in the objective function during an interval of time in seconds equal to stall time limit.

4.8 Summary

Prototype of a space layout planning is developed by a problem formulation including a series of required constraints and objectives. Spatial Units (SU) are designed to surround the corridor for the purpose of accessibility. Spatial units are represented in rectangular spaces and the corridor is designed with one or two compartments. Variation of the corridor size will fit in the dimensional requirement to the building design. A prototype of automatic SLP was developed based on this problem formulation. GA tool box was applied to help search the optimum result. An integrated version of SLP was developed by integrating the results from questionnaire findings. Evaluation and further improvement of the performance of the prototype are explained in the Chapter Six.

Chapter 5

Results and discussion: User perception studies

Results from the implementation of the framework during investigation of user perception with regards to the layout design are described and analysed in this chapter. As illustrated in the chapter of methodology, the questionnaire survey was conducted among three groups of participants: care providers, outpatients and inpatients. Hence, this chapter mainly demonstrate the categorised results and discussions among these three grouped participants respectively. Descriptive analysis and PCA analysis are carried out and relationships between personal information with their perception of the physical layout is investigated. The rest of the chapter discusses perceptions from three group of participants on the corresponding environmental design factors.

5.1 Care providers perception on working environment design factors

5.1.1 Respondents characteristics

Demographic and work related characteristics of the respondents are given in Table 5.1. Among 304 surveyed healthcare providers, 110 (36.2%) were male and 194 (63.8%) were female. Almost half of the respondents (46.1%) were aged between 26 and 35 years whereas the percentages of respondents at either ends of the population were 17.1% and 3.9% for age groups 18-25 and above 50 years, respectively. The percentage of younger female staff is representative of health labor markets in most countries where female nurses make up the majority of the staff (Zurn *et al.*, 2004). At the time of the survey 31.6% and 34.9% of the respondents had been working in respective hospitals for periods 1 to 5, and 6 to 10 years, respectively. Majority of them (72.4%) worked between 40 and 60 hours per week while only 4.6% of the respondents worked more than 60 hours per week. The department of general surgery represents the highest number (13.8%) of returned questionnaires. Other respondents came from the remaining 26 departments across the hospitals. The diversity of different working areas ensured that a wide range of respondents was represented in this study.

5.1.2 Results of PCA analysis and reliability test

A principal component analysis (PCA) was conducted on the 16 questionnaire items with varimax rotation. The Kaiser-Meyer-Olkin (KMO) (Kaiser, 1974) measure verified the sampling adequacy for the analysis, KMO= 0.883, which can be considered high (Field, 2009). Bartlett's test of sphericity yielded a statistically significant value (Chi-square= 2255.424; p=0.000). These indices implied that the matrix was well suited for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Three components had eigenvalues over Kaiser's criterion of 1 and in combination explained 58.4% of the variance. Given the large sample size, and the convergence of the scree plot and Kaiser's criterion on three components, this is the number of components that were retained in the final analysis. Table 5.3 shows the factor loadings after rotation. The PCA result suggests that component 1 represents spatial design aspects; component 2 represents environmental design aspects; and component 3 represents the design for maintenance aspects.

Table 5.1: Background information of the care providers.

Variable	**Scale/category**	*N*	%
Age (yr)	18-25	52	17.1
	26-35	140	46.1
	36-50	100	32.9
	>50	12	3.9
Gender (-)	Male	110	36.2
	Female	194	63.8
Working hour (hr)	<20	2	0.7
	20-40	68	22.3
	40-60	220	72.4
	>60	14	4.6
Length of service (yr)	<1	33	10.9
	1-5	96	31.5
	6-10	106	34.9
	>10	69	22.7
Department	Accident and emergency	14	4.6
	Administration	35	11.5
	Burns	5	1.6
	Cardiac	17	5.6
	Chest surgery	9	3.0
	Chinese medicine	6	2.0
	Clinical pharmacology	12	3.9
	Critical care (ICU/HDU)	10	3.3
	Dermatology	3	1.0
	Elderly care	2	0.7
	Gastrointestinal	11	3.6
	General surgery	42	13.8
	Hematology	15	4.9
	Hepatology	6	2.0
	Incretion	1	0.3
	Infectious diseases	3	1.0
	Management	12	3.9
	Midwifery	11	3.6
	Neurosurgery/neurology	6	2.0
	Operating theaters	6	2.0
	Orthopedics	17	5.6
	Ophthalmology	3	1.0
	Pediatrics/ neonatal	4	1.3
	Respiratory	24	7.9
	Stomatology	2	0.7
	Urology	14	4.6
	X-Ray/pathology	14	4.6

Table 5.2: Descriptive analysis (care providers).

Questionnaire item	Response* (%)					Mean	SD
	1	2	3	4	5		
Cleanliness and ease of maintenance	0.0	0.0	2.3	29.6	68.1	4.66	0.522
Air quality and freshness†	0.3	0.7	6.3	45.4	47.4	4.39	0.666
Noise level	0.3	1.0	9.2	43.4	46.1	4.34	0.713
Thermal comfort	0.0	1.0	10.2	48.0	40.8	4.29	0.685
Proximity to wards	0.0	1.6	9.9	46.7	41.8	4.29	0.709
Provision for hand hygiene	0.0	3.3	10.9	49.0	36.8	4.19	0.757
Adequate illumination‡	0.0	0.7	13.2	55.6	30.6	4.16	0.663
Availability of daylight	0.0	1.0	17.1	57.2	24.7	4.06	0.675
Spaciousness	1.1	1.1	20.4	52.0	25.7	4.00	0.769
Location and orientation of the space	0.3	2.6	27.0	51.6	18.4	3.85	0.754
Architectural design of the space	0.0	5.3	27.3	50.0	17.4	3.80	0.786
Pleasant color scheme	0.0	5.3	33.6	48.7	12.5	3.68	0.757
Exterior view from the space	1.3	4.9	32.2	49.3	12.2	3.66	0.804
Furniture layout	1.0	5.6	39.1	47.7	6.6	3.53	0.744
Indoor plants, interior/exterior landscaping	0.0	7.6	39.5	46.7	6.3	3.52	0.726
Presence of coordinated art objects	1.0	11.5	42.1	41.4	3.9	3.36	0.775

Notes:
*1: Least important; 2: Unimportant; 3: Neutral; 4: Important; 5: Very important.
†Defined as the absence of unpleasant smell.
‡Overall lighting: artificial and natural lighting combined.

The reliability of each attribute was examined by the Cronbach's alpha coefficients. The reliability estimates of all three components were greater than 0.70 as shown in Table 5.3, indicating a strong internal reliability among items with the same attributes. The internal consistency reliability of the overall scale was 0.901 that exceeded Nunnally's criteria, suggesting little measurement error in the instrument. Table 5.3 also shows that the factor loads explain 58.4 percent of the total variance after varimax rotation. According to the results, nearly half of the total variance (40.837%) is explained by the component 1, special design aspects, and the rest of the total variance was explained by the remaining two components.

Table 5.3: Rotated component matrix of questionnaire items (care providers).

Item	Component		
	Spatial	Environmental	Maintenance
Indoor plants, interior/exterior landscaping	0.729	–	–
Furniture layout	0.715	–	–
Exterior view from the space	0.713	–	–
Presence of coordinated art objects	0.699	–	–
Pleasant color scheme	0.699	–	–
Architectural design of the space	0.658	–	–
Location and orientation of the space	0.647	–	–
Adequate illumination	–	0.753	–
Availability of daylight	–	0.737	–
Thermal comfort	–	0.726	–
Noise level	–	0.694	–
Air quality and freshness	–	0.682	0.408
Provision for hand hygiene	–	–	0.746
Proximity to wards	–	–	0.643
Cleanliness and ease of maintenance	–	0.449	0.522
Spaciousness of working areas	0.475	–	0.487
Percentage of explained variance (58.4)	40.83	11.12	6.4
Cronbach's alpha coefficient (0.901)	0.863	0.852	0.736

5.1.3 Relationship of personal information and perception of design factors

Before investigating the relationship between respondent characteristics and perception of design factors, respondents were regrouped to simplify the data analysis and interpretation. A small number of staff worked less than 20 hours per week; therefore, the variable 'working hours' was rescaled to have the ranges: less than 40 hours, between 40 and 60 hours and longer than 60 hours. The rescaled working hours variable corresponded to a short, medium and long period of working time. Similarly, the variable 'age' was re-categorized to indicate the ranges: young (18-35 years), middle aged (36-50 years) and senior staff (older than 50 years).

Table 5.4: Non-parametric test result (care providers).

Questionnaire item	***p*-value**			
	Gender†	Age‡	Working hours‡	Length of service‡
Spatial				
Indoor plants, interior/exterior landscaping	0.529	0.258	0.297	0.047*
Furniture layout	0.111	0.075	0.726	0.038*
Exterior view from the space	0.904	0.355	0.471	0.115
Presence of coordinated art objects	0.672	0.890	0.593	0.694
Pleasant color scheme	0.222	0.060	0.118	0.642
Architectural design of the space	0.684	0.047*	0.835	0.064
Location and orientation of the space	0.251	0.028*	0.079	0.052
Environmental				
Adequate illumination	0.979	0.123	0.020*	0.332
Availability of daylight	0.839	0.116	0.033*	0.619
Thermal comfort	0.141	0.334	0.027*	0.991
Noise level	0.037*	0.047*	0.326	0.494
Air quality and freshness	0.038*	0.623	0.089	0.688
Maintenance				
Provision for hand hygiene	0.036*	0.868	0.259	0.155
Proximity to wards	0.130	0.346	0.025*	0.001*
Cleanliness and ease of maintenance	0.030*	0.833	0.087	0.062
Spaciousness	0.987	0.005*	0.028*	0.367

Notes:
†Mann-Whitney U-test.
‡Kruskal-Wallis test.
$^*p < 0.05$.

Non-parametric tests are carried out on 16 questionnaire items and reported in Table 5.4. Results show that there is a significant difference in perceptions between male and female healthcare providers in the cases of cleanliness and ease of maintenance; air quality and freshness; noise level and provision for hand hygiene. Age has significant effect on the perception of the following design factors: noise level; spaciousness; location and orientation of the space and architectural design of the space. The perception of the factors: thermal comfort; proximity to wards; adequate illumination; availability of daylight and spaciousness is significantly influenced by working hours per week. This translates to 5 out of 9 items in components 2 and 3 (i.e., environmental and maintenance), demonstrating the importance of the number of hours worked per week on perceptions of maintenance and environmental design factors. There is also a significant difference in the perception of factors: indoor plants, interior/exterior landscaping; furniture layout and proximity to wards between different groups of respondents, based on their length of service. The design factor, proximity to wards has a high level of significance, $p < 0.001$.

5.1.4 Discussion

Healthcare providers are key stakeholders and critically important informants in the process of design and refurbishment of healthcare facilities. Their perceptions of physical environment features are based on their observation of and interaction with hospital spaces over their working life. All of the 16 investigated design aspects were ranked relatively high with mean scores ranging between 3.36 and 4.66, from the lowest to the highest, on a scale of 1 to 5. Overall, 'cleanliness and ease of maintenance' was considered to be very important and had the highest mean score (= 4.66) and lowest standard deviation (= 0.522). The item, 'presence of coordinated art objects' was considered to be the least important of the analysed design aspects. In terms of constructed dimensions, the respondents appear to be more concerned about the environmental and maintenance design factors, compared to spatial design. This is evident in Table 5.2, where all of the nine items under environmental and maintenance design dimensions topped the list with a minimum mean score of 4.00.

The overall findings agree with conventional wisdom and results from past research on quality of care and user satisfaction, the closely aligned topics of research to the present study. Cleanliness is routinely reported in literature as one of the most important attributes of a healthcare environment and has the potential to influence care quality and staff and patient well-being. Although, there exists a greater need for cleanliness in departments such as surgery, emergency and intensive care units where patients are more vulnerable to the risk of infection (Lavy & Dixit, 2010), it is also important in lower risk areas such as care homes. In a review of service users' expectations of inpatient mental health care, Hopkins *et al.* (2009) identified cleanliness as an important aspect along with comfort. In a recent article, Dancer (2011) noted the emergence of evidence on the importance of the clinical environment in encouraging hospital infection. Given the wide-ranging surfaces, equipment and building design, the article argued for a tailored approach towards cleanliness. Cleanliness in the hospital environment has also been linked with the recruitment, retention and performance of nurses in the UK National Health Service (NHS) (PricewaterhouseCoopers LLP, 2004).

In terms of mean response scores, 'air quality and freshness' was ranked as the second most important item. Air quality has previously been associated with user satisfaction (PricewaterhouseCoopers LLP, 2004), staff performance (Seppnen *et al.*, 2006) and the prevention of nosocomial infections among staff and patients (Leung & Chan, 2006). Gosden *et al.* (1998) discussed the importance of air quality in infection control by citing examples of how small numbers of organisms could cause orthopaedic implant infections, giving rise to a considerable degree of morbidity and mortality. Leung & Chan (2006) noted that parameters of indoor air quality (IAQ) were well understood in commercial and public buildings and how these could adversely affect occupant health, with conditions ranging from sick building syndrome (SBS) to building related illnesses (BRI) such as pneumonitis and cancers. IAQ, to a large extent, depends on the rate of outdoor/fresh air flow, a higher rate of which is more efficient in diluting the concentration of odour and volatile organic compounds (VOC). In a review of published sources that investigated the link between ventilation rates and staff performance, Seppnen *et al.* (2006) noted that in all of the reviewed cases higher ventilation rates resulted in higher performance.

'Noise level' has been rated as the third most important design aspect by the respondents. The impact of noise pollution on both the patient and healthcare providers has been extensively studied in critical care units and other healthcare areas. Patients' well-being and their health outcomes are found to be affected by higher levels of noise because of poor sleep quality (Freedman *et al.*, 1999) and increased stress. In the case of healthcare providers, noise pollution increases the probability of errors and is one of the risk factors for provider burnout (Tijunelis *et al.*, 2005). It is widely acknowledged that sound levels higher than 55 dBA brings disturbing effect (Beranek, 1971). The Environmental Protection Agency (EPA) in the United States recommends that the ambient noise level in a hospital should not exceed 40 dB. However, many studies suggest that the exceedance of the recommended level of ambient sound levels is common (Busch-Vishniac *et al.*, 2005; Soutar & Wilson, 1986).

'Thermal comfort' is considered by the respondents to be the fourth most important aspect. The sensation of comfort is dependent on many physical and psycho-physiological variables such as indoor air temperature, metabolism, clothing insulation, ability to modify/control the indoor environment, etc. (De Dear, 2004). The effect of physical environment aspects on thermal comfort is more pronounced for naturally ventilated buildings, compared to fully air-conditioned buildings. Thermal comfort is also indirectly linked with indoor air quality in the sense that increased ventilation helps in diluting odour and VOC, as well as in bringing down indoor temperatures to a comfortable level.

The order of importance of the remaining environmental and maintenance design factors is as follows: 'proximity to wards', 'provision for hand hygiene', 'adequate illumination', 'availability of daylight' and 'spaciousness'. All of the architectural design aspects were ranked lower than environmental and maintenance design aspects, with mean scores ranging from 3.36 for 'presence of coordinated art objects' to 3.85 for 'location and orientation of the space'. The fact that mean scores for all spatial design aspects were lower than 4.00 indicates that the respondents considered them to be important but not as important as environmental and maintenance design factors. Aspects related to various environmental stimuli such as art objects, indoor plants and interior/exterior landscaping were considered to be of low importance, as shown in Table 5.2. The effect of such stimuli on staff and patient well-being and patient recovery have been found to be positive in past research (Dijkstra *et al.*, 2006; Golden *et al.*, 2005; Ulrich, 1984; Ulrich *et al.*, 2005). However, their relatively low ranking in this research may be due to the fact that previous research looked at individual aspects, rather than the integrated whole, as is the case in this research. Another reason may be that the respondents did not make a strong connection between abstract environmental stimuli and staff performance and/or patient outcomes. Further research is, therefore, necessary to investigate the low mean scores of spatial design aspects.

Of the four demographic and work related variables investigated in detail in this study, working hours per week explained significant differences in perception of several of the maintenance and environmental design factors. Women were found to be more perceptive of sense-sensitive (Mazuch & Stephen, 2005) design factors such as the ones related to five senses: smell, taste, sight, feel and hearing. Mean scores by female staff were higher than their male counterparts on cleanliness and ease of maintenance (mean score of 4.71 vs. 4.56); indoor air quality and freshness (4.44 vs. 4.30); noise level (4.40 vs. 4.23); and provision for hand hygiene (4.27 vs. 4.05). This result is in accordance with previous research, which indicated that females showed greater sensitivity and/or physiologic responsiveness to stimuli in a number of sensory modalities, in particular in olfactory sensitivities, than males (Velle, 1987). Women are also reported to suffer from sick building syndrome (SBS) more often than men (Brasche *et al.*, 2001). In

Chinese culture, women take more responsibility for environmental cleanliness at home, which may account for and translate into them having a higher expectation of cleanliness than men. In other words, females expect cleaner and quieter environments to focus on work. Nursing stations and patient rooms are their primary working locations where a minimum level of noise and better air quality and freshness are highly demanded. All six interviewed nurses expressed their preference for design for cleanliness that eliminates clutter and helps them care for patients more effectively.

In addition, the research has identified different perceptions of design factors between respondents who worked less than or equal to 40 hours a week than the staff who worked more hours per week. Respondents who worked less than or equal to 40 hours represent the working pattern of the majority of the staff in the two hospitals. They considered 10 out 16 investigated design factors to be more important than the other groups. The 10 design factors came from all three principal components: spatial, maintenance and environmental design and included both the highly ranked ones (e.g., proximity to wards) as well as the factors with low mean scores (e.g., presence of coordinated art objects). In comparison, respondents who worked 41-60 hours per week considered the following design factors to be more important than the others: cleanliness and ease of maintenance (mean score of 4.68); Noise level (4.35); Adequate illumination (4.18); Pleasant color scheme (3.7); Indoor plants, interior/exterior landscaping (3.55) and Furniture layout (3.54). Exterior view from the space had an equal mean score of 3.68 from the respondents who worked less than or equal to 40 hours per week and the respondents who worked between 41 and 60 hours per week. Findings related to 'working hours' can be used for designing departments with varying work patterns; e.g., inpatients vs. outpatients.]

Among the spatial design factors, 'location and orientation of a space' was rated higher by the respondents than most of the other factors in the category. This may be due to the cultural preference of the Chinese for coordinated location and orientation of a space and furniture within. Evidence of locational preference can be seen in the ancient Chinese wisdom called Feng Shui, which was based on the observation of astronomical phenomena, natural phenomena and human behaviour (Mak & Thomas Ng, 2005). These three aspects were combined with Chinese astronomy, geography and philosophy to devise rules for the design of spaces, buildings and cities. Interviewed nurses also stated their preferences for a better orientation of the space they worked in. Some of the comments in the returned questionnaires also support this finding; e.g., one responded commented ...[I] prefer to work in a south-faced room with more natural light....

Nurses described their preferences for the design of nursing stations in both the questionnaire and interview. They noted that the design of nursing stations could be such that there was a degree of acoustic separation between their working areas and adjoining corridors and patient areas. In essence, they referred to the ambient noise level, which could be brought down through careful design. The preference for better acoustic design was mentioned often by nurses working in departments such as accident and emergency where there were increased interactions with patients and families. This is an interesting finding, which illustrates the multi-dimensional and multi-objective nature of architectural design. From a spatial design perspective, visual and auditory links need to be maintained between nursing stations and patient areas for effective care delivery, which may contribute to an increased noise level. At the same time, staff working in these areas need a quiet space to concentrate on work. The use of hard surfaces (for easy cleaning and better control of infection) adds to this problem as they reflect sound and, therefore, contribute to the ambient noise level. The 'push and pull' between the aforementioned design objectives: efficient care delivery, reduction of noise and cleanliness serve to illustrate the challenges in integrating user perception in design. With the increase in the number of design variables (i.e., factors or aspects) and goals, the reconciliation between conflicts becomes complicated, rendering the conventional 'cognitive' and 'trial and error' approach inefficient for effective decision making.

5.2 Outpatients perception on waiting areas design factors

5.2.1 Respondents' characteristics

Demographic and other clinical information from the respondents are given in Table 5.5. Among 337 surveyed outpatients, 124 (36.%) were male and 213 (63.2%) were female. More than half of the male respondents were aged between 26 and 35 years following by 30 male respondents aged between 36 and 50 years old, with 14 and 16 respondents were older than 50 and aged between 18 and 25 years respectively. Similarly, majority of female respondents aged between 26 and 35 years with only 15 female participants are older than 50. Males visited the hospital less frequently than females, table shows 66.1% of male respondents have visited the hospital more than twice compared with a higher ratio of 77.5% in female. Only 7 male respondents visited the hospital during emergency, all other

Table 5.5: Demographic information of outpatients.

Variable	Scale	Male	Female	p value	Total
Age (yr)				0.019†	
	18-25	16	51		19.9
	26-35	64	84		43.9
	36-50	30	63		27.6
	>50	14	15		8.6
Number of visit (-)				0.136†	
	1-2	42	48		26.7
	3-4	37	71		32.0
	5-10	21	39		17.8
	>10	24	55		23.4
Appointment type				< 0.001†	
	Emergency	7	0		2.1
	Pre-arranged	117	213		97.9
Department				< 0.001†	
	Accident and emergency	0	4		1.2
	Burns	0	2		0.6
	Cardiac	0	2		0.6
	Chest surgery	5	11		4.7
	Chinese medicine	4	2		1.8
	Dermatology	0	8		2.4
	Elderly care	2	0		0.6
	Gastrointestinal	6	16		6.5
	General surgery	35	44		23.4
	Gynaecology	0	22		6.5
	Haematology	0	4		1.2
	Incretion	1	0		0.3
	Midwifery	0	2		0.6
	Neurosurgery/neurology	2	6		2.4
	Operating theaters	2	6		2.4
	Orthopedics	4	16		5.9
	Otolaryngology	4	2		1.8
	Ophthalmology	11	25		10.7
	Pediatrics/neonatal	2	4		1.8
	Respiratory	30	29		17.5
	Stomatology	12	8		5.9
	Urology	4	2		1.8

Note:
† Chi-square table test.

outpatients pre-arranged their visits. Outpatients were selected from 22 departments across the hospitals, the department of general surgery and respiratory represent higher number of returned questionnaires than other departments. The diversity of different departments ensured a wide range of respondents were represented in the study.

5.2.2 Principal component analysis

An exploratory factor analysis was carried out by performing a principal component analysis (PCA) with an orthogonal varimax rotation for the 16 individual items at a significance level 0.001. Factor solution was based on the Bartlett's test showing a significant correlation between items (Chi-square = 2444.295; $p<0.001$) and the Kaiser-Meyer-Olkin test for sample adequacy measuring 0.838 ("great" according to (Field, 2009)). These indices implied that the matrix was well suited for factor analysis. An initial analysis was run to obtain eigenvalues for each component in the data. Five summated indices from the 16 question items that had eigenvalues greater than 1.0 represented five different scales. Factor 1 consisted of 4 items accounting for 34.7% of the variance, factor 2 represented 4 items accounting for 14.7% of the variance, factor 3 had 4 items which accounted for an additional 8.5% of the variance. Factor 4 and 5 both had 2 items accounted for 6.8% and 6.2% of the variance respectively. The total variance is 71.2%. Given the large sample size, and the convergence of the scree plot and Kaiser's criterion on five components, this is the number of components that were retained in the final analysis. Table 5.7 shows the factor loadings after rotation. These five scales were identified as general environment, facilities, spatial environment, lighting environment and seating environment.

5.2.3 Internal consistency reliability

The reliability of each attribute was examined by the Cronbach's alpha coefficients. The obtained values of the reliability estimates were all greater than 0.70 as shown in Table 5.7, indicating a strong internal reliability among items with the same attributes. The Cronbach's alpha coefficient for the overall scale was 0.870. Table 5.7 also shows the internal consistency reliability level (Cronbach's alpha coefficients) for each generated factor that 0.792 for environmental design, 0.768 for facility design, 0.748 for spatial design, 0.850 for lighting design and 0.714 for seating design. Combined, these five factors explained 70.2% of all variables.

Table 5.6: Descriptive analysis (outpatients).

Questionnaire item	Response* (%)					Mean	SD
	1	2	3	4	5		
Architectural design of the space	0.6	5.3	40.1	34.4	19.6	3.67	.870
Pleasant colour scheme	1.2	7.7	40.9	38.6	11.6	3.52	.842
Spaciousness	1.2	1.5	23.1	52.2	22.0	3.92	.783
Indoor plants, interior/exterior landscaping	2.7	8.0	42.7	39.5	7.1	3.40	.840
Presence of coordinated art objects	3.9	16.9	44.5	26.4	8.3	3.18	.943
Seating sufficiency (adequate number of seats)	0.3	0.6	12.8	53.7	32.6	4.18	.689
Seating comfort	0.9	4.5	29.1	38.6	27.0	3.86	.896
Exterior view	2.4	11.3	50.4	30.0	5.9	3.26	.825
Availability of daylight	0.0	1.5	28.2	50.7	19.6	3.88	.725
Adequate illumination†	0.0	1.5	23.4	45.4	29.7	4.03	.769
Furniture layouts	3.9	8.9	57.3	26.4	3.6	3.17	.789
A thermally comfortable environment	0.0	0.6	12.8	53.1	33.5	4.20	.671
Noise	0.0	2.1	13.9	34.1	49.9	4.32	.789
Air freshness (absence of unpleasant smell)	0.0	0.0	5.9	35.3	58.8	4.53	.607
Cleanliness	0.0	0.0	3.6	37.7	58.8	4.55	.565
Entertainment facilities	1.2	21.1	49.3	23.4	5.0	3.10	.828

Notes:
*1: Least important; 2: Unimportant; 3: Neutral; 4: Important; 5: Very important.
†Overall lighting: artificial and natural lighting combined.

5.2.4 Relationship of personal information and perception of design factors

Non-parametric tests are carried out on 16 questionnaire items as shown in Table 5.8. Results show that there is a significant difference in perception between male and female outpatients in the general environment including air freshness, cleanliness and noise. Age has significant effect on the perception of both general and seating environments. People don't have significant difference in perception in terms of the appointment type, however, the findings suggest the times outpatients visit the hospital has influenced their perception of spatial environment and seating environment, which represent 6 over 16 items in the whole questionnaire.

Table 5.7: Rotated component matrix of questionnaire items (outpatients).

Item	Component				
	General	Facilities	Spatial	Lighting	Seating
Air freshness(absence of unpleasant smell)	0.856	-	-	-	-
Cleanliness	0.833	-	-	-	-
Noise	0.719	-	-	-	-
Exterior view	-	0.805	-	-	-
Presence of coordinated art objects	-	0.781	-	-	-
Indoor plants, interior/exterior landscaping	-	0.696	-	-	-
Entertainment facilities	-	0.574	-	-	-
Furniture layouts	-	-	0.791	-	-
Architectural design of the space	-	-	0.755	-	-
Pleasant colour scheme	-	-	0.669	-	-
Spaciousness	-	-	0.566	-	-
Availability of daylight	-	-	-	0.792	-
Adequate illumination	-	-	-	0.720	-
A thermally comfortable environment	-	-	-	0.574	-
Seating sufficiency(adequate number of seats)	-	-	-	-	0.805
Seating comfort	-	-	-	-	0.773
Cronbach's alpha coefficient (0.870)	0.792	0.768	0.784	0.850	0.714
Percentage of explained variance (71.2)	34.714	14.713	8.482	6.819	6.437

5.2.5 Discussion

Among the dimensions of the waiting environment evaluated by 337 outpatients, cleanliness (mean = 4.55) was ranked as the most important indicator, followed by air freshness (mean = 4.53) and noise (mean = 4.32), entertainment facilities (mean = 3.10) was the least important indicator in the overall waiting environment, whereas the furniture layouts (mean = 3.17), presence of coordinated art objects (mean = 3.18) were ranked as the bottom three (Table 5.6). The reason of relatively low scores in these three items may due to the physical situation in both surveyed hospitals, on one hand, there are a big number of outpatients everyday (average number of daily hospital outpatient visits was nearly 1500 in the surveyed departments) and the waiting rooms are always full with patients and their families, some patients even have to wait outside in the corridor. All the patients are waiting to meet care providers in queue. Not like some hospitals in developed countries, equipped with electronic queuing system to display patient numbers in flat screen. The outpatients in the surveyed hospital have to pay more attention on the callings rather than entertain themselves. On the other hand, some outpatients suffered

Table 5.8: Comparison of mean PCA scores between demographic variables (outpaient).

Variable	Category	General	Facilities	Spatial	Lighting	Seating
Gender	Male	4.31(0.53)	3.22(0.64)	3.56(0.66)	3.89(0.68)	4.01(0.69)
	Female	4.45(0.52)	3.24(0.67)	3.57(0.63)	3.99(0.72)	4.01(0.71)
	p-value†	**0.046***	0.703	0.929	0.184	0.952
Age (years)	18-25	4.34(0.55)	3.30(0.61)	3.59(0.67)	3.95(0.72)	4.14(0.77)
	26-35	4.45(0.51)	3.30(0.69)	3.66(0.64)	4.04(0.65)	4.12(0.67)
	36-50	4.42(0.52)	3.16(0.53)	3.47(0.54)	3.92(0.72)	3.87(0.64)
	>50	4.19(0.56)	3.00(0.91)	3.37(0.81)	3.69(0.82)	3.69(0.77)
	p-value‡	**0.002***	0.169	0.265	0.839	**0.007***
Appointment type	Emergency	4.57(0.35)	3.54(0.70)	4.03(0.47)	4.57(0.53)	4.36(0.56)
	Pre-arranged	4.39(0.53)	3.23(0.66)	3.56(0.64)	3.95(0.70)	4.01(0.71)
	p-value†	0.978	0.329	0.071	0.109	0.562
Number of visit	1-2	4.51(0.51)	3.31(0.66)	3.64(0.67)	4.11(0.75)	4.14(0.69)
	3-4	4.39(0.52)	3.31(0.64)	3.70(0.62)	4.02(0.68)	4.11(0.71)
	5-10	4.30(0.64)	3.10(0.79)	3.38(0.59)	3.85(0.79)	3.86(0.76)
	>10	4.36(0.43)	3.16(0.55)	3.45(0.62)	3.79(0.55)	3.89(0.64)
	p-value‡	0.143	0.774	**0.008***	0.755	**0.010***

Notes:
†Mann-Whitney U-test
‡Kruskal-Wallis test
*p<0.05

from illness and had no mood watching TV or reading newspapers at all. However, although most outpatients didn't consider entertainment facility and art objects in hospital as important as other aspects, they are welcomed in some inpatient unit design (Dobrohotoff & Llewellyn-Jones, 2011) and are suggested to supply newspaper or magazines to improve the entertainment in some particular department (Walsh & Knott, 2010).

Results also show that the overall rating scores are quite high ranging from 3.10 to 4.55, indicating the importance of questionnaire items of which very few items were evaluated as unimportant and least unimportant. 6 out of 16 items had mean scores higher than 4 (=important) and the remaining 10 items all had mean scores higher than 3 (= neutral). In terms of constructed dimensions, sensory design, seating design and design of lighting and thermal environment were more concerned by respondents since all the items under these dimensions were listed in the highest 9 mean scores (8 out of 9), compared with design of spatial and facilities dimensions.

From the results of surveyed items, relatively high rating scores indicate respondents prefer more natural daylight and adequate illumination when they are waiting for the doctors. A large body of evidence show that exposure to bright artificial light and daylight is effective in reducing depression and improving patients' mood (Ulrich *et al.*, 2008). Further researches indicate the exposure to light is critical to patient health and wellbeing as well as staff in healthcare settings (Campbell *et al.*, 1988; Shikder *et al.*, 2011; Lockley *et al.*, 2007). However, excessive daylight can also cause visual discomfort through glare and distraction, which matters the design of room windows. A big window size could let more daylight come in and at the same time will consume more energy in heating or cooling. Therefore, it is a trade-off in designing the window area and providing enough daylight in the room.

Mean scores received from female outpatients were higher than male in most of the surveyed items except architectural design of the space (mean scores 3.61 vs. 3.78); indoor plants, interior/exterior landscaping (3.39 vs. 3.43) and seating comfort (3.85 vs. 3.89). Result from non-parametric test shows there is a significant difference of perspectives on sensory design aspect between male and female. Female respondents highly evaluated the importance of air freshness (4.55) and cleanliness (4.60). It is a fairly natural response because these two items are frequently reported in literature as most important attributes of a physical environment. Also, women in China are more responsible in housing and cleaning than men, which may leads to higher expectation of the environment they spend hours staying in. Cleanliness is also considered the most important as it was ranked the first place in the mean scores of respondents' perspectives. Such result is in line with another study conducted by the authors in which cleanliness was ranked the 1st place with regards to the hospital accommodation environment by a group of surveyed inpatients and care providers (Mourshed & Zhao, 2012; Zhao & Mourshed, 2012). Similar result was also found by Shah & Dickinson (2010), they investigated what factors patients may consider when they choose hospitals and what weight of the factors when they make decisions. Result from their study showed hospital cleanliness was the most important factor following by hospital reputation and other 7 factors. For patients, cleanliness is inexorably related with healthcare associated infections (HAIs) (Shah & Dickinson, 2010), and it is therefore necessary for any healthcare facility maintain a high standard of cleanliness.

Noise is the most frequently studied environmental factor in hospitals that relates to both patient and care providers (Ulrich *et al.*, 2008). Hagerman *et al.* (2005) found a relationship between the noise level in patient room and patient satisfaction. They also found a bad acoustics environment is likely to produce a bad working environment for staff that could adversely affect the patients (Hagerman *et al.*, 2005). Males and females have different perspectives to the ambient environment as a fact that males might be more tolerant than females (Yu & Kang, 2008). This argument is supported in this study that females consider noise is more important in the hospital design than their male counterparts (4.40 vs. 4.18).

Analysed result (Table 5.8) also shows that female are more perceptive than men on the sum-mated five factors except they have same mean score on seating environment (4.01 vs. 4.01). Significant difference in perspectives based on gender was found for sensory design within the constructed dimensions. Female considered that sensory design (air freshness, cleanliness and noise) to be more important (mean score= 4.45) than male (mean score= 4.15). This result suggests women are more perceptive of overall sense-sensitive design factors which are in accordance with previous research showing women have greater sensitivity in sensory factors than men (Velle, 1987; Feine *et al.*, 1991; Fillingim & Maixner, 1995). Respondents were categorised in appointment types in this research: prearranged and emergency. Result showed that appointment type did not significantly affect outpatients' response on the importance of the five design factors. However, it is noticed that emergently admitted outpatients evaluated higher mean scores on the five dimensions than those outpatients who were admitted non-emergently. There is a significant difference in respondents' perspectives based on age for the dimensions of sensory and seating design. In this study, seating dimensions include two indicators: seating sufficiency and seating comfort. Results show that the younger respondents thought seating dimension more important than older respondents, in which mean score from 18-25 years old outpatients was 4.14 and 3.69 by outpatients older than 50. It is speculated that maybe younger respondents require more interaction in the waiting room rather than merely waiting for doctor's call. Evidence has been highlighted in one of Ulrich's paper (2001) that in waiting rooms, day rooms, and lounges the widespread practice of arranging seating side-by-side along the walls of a room markedly inhibits social interaction among patients or other users (Charles, 1972; Sommer & Ross, 1958). Younger outpatients also evaluated all the five design dimensions with higher mean scores compared with elder outpatients ($>$ 50 years). However, lateral comparison within the five dimensions, elder patients thought sensory design factor more important (mean score = 4.19) and the facilities design factor (mean score = 3.00) the least important.

Most of research assessed patients' satisfaction as the patient outcome measure through evaluation of healthcare service, quality of care, etc. Very few studies link between patients' visits with how they are satisfied with the healthcare environment. This study has identified outpatients' perspectives regarding their frequency of visits to the hospital. Respondents who have been to the hospital for more than 5 times have relatively low mean scores (lower than 4.00) on all 4 dimensions except the 'sensory design'. This may be due to the fact that people visited the hospital more times will have less expectations of their known environments. People are more perceptive of the environment where he/she is not familiar with. On the other hand, it relates to the waiting time In China, patients who are more familiar with the environment would choose to visit in a time with less crowded patients to reduce their waiting time. It is also reflected by the answers from the interview that some outpatients "prefer to come in the afternoon to avoid waiting and delay in the morning". In addition, other than sensory design factor, seating design has been rated more important than the other three environmental aspects. Significant difference in outpatients' perspectives was found in spatial and seating dimensions. Patients visiting hospital less frequently thought the seating environment more important than patients having visited hospital more often. This result is agreed by other researchers, Tsai *et al.* (2007) combined the seating environment with general environment into a 'body-contact environment' which was found less favourable perceived by first-time visitors as a large number of patients waiting in the waiting room may surprise them. In China, same situation is shared as they have the largest volume of outpatients in hospitals every day. As discussed earlier, good arrangement of seats may enhance the interaction between patients, nevertheless, the waiting room's crowded conditions often lead to patients' uncomfortable feeling to the surroundings of the environment. Therefore such factors make them more important in outpatients' perspectives and deserve more attention in the design process.

5.3 Inpatients perception on designing a better accommodation environment

5.3.1 Respondents' characteristics

Table 5.9 summarises demographic and other admission related data from the respondents. Among 287 surveyed inpatients, 145 (50.5%)were male and three persons less of female participants (49.5%). 72% of inpatients were older than 36, most of them aged between 36 and 50 (56 and 60 for male and female). 15 males and 26 females aged between 18 and 25 and for the group 26 to 35 there are 22 males and 17 females. More inpatient (187) were entitled to short term stay in wards compared with those who stay longer (100). (In China, the average admission time is two weeks) 69.3% inpatients were located in a multi-bed ward with 2 to 4 people's capacity. More people choose to live in single ward rather than share the room with more than 4 people. 58.5% of the inpatients stayed less than two wards before and 17.8% inpatients have stayed more than three different wards in the hospitals. Nearly half of the respondents only visited the hospital once or twice, there were 25.4% and 13.2% inpatients visited the hospital between 3-4 and 5-10 times. 12.2% inpatients were very familiar with the accommodation environment while they have been to the hospital more than 10 times. Most of the inpatients were admitted involuntary and they welcome chaperon during staying at the wards. 20.9% inpatients were admitted because of an emergency and only 7.3% of the respondents say no to chaperon.

5.3.2 Principal component analysis

Principal component analysis, followed by a orthogonal rotational solution (varimax), was conducted on the final 19 items at a significance level 0.001. No item was removed from the scale for all have substantial factor loadings larger than 0.40. Factor solution was based on the Bartlett's test showing a significant correlation between items (Chi-square = 2340.39; $p<0.001$) and the Kaiser-Meyer-Olkin test for sample adequacy measuring 0.852 ("great" according to (Field, 2009)). These indices implied that the matrix was well suited for factor analysis. An initial analysis was run to obtain eigenvalues for each component in the data. Five summated indices from the 19 question items that had eigenvalues greater than 1.0 represented five different scales. The total variance extracted was 64.5%. Factor 1 was clustered by 6 items, representing a largest percentage of explained variance (33.4%). Both factor 2 and 3 contains 3 items, accounting for 11.1% and 8.99% of the variance respectively. Factor 4 had 4 items and factor 5 had 3 items, accounting for 5.6% and 5.5% of the variance. Given the large sample size, and the convergence of the scree plot and Kaiser's criterion on five components, this is the number of components that were retained in the final analysis. Table 5.10 shows the factor loadings after rotation. These five factors were identified as general environment, body contact environment, lighting environment, patient privacy and dimensional environment.

Table 5.9: Demographical information of inpatients

Variable	Scale	Male	Female	p value†	Total
Age(yr)				0.084	
	18-25	15	26		14.3
	26-35	22	17		13.6
	36-50	56	60		40.4
	>50	52	39		31.7
Inpatient type				0.706	
	Short term stay	96	91		65.2
	Long term stay	49	51		34.8
Accommodation type				0.387	
	Single-bed room	25	23		16.7
	Multi-bed 2-4	96	103		69.3
	Multi-bed 4-8	24	16		13.9
Number of wards stayed				0.117	
	0	27	15		14.6
	1	59	67		43.9
	2	31	37		23.7
	≥ 3	28	23		17.8
Hopitalisation times				0.816	
	1-2	73	68		49.1
	3-4	34	39		25.4
	5-10	21	17		13.2
	>10	17	18		12.2
Enviornmental effect				0.472	
	Very much	47	51		34.1
	Much	37	41		27.2
	A fair amount	34	30		22.3
	A little	12	13		8.7
	Not at all	15	7		7.7
Admission type				0.034*	
	Emergency	23	37		20.9
	Pre-arranged	122	105		79.1
Chaperon				0.860	
	Yes	134	132		92.7
	No	11	10		7.3

Notes:
† Chi-square table test.
* $p < 0.05$

Table 5.10: Rotated component matrix of questionnaire items (inpatients).

Item	Component				
	General	Body Contact	Lighting	Privacy	Dimensional
Ability to custimise the space	0.795	-	-	-	-
Pleasant exterior view	0.746	-	-	-	-
Adequate sitting area for visitors	0.720	-	-	-	-
Entertainment facilities	0.716	-	-	-	-
Spaciousness and furniture layout	0.544	-	-	-	-
Location and orientation of the room	0.454	-	-	-	-
Noise	-	0.847	-	-	-
Unpleasant smell	-	0.846	-	-	-
Cleanliness	-	0.731	-	-	-
Appropriate level of luminance	-	-	0.795	-	-
Availability of natural light	-	-	0.793	-	-
A thermally comfortable environment	-	-	0.694	-	-
Measures to prevent patient falls	-	-	-	0.620	-
Privacy from other patients and staff	-	-	-	0.766	-
Number of patients in a room	-	-	-	0.542	-
En-suite bathroom	-	-	-	0.473	-
Proximity to nursing staff for easy observation	-	-	-	0.505	0.521
Proximity to service delivery points	-	-	-	-	0.807
Proximity to social facilities	-	-	-	-	0.754
Cronbach's alpha coefficient (0.888)	0.822	0.817	0.788	0.749	0.762
Percentage of explained variance (64.5)	33.419	11.052	8.990	5.583	5.453

5.3.3 Internal consistency reliability

Generated factors were examined for reliability using the Cronbach's alpha coefficients. The obtained values of the reliability estimates were all greater than 0.70 as shown in Table 5.10, indicating a strong internal reliability among items with the same attributes (Nunnally & Bernstein, 1994). The Cronbach's alpha coefficient for the overall scale was 0.888. Table 5.10 also shows the internal consistency reliability level (Cronbach's alpha coefficients) for each generated factor that 0.822 for general environmental design, 0.817 for body contact environment design, 0.788 for lighting design, 0.749 for design of patient privacy and 0.762 for design of distance dimension. Combined, these five factors explained 64.5% of all variables.

5.3.4 Relationship of personal information and perception of design factors

Non-parametric tests are carried out on 19 questionnaire items as shown in Table 5.11. Results show that there is no significant difference in perception between male and female inpatients in the summated five design aspects. Age has significant effect on the perception of lighting design aspects. Different perception of the design of body contact environment is supported by people accommodated in different type of wards. Previous experience of accommodation affect inpatients' perception of both lighting and physical dimensions of the environment which was also reported as significantly different in perception by inpatients having different opinions of environmental effect on their overcomes.

5.3.5 Discussion

Among the dimensions of the accommodation environment evaluated by 287 inpatients (see Table 5.12), Cleanliness (mean = 4.41) was ranked as the most important dimension, followed by a thermally comfortable environment (mean= 4.34) and measures to prevent patient falls (mean = 4.33). The item, entertainment facilities (mean= 3.46) in the accommodation area was rated as the least important design factor, whereas the items: pleasant exterior view (mean=3.59) and ability to customise the space (mean=3.63) were second and third least important item. This result suggests that inpatients are more concerned about environmental and safety factors such as cleanliness, thermal comfort and prevention of falls, than subjective ones such as views to the exterior or entertainment facilities. The overall responses generally agree with previous findings in the sense that all design factors, which were initially identified through extensive literature reviews, had reasonably high mean scores – indicating their importance to inpatients. Twelve out of 19 items had mean scores higher than 4 (= important) and the remaining 7 had mean scores higher than 3 (= neutral).

There were greater percentages of older inpatients among the respondents (see Table 5.9). Patients aged 36-50 years and older than 50 years accounted for 40.4% and 31.7% of the respondents respectively. This distribution, although appears biased towards older patients, is representative of hospitalisation patterns in most countries. As an example, hospitalisation rates fro patients of age 65 and older accounted for 37% of hospitalisations and 43% of hospital days (Hall *et al.*, 2010). No significant difference in perception based on age was found for the constructed dimensions, except for lighting and thermal

Table 5.11: Comparison of mean scores between demographical inputs (inpatients)

-	-	**General**	**Contact**	**Lighting**	**Privacy**	**Dimensional**
Gender	Male	3.79(0.68)	4.31(0.54)	4.23(0.61)	4.16(0.56)	4.06(0.68)
	Female	3.65(0.66)	4.26(0.58)	4.24(0.59)	4.14(0.51)	3.94(0.68)
	p-value†	0.363	0.677	0.760	0.056	0.948
Age (yr)	18-25	3.79(0.54)	4.23(0.59)	4.27(0.60)	4.20(0.47)	3.93(0.70)
	26-35	3.55(0.72)	4.46(0.61)	4.36(0.62)	4.24(0.53)	3.91(0.72)
	36-50	3.71(0.69)	4.24(0.54)	4.19(0.58)	4.13(0.53)	4.02(0.65)
	>50	3.78(0.68)	4.30(0.54)	4.21(0.62)	4.10(0.57)	4.04(0.71)
	p-value‡	0.056	0.909	**0.039***	0.316	0.058
Admission type	Emergency	3.71(0.65)	4.31(0.48)	4.28(0.63)	4.11(0.57)	4.00(0.69)
	Pre-arranged	3.72(0.68)	4.28(0.58)	4.22(0.59)	4.16(0.52)	4.00(0.68)
	p-value†	0.956	0.620	0.779	0.591	0.645
Hopitalisation times	1-2	3.78(0.62)	4.29(0.60)	4.23(0.59)	4.14(0.55)	4.03(0.65)
	3-4	3.72(0.69)	4.24(0.51)	4.22(0.56)	4.14(0.49)	3.98(0.66)
	5-10	3.68(0.66)	4.32(0.54)	4.21(0.69)	4.13(0.52)	4.01(0.78)
	>10	3.59(0.83)	4.35(0.48)	4.30(0.63)	4.19(0.58)	3.92(0.76)
	p-value‡	0.363	0.493	0.417	0.449	0.285
Inpatient type	Short term stay	3.75(0.72)	4.31(0.55)	4.24(0.62)	4.16(0.55)	4.03(0.67)
	Long term stay	3.68(0.57)	4.24(0.57)	4.22(0.57)	4.12(0.50)	3.93(0.70)
	p-value†	0.196	0.909	0.603	0.159	0.457
Accommodation type	Single bed	3.83(0.65)	4.35(0.59)	4.30(0.64)	4.23(0.49)	4.14(0.67)
	2-4 multi-bed	3.77(0.61)	4.31(0.52)	4.25(0.57)	4.18(0.52)	3.99(0.68)
	4-8 multi-bed	3.40(0.89)	4.08(0.67)	4.08(0.69)	3.89(0.58)	3.86(0.67)
	p-value‡	0.298	**0.030***	0.633	0.826	0.081
Number of wards stayed	0	3.66(0.74)	4.23(0.59)	4.21(0.62)	4.18(0.50)	4.04(0.63)
	1	3.74(0.57)	4.25(0.57)	4.19(0.56)	4.11(0.52)	3.97(0.69)
	2	3.70(0.69)	4.25(0.55)	4.22(0.57)	4.08(0.58)	3.94(0.68)
	≥ 3	3.76(0.82)	4.47(0.48)	4.39(0.69)	4.31(0.51)	4.12(0.71)
	p-value‡	0.832	0.340	**0.011***	0.419	**0.011***
Environmental effect	Very much	3.90(0.62)	4.37(0.57)	4.34(0.62)	4.29(0.48)	4.14(0.65)
	Much	3.74(0.56)	4.24 (0.52)	4.20(0.56)	4.12(0.49)	3.92(0.61)
	A fair amount	3.58(0.64)	4.18(0.63)	4.14(0.57)	4.08(0.50)	4.03(0.62)
	A little	3.41(0.83)	4.25(0.52)	4.19(0.59)	4.04(0.75)	4.02(0.89)
	Not at all	3.66(0.94)	4.41(0.38)	4.21(0.70)	4.05(0.75)	4.02(0.89)
	p-value‡	0.112	0.260	0.217	0.257	**0.035***
Chaperon	Yes	3.71(0.68)	4.29(0.56)	4.24(0.60)	4.14(0.54)	4.00(0.69)
	No	3.90(0.57)	4.22(0.48)	4.17(0.59)	4.17(0.49)	4.00(0.62)
	p-value†	0.316	0.670	0.272	0.791	0.245

Notes:
†Mann-Whitney U-test
‡Kruskal-Wallis test
* $p < 0.05$

design. Respondents aged between 26 and 35 thought that lighting and thermal design factors were important (mean score = 4.36), more than the other age groups. Evidence suggests that as we grow older, our visual abilities decrease – so does our tolerance to variations in the luminous environment (Shikder *et al.*, 2011). Designing thermal and luminous environments for older people, therefore, need to consider various physical and psychological factors.

Admission type and number of previous visits did not affect too much on inpatients' response on the importance of design factors. However, short-term (less than two weeks of hospitalisation) stay patients considered all constructed design dimensions to be more important than the long-term (more than two weeks of hospitalisation) stay patients. It may be due to the fact that long-term patients had more time than short-term patients to adapt themselves to the hospital environment, resulting in differing perceptions.

Table 5.12: Descriptive analysis (inpatients).

Questionnaire item	**Response*** (%)					**Mean**	**SD**
	1	2	3	4	5		
Entertainment facilities	4.9	11.1	35.2	30.7	18.1	3.46	1.063
Pleasant exterior view	1.7	10.1	32.4	39.0	16.7	3.59	.941
Ability to custimise the space	2.8	7.3	34.1	35.5	20.2	3.63	.977
Proximity to social facilities	1.7	6.3	35.5	34.5	22.0	3.69	.942
Spaciousness and furniture layout	0.7	5.6	22.6	52.6	18.5	3.83	.818
Location and orientation of the room	1.0	3.1	21.6	55.1	19.2	3.88	.784
Adequate sitting area for visitors	1.0	4.9	24.7	35.9	33.4	3.96	.934
Number of patients in a room	0.0	1.0	19.2	55.1	24.7	4.03	.694
Privacy from other patients and staff	0.3	3.5	16.0	50.2	30.0	4.06	.793
Proximity to service delivery points	0.0	3.1	14.3	48.4	34.1	4.14	.770
Availability of natural light	0.0	1.4	16.7	47.7	34.1	4.15	.738
En-suite bathroom	0.0	2.8	14.6	46.0	36.6	4.16	.774
Proximity to nursing staff for easy observation	0.3	2.8	13.9	44.9	38.0	4.17	.796
Noise	0.0	0.0	14.6	50.5	34.8	4.20	.675
Appropriate level of luminance†	0.0	1.7	13.2	46.7	38.3	4.22	.735
Unpleasant smell	0.0	0.0	14.3	46.0	39.7	4.25	.691
Measures to prevent patient falls	0.0	0.0	13.6	40.1	46.3	4.33	.703
A thermally comfortable environment	0.0	0.3	10.1	44.9	44.6	4.34	.670
Cleanliness	0.0	0.0	4.9	49.5	45.6	4.41	.583

Notes:
*1: Least important; 2: Unimportant; 3: Neutral; 4: Important; 5: Very important.
†Overall lighting: artificial and natural lighting combined.

There is a significant difference in perception based on accommodation type for the sensory and hygiene design factor, comprising three design indicators: cleanliness, noise and unpleasant smell. Inpatients who stayed in single patient rooms considered these three design indicators to be more important than those in multi-bed wards. This correlation between accommodation type and sensory and hygiene design factor is an important finding because of the fact that single-patient accommodation has become a popular option in the domain of hospital design in recent times (Lawson & Phiri, 2000; NHS Estates, 2001; Chaudhury *et al.*, 2005). Patients' preferences for single rooms may be due to their wish to be close to their families while being hospitalised or may simply be due to their own preference for privacy. Other interesting observation is that mean scores on all constructed PCA factors by patients staying at single-bed accommodation were higher than patients in other accommodation types. In the Chinese context, patients who stay in single-patient rooms are often more financially able than those who choose to stay in multi-bed wards. This may contribute to their higher expectations from the physical environment in hospitals and the significant correlation with sensory and hygiene design factor. Other feature of single-patient rooms is that the isolation from other patients contributes to the reduction in nosocomial infections, compared to multi-bed wards (van de Glind *et al.*, 2007). On the contrary, single-patient accommodation is not appropriate for all types of patients, in particular for those who need an opportunity to interact and communicate with others for their recovery.

Opportunity for adaptation may be another contributing factor in differing perceptions. Single-patient rooms are better in creating an isolated environment by reducing the ambient noise level. Patients in multi-bed wards are subjected to more noise than those in single-patient rooms; therefore, their tolerance levels may be higher. However, it should be noted that research has found links with higher noise levels in wards and poor sleep quality and sleeplessness in daytime, affecting patients' health outcomes (Freedman *et al.*, 1999). It is widely acknowledged that sound levels higher than 55 dB_A brings a disturbing effect (Beranek, 1971). Many studies suggest that the exceeding of the recommended level of ambient sound levels is common (Soutar & Wilson, 1986; Busch-Vishniac *et al.*, 2005), resulting in increased stress among patients. However, the relationship between accommodation type and perception is complex, involving many social and psychological parameters. Further research is needed to fully understand this.

Mean scores from male inpatients were higher than females in most of the PCA factors, except for lighting and thermal design, in which mean score from male participants was

4.23, compared to 4.24 by females. Significant difference was found in patients' perception of both the lighting and thermal design and dimensional design factors, based on their previous hospitalization experience. Patients, who previously stayed at three or more wards, thought that the lighting and thermal design factor was more important (mean score = 4.39) than others who previously stayed at less than three wards. They also considered the dimensional design factor to be more important (mean score = 4.12) than others. One such dimensional design indicator is the proximity to service delivery points such as nursing stations, which is important for ensuring the quality of care and patients' well-being. Nurses are front-line caregivers in a hospital, and depending on the design of a healthcare facility they may be required to walk considerable distances during their shifts. An investigation into the nursing practices in 36 hospital surgery units has found that individual nurses travelled between 1 and 5 miles per 10-hour daytime shift (Hendrich *et al.*, 2008). General consensus is that this travelling needs to be reduced through careful hospital design.

The results of the PCA showed that the five constructed factors generally had good internal consistency, even if those factors comprised only three items. This multidimensional structure matches the findings from previous investigations on patient satisfaction, the closely related topic of research to the one described here (Douglas & Douglas, 2004; Hutton & Richardson, 1995). This research also confirms the hypothesis, from a Chinese perspective, that there exists a positive relationship between patients' perception and their overall evaluation of the role of physical environments in their care. This points towards greater criterion validity within this instrument.

This study also explored inpatients' perception of design factors related to privacy and safety. Principal component analysis suggested that five items (see Table 5.10) contributed to this constructed factor: measures to prevent patient falls; privacy from other patients and staff; number of patients in a room; en-suite bathroom and proximity to nursing staff. The last item, proximity to nursing staff, was the only item with dual loading of 0.505 and 0.521 in two factors, privacy and safety and dimensional, respectively. In both cases, the loadings were significant and higher than 0.40, indicating the importance of the item. However, considering the differences in loadings,the item was clustered with the dimensional design factor, leaving the privacy and safety factor with four items. The reason the item is kept is because of the fact that the item is a very important dimensional design aspect for efficient and safe delivery of care.

Chapter 6

Results and discussion on the implementation of spatial layout optimisation

This chapter implements a method to integrate user preference with spatial layout optimisation, addressing the findings from last chapter to define the weightings of constraints' infeasibility[1]. This chapter also discusses the results obtained from implementation of the optimisation prototype, as illustrated in Chapter 4, in two hospital design case studies. The first case study is a design problem typically found in the concept design stage where groups of spaces are organised. The second case study represents a design problem typically found during detail design stage. The rest of this chapter also presents the process of integrating the user perception to design the input file for the Space Layout Problem (SLP) and form the optimisation constraints. Evidence of optimisation parameters influencing the result is also discussed and results of each implementation are given respectively.

6.1 Integration of user preference with spatial layout optimisation

This research has emphasised the importance of adopting a systematic approach to integrating the preference of users to the planning, design and ongoing management and

[1] Infeasibility value evaluates the performance of constraint functions

adaptation to healthcare buildings. Lacking of integration of users' preference always bring with adverse impacts on building management and overall healthcare performance. Even the quality of care that patients receive will also be jeopardized.

While an understanding of the effects of the physical environment is helpful in conceiving design ideas at early stages, their utility diminishes at latter stages when conflicts between multiple objectives need to be resolved or when decisions need to be made based on objective assessments. This is because the mere understanding of the effects does not necessarily help in navigating the complex solution space, typical of building design problems. On the other hand, the ranking of design aspects based on users perception can be of help in both cognitive and non-cognitive design processes. This section discusses nature of architectural design process and optimisation problems, following by the proposed strategy to integrate user perception with spatial layout planning in healthcare facilities.

6.1.1 The design process

Architectural design is an iterative process that aims to improve the design so as to achieve the best way of meeting design goals while satisfying defined constraints (Mourshed, 2006). Design iterations are performed by changing the design variables; i.e., building parameters that describe the design problem as a system. The resulting system is evaluated, typically using a cognitive and/or 'trial and error' approach, to find the best or optimal solution(s). Design evaluation can also be accomplished using non-cognitive means; i.e., by using building simulation or defined heuristics such as rules of thumb. Design goals can be defined as the maximization and/or minimization of one or more performance criteria. In addition, constraints are used to exclude infeasible solutions. Constraints can be thought of as acceptable limits on design goals and/or variables that the process aims to meet. Design solutions meeting the constraints are termed as feasible designs.

6.1.2 Multi-objective and single objective optimisation problem

Most, if not all, of the design problems are multi-objective. A design may need to achieve several goals, which may be in conflict with each other. For example, maximizing daylighting in a space requires larger window area, which may result in greater heat loss from or heat gain into the space, thus requiring more energy for heating or cooling respectively.

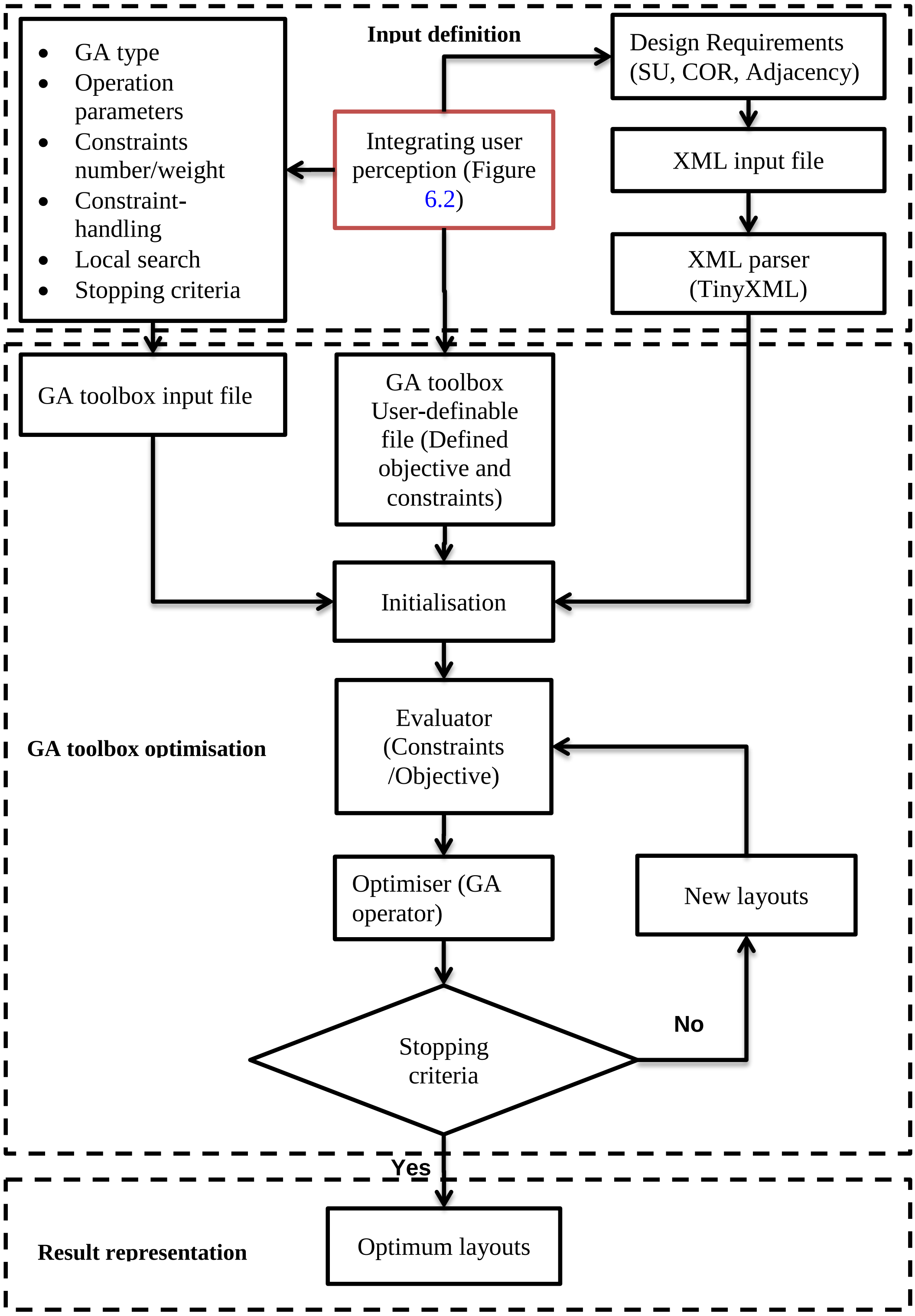

Figure 6.1: Design of integration of user perception with SLP.

In this case, the goals, maximisation of daylight and minimisation of energy demand are in conflict with each other – for an improvement in one there is a corresponding decline in the other. A typical healthcare layout problem may have many of these conflicting goals or objectives. Several techniques are available to deal with multi-objective design problems, including those with conflicting goals. A simple approach is to transform a multi-objective problem into a single objective optimisation by applying scalar weights to the design goals. This approach is known as weighted sum and its mathematical formulation is given by:

Minimise:

$$\sum_{i=1}^{n} \lambda_i f_i(\mathbf{X}) \tag{6.1}$$

Subject to:

$$\mathbf{X} \in S, \mathbf{X} = [x_1, x_2, ..., x_n]^T \tag{6.2}$$

$$\lambda \in \mathbb{R}^n | \lambda_i \geq 0, \sum \lambda_i = 1 \tag{6.3}$$

where, $\mathbf{X}$ is a vector of design variables (x_1,x_2,,x_n) that define a design alternative and λ_i is a positive scalar weight applied to the n^{th} goal or objective function, $f_i(\mathbf{X})$. The application of scalar weights, although appears straightforward, requires care as it has the ability to skew optimization results in factor of the highest λ_i. On the other hand, the bias towards a particular design goal may be desirable. For example, if hospitals are to be designed according to the findings of this research, the designer may wish to introduce bias towards the maximization of cleanliness related aspects in the optimal design. Here the challenge is to identify relative weights of design goals, which needs to be based on a sound evidence base. It should be noted that in some cases, objective function may need to be normalized before applying the weight, in particular in cases where they are on different scales to each other.

6.1.3 Integrate user preference with the SLP optimisation

Integration of user preference mainly takes place in the first phase (input definition from Figure 6.1) of the whole optimisation process, where there are three phases during the whole optimisation process: input definition; GA optimisation and Result representation as shown in the Figure 6.1. The integration of user preference is associated with defining the input files of design requirements, and generating the weighting values for infeasibility of constraints.

A method was introduced to integrate user perception with the spatial layout optimisation prototype. The first step is to transform the items of the questionnaire into design goals, for example, in the care providers questionnaire; there are 16 items which will be defined as 16 design goals. The design question is to optimise these 16 design factors in a multi-objective optimisation problem using the weighted sum approach. To transform the multi-objective problem into a single objective one, the weights corresponding to each design factor need to be identified. Responses from the questionnaire can be used as weights by normalising them so that the sum of all weights equals to 1. The other approach is to normalise the reverse ranks of design factors to find the corresponding weights using the equation below:

$$\lambda_{rank,i} = \frac{R_i}{\sum_{i=1}^{n} R_i} \tag{6.4}$$

Where, $\lambda_{rank,i}$ is the ranked weight and R_i is the reverse rank of the i-th design factor. Weights based on normalised mean responses, $\lambda_{rank,i}$ and normalised reverse ranks, are given in the Table 6.1.

After the design goals were transferred from questionnaire results (Table 6.1–6.3), a method of categorising the design indicators was employed to justify the design purpose. This is because in the process of hospital design, different design purpose is reflected in different design stages. For example, the design of the physical environments requires designers' focus on the dimensional design aspects, which needs to consider users preference based on this particular design aspect. However, the user perception include not only their preference on physical environments but also other design aspects. For example, their perceptions of sensory design, privacy and safety, etc. These design indicators are irrelevant to form the requirements according to the specified design goal thus will be excluded. Moreover, some of the design factors have little influence on the physical environment design, such as design factor 'Indoor plants, interior/exterior landscaping'. Nevertheless, some design indicators have interrelationships with each other which need to be considered to form either the design input files or constraints, such as in the inpatient questionnaire, the design factor 'privacy from other patients and staff' has impact on the factor 'proximity to nursing staff'. Also in the outpatient questionnaire: 'Spa-

Table 6.1: Generated goal weights from care providers' responses for use in multi-objective design.

Design factor (care providers)	Mean response	Rank	Weight	
			$\lambda_{norm,i}$ †	$\lambda_{rank,i}$ ‡
Cleanliness and ease of maintenance	4.66	1	0.073	0.118
Air quality and freshness†	4.39	2	0.069	0.110
Noise level	4.34	3	0.068	0.103
Thermal comfort	4.29	4	0.067	0.096
Proximity to wards	4.29	5	0.067	0.088
Provision for hand hygiene	4.19	6	0.066	0.081
Adequate illumination‡	4.16	7	0.065	0.074
Availability of daylight	4.06	8	0.064	0.066
Spaciousness	4.00	9	0.063	0.059
Location and orientation of the space	3.85	10	0.060	0.051
Architectural design of the space	3.80	11	0.059	0.044
Pleasant color scheme	3.68	12	0.058	0.037
Exterior view from the space	3.66	13	0.058	0.029
Furniture layout	3.53	14	0.055	0.022
Indoor plants, interior/exterior landscaping	3.52	15	0.055	0.015
Presence of coordinated art objects	3.36	16	0.053	0.007

Notes:
†Uses normalised mean scores of design factors; $\sum \lambda_{norm,i} = 1$.
‡Uses reverse ranks of design factors; $\sum \lambda_{rank,i} = 1$

ciousness' is associated with making decisions on 'seating sufficiency'. Based on this, in order to better translate user perception of different design indicators, only the design factors associated with designing topology constraints and geometry constraints are considered to generate the weighting values. (to calculate the infeasibilities for constraints in designing the physical environments)

The flow chart of integration of user perception is given in Figure 6.2. Typical geometrical and topological constraints are also generated according to user perception from Table 6.1–6.3. For instance, design factors of 'Proximity to service delivery points', 'Proximity to social facilities', 'Proximity to wards', 'Proximity to nursing staff' are contributing to generate the constraints of travelling distance (Proximity) and accessibility. 'Location and orientation of rooms' is associated in forming the constraints of 'within building site' and 'non-overlapping'. Other typical design factors are associated with definitions of input files. Such as: 'En-suite bathroom', 'Number of patients', 'Adequate sitting area for visitors' are utilised in design the room size and shape in the XML input files.

Since the surveyed healthcare facility users group consists of inpatients, outpatients

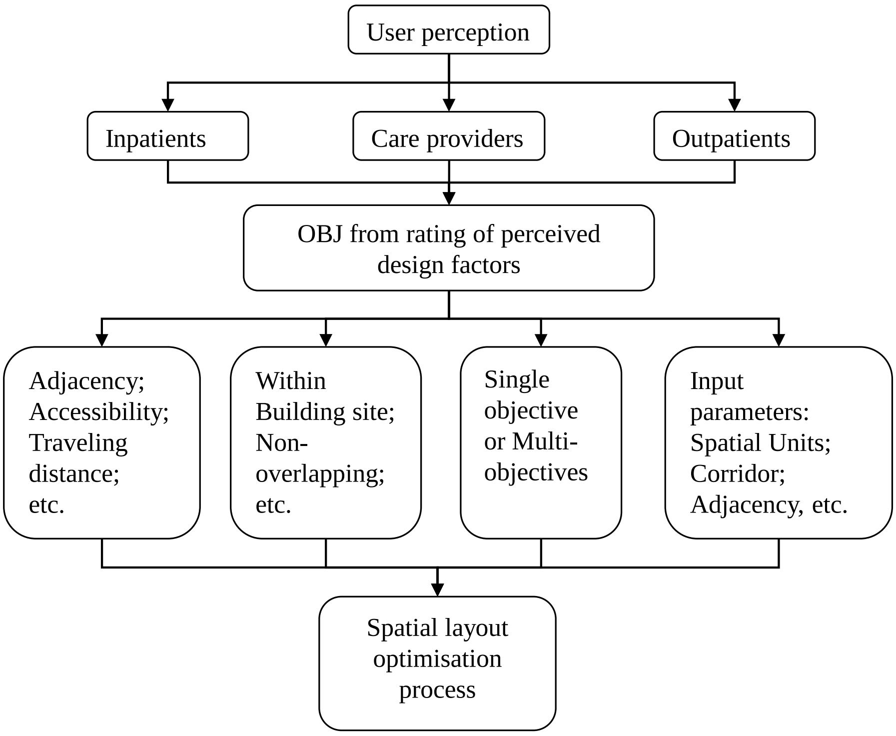

Figure 6.2: Flow chart of integration of user perception.

Table 6.2: Generated goal weights from outpatients' responses for use in multi-objective design.

Design factor (outpatient)	Mean response	Rank	Weight	
			$\lambda_{norm,i}$ †	$\lambda_{rank,i}$ ‡
Cleanliness	4.55	1	0.075	0.118
Air freshness	4.53	2	0.074	0.110
Noise	4.32	3	0.071	0.103
A thermally comfortable environment	4.20	4	0.069	0.096
Seating sufficiency(adequate number of seats)	4.18	5	0.069	0.088
Adequate illumination	4.03	6	0.066	0.081
Spaciousness	3.92	7	0.065	0.074
Availability of daylight	3.88	8	0.064	0.066
Seating comfort	3.86	9	0.064	0.059
Architectural design of the space	3.67	10	0.060	0.051
Pleasant colour scheme	3.52	11	0.058	0.044
Indoor plants, interior/exterior landscaping	3.40	12	0.056	0.037
Exterior view	3.26	13	0.054	0.029
Presence of coordinated art objects	3.18	14	0.052	0.022
Furniture layouts	3.17	15	0.052	0.015
Entertainment facilities	3.10	16	0.051	0.007

Notes:
†Uses normalised mean scores of design factors; $\sum \lambda_{norm,i} = 1$.
‡Uses reverse ranks of design factors; $\sum \lambda_{rank,i} = 1$

and care providers, it is necessary to find out if there are any objective factors in common and how they were ranked in each perception items list. The purpose of doing this is to find out if there are some conflicts in the design factors, overall higher ranked items obtain higher priority in the design process. A combination of design goals follows such rules:

- Common design factors were calculated based on the average score of importance.
- Design factors were categorised into groups to reflect needs of design topology and geometry constraints.

The overall infeasibility of constraints is designed as:

$$I_t = \sum_{i=1}^{n} \lambda_i C_i \tag{6.5}$$

Where n is the number of constraints, C is the constraints defined for the optimisation and λ is the weighting values from user perceptions. In chapter four, problem constrains has been defined and divided into geometrical constraints and topological constraints. In

Table 6.3: Generated goal weights from inpatients' responses for use in multi-objective design.

Design factor (outpatient)	Mean response	Rank	Weight	
			$\lambda_{norm,i}$ †	$\lambda_{rank,i}$ ‡
Cleanliness	4.41	1	0.058	0.100
A thermally comfortable environment	4.34	2	0.057	0.095
Measures to prevent patient falls	4.33	3	0.057	0.089
Unpleasant smell	4.25	4	0.056	0.084
Adequate illumination	4.22	5	0.055	0.079
Noise	4.20	6	0.055	0.074
Proximity to nursing staff	4.17	7	0.055	0.068
En-suite bathroom	4.16	8	0.054	0.063
Availability of natural light	4.15	9	0.054	0.058
Proximity to service delivery points	4.14	10	0.054	0.053
Privacy from other patients and staff	4.06	11	0.053	0.047
Number of patients in a room	4.03	12	0.053	0.042
Adequate sitting area for visitors	3.96	13	0.052	0.037
Location and orientation of the room	3.88	14	0.051	0.032
Spaciousness and furniture layout	3.83	15	0.050	0.026
Proximity to social facilities	3.69	16	0.048	0.021
Ability to customize the space	3.63	17	0.047	0.016
Pleasant exterior view	3.59	18	0.047	0.011
Entertainment facilities	3.46	19	0.045	0.005

Notes:
†Uses normalised mean scores of design factors; $\sum \lambda_{norm,i} = 1$.
‡Uses reverse ranks of design factors; $\sum \lambda_{rank,i} = 1$

total, four constraints are applied to the optimisation, namely, C_{wbs} (constraint of within the building site), C_{nolp} (constraint of non-overlapping), C_{adj} (constraint of adjacency) and C_{trd} (constraint of travelling distance).

6.2 Case study one: concept design

The process of managing and designing building projects is categorised into five key work stages (preparation, design, pre-construction, construction and use) by RIBA (Royal Institute of British Architects). According to these five steps, healthcare designers will be beneficial mainly in the design brief processes (stage 1 & 2), which are representative in the two conducted case studies. The first case study implemented the developed space layout plan optimisation prototype in a relatively small scale to interpret a concept design of a hospital layout. And the second case study includes more spatial units and a complex corridor in order to represent more flexibility in the concept design process (stage 2).

6.2.1 Problem specification

The optimisation problem selected for this case study is a healthcare facility (St John's Street Surgery, Bedford, UK) with seven groups of spaces. This surgery facility is chosen because it well represented a typical healthcare layout. The seven spatial units represent seven different zones in the facility (Figure 6.3) including consulting rooms; reception room, treatment room, etc.

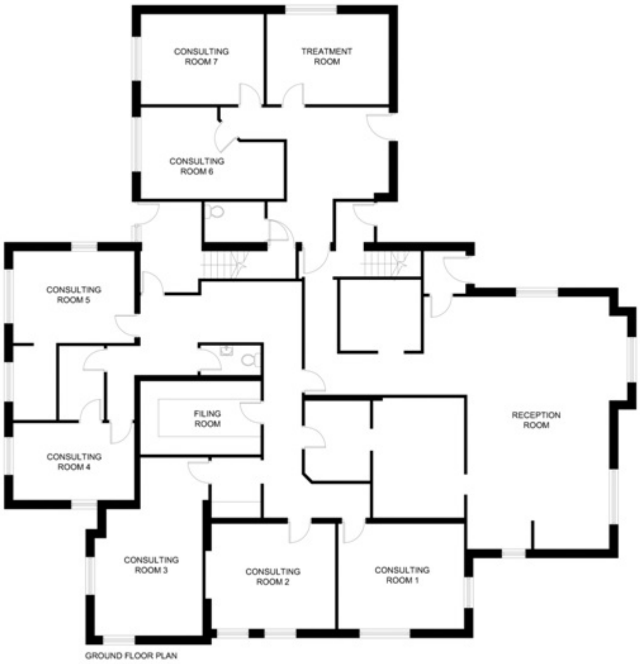

Figure 6.3: St Jonhn's Street Surgery, Ground Floor Plan.

The XML input file contains the associated physical parameters of each spatial unit. An example XML input format is given in Figure 6.4. Firstly, name, length and width of each spatial unit is defined, following by the proximity to corridor with maximum distance allowed. Adjacency defined here allows the minimum adjacency length to be adjacent with the corridor. Maximum travelling distance is also defined in XML from SU_1 to SU_4.

In order to implement this problem in the developed space layout optimiser, the genetic algorithm (GA) parameter set shown in Table 6.4 was used. Chapter four explains the selection of this combination of genetic operators, using the GA toolbox to optimise the problem.

```
<SpatialUnit>
      <Name>SU1</Name>
      <Length>2000</Length>
      <Width>1500</Width>
      <Proximity>
                  <AdjacenctSUnumber>COR1</AdjacentSUnumber>
                  <MaxDistance>700</MaxDistance>
      </Proximity>
      <Adjacency>
                  <AdjacenctSUnumber>COR1</AdjacentSUnumber>
                  <Length>1000</Length>
                  <Tolerance>10</Tolerance>
      </Adjacency>
      <Accessibility>
                  <ConnectedSUnumber>SU4</ConnectedSUnumber>
                  <TravelingDistance>2500</TravelingDistance>
                  <Length>400</Length>
      </Accessibility>

</SpatialUnit>
```

Figure 6.4: Structure of the XML input file.

6.2.2 Results of the optimisation

The optimisation was run for 1000 generations and the variation of degree of infeasibility of the best generated layout of each generation is shown in the Figure 6.5. It took around seven minutes, which is quite short considering the relatively small scale of the optimisation problem. From the figure, it can be observed that the degree of infeasibility of best solutions decrease dramatically during the initial 30 generations and afterwards the degree of infeasibility of the generated layouts appear to improve slowly. The optimisation

Table 6.4: Optimisation parameters for case study one.

Optimisation Parameters	Value
Polulation size	500
Ranking probability	0.45
Tournament size	2
Crossover probability	0.85
Crossover distribution parameter	2
Mutation probability	0.15
Mutation distribution parameter	20

has reached a near optimal solution within 200 generations. Figure 6.6 and 6.7 present the variation of infeasibility of two constraints during the 1000 generations. Comparing these two figures, it is evident to see the difference as the feasibility of C_{wbs} falls down to zero very quickly after several generations, meaning that all the layouts have been located within the building site. While C_{nolp} varies during the whole generation because the constraint of non-overlapping is difficult to satisfy to the minimum level.

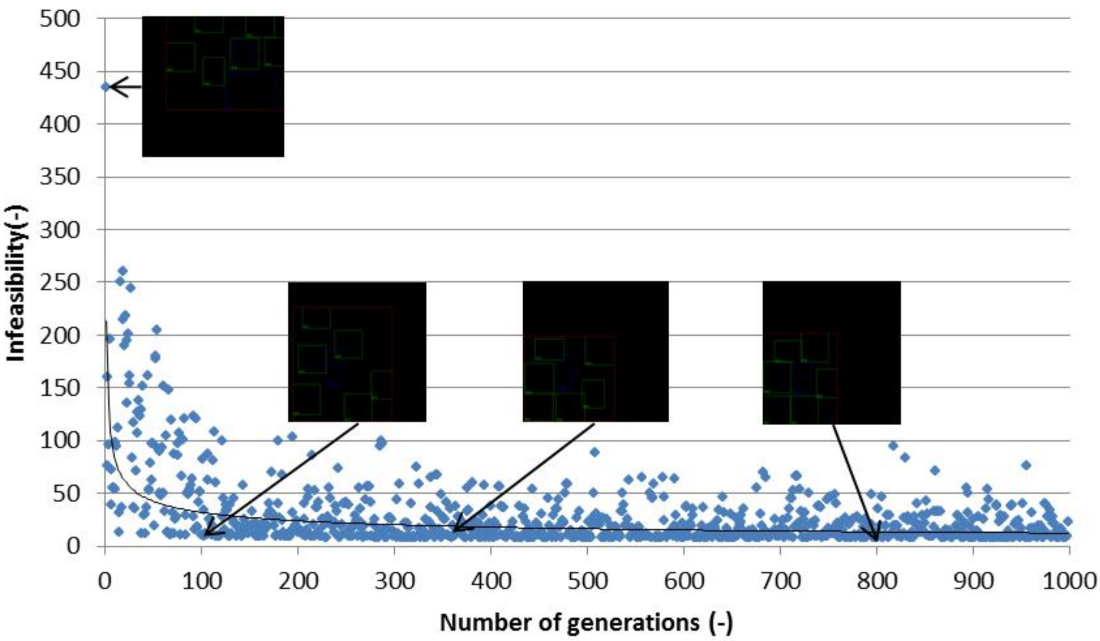

Figure 6.5: Degree of infeasibility of 1000 generations.

The diagrams in Figure 6.8 show larger images of four best layouts selected from different stages of the optimisation, which present the improvement of the layout optimisation process over 1000 generations. The green boxes represent spatial units and the blue one represents the corridor. The first layout is the initial random generated layout, some of the green spatial units (SU_1, SU_2 and SU_5) are found out of the boundary, and there is a large area inside of SU_6 getting overlapped with the corridor (shown as the blue box). The second image shows the improvement after 100 generations, value of the infeasibility drops down from 435 to 51.5 and every spatial units are within the building site. However, the layout still doesn't present the desired compactness as each spatial unit is located

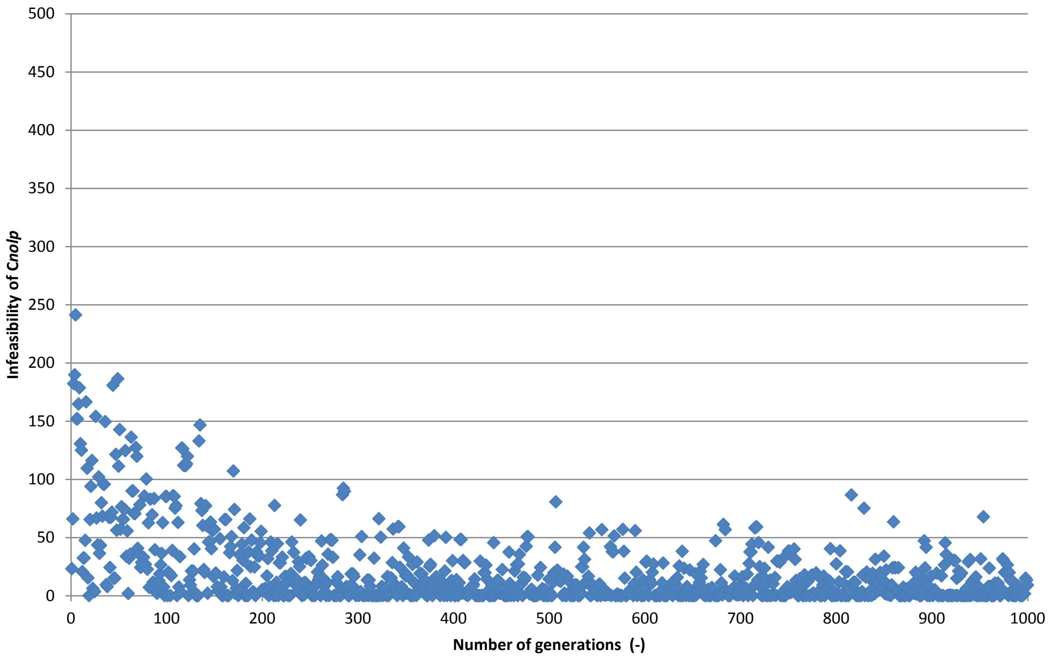

Figure 6.6: Degree of infeasibility for constraint of non-overlapping(C_{nolp}).

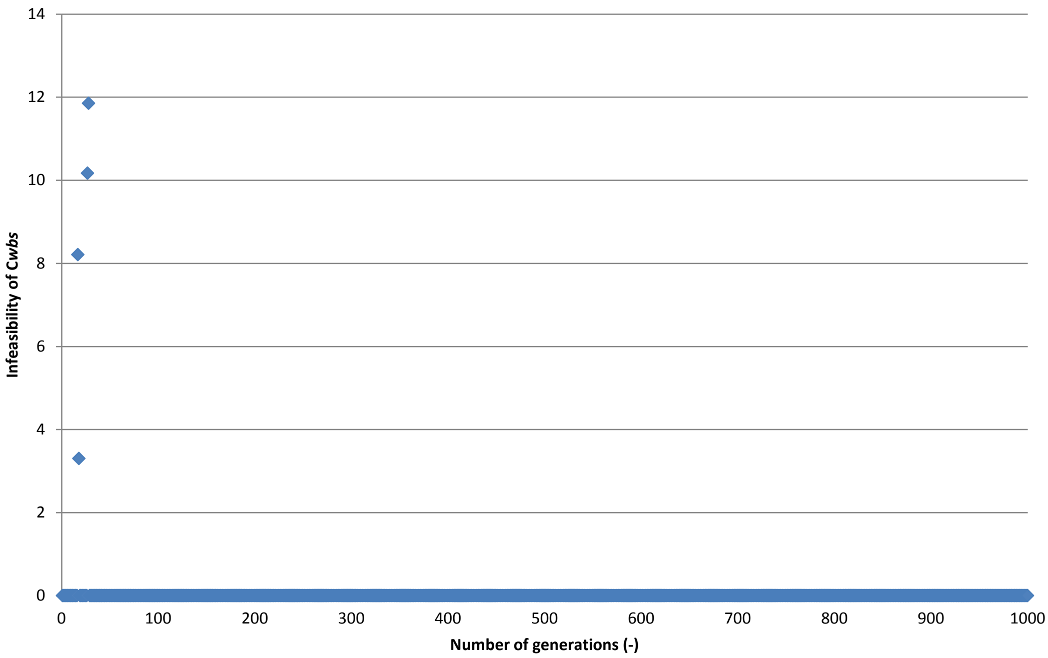

Figure 6.7: Degree of infeasibility for constraint of within building site(C_{wbs}).

Figure 6.8: Generated spatial layouts (generation 1, 100, 350 and 800). Green boxes represent spatial units and blue ones represent the corridor.

separately on the site. The third image enhances the compactness with a lower value of infeasibility though SU_4 and SU_7 are slightly overlapped with each other. The last image shows the best layout produced within 800 generations, the value of infeasibility is 9.11, nearly 50 times lower than the first random one. From generated figures it clearly showed a compact layout with very little overlap between SU_2 and SU_4 at the corner. SU_1 has adjacencies with SU_5 and SU_6, while SU_3 is located adjacently with SU_6 and SU_2, a small gap[1] between two spatial units is considered to be adjacent with tolerance. Accessibility among compartments has been achieved naturally with corridor surrounded by all spatial units; in addition, the generated corridor with two compartments is more design oriented in its shape rather than a simple rectangular one (flexible in orienting and locating a group of spaces). However, it should be noted that this generated layout may not be the last optimal layout to be used by designers because of the limit of the generations. Although the produced layout fulfils most of the design requirements (adjacency, within boundary, etc), the layout didn't match the real hospital plan perfectly. There is still room to improve the solution quality via more genetic operations such as reseeding. Reseeding is a technique applied in the searching process in order to omit those sequential parts that are not helpful or needed for the search. Its utilisation in GA can offer the advantage of starting a new search space and being able to populate a specific region more densely, leading to better results (Orszulik & Shan, 2012). Alternatively, the designer is able to run the optimisation several times to have comparative layout solutions, it is very likely that the produced optimal layouts may have slight difference with each other since the infeasibility of constraints drops down very slowly after some point.

Comparing with the real hospital plan, the generated layout has represented nearly the same positions of spatial units as shown in Figure 6.9. It is considered this prototype is capable of handling the SLP optimisation in a small scale and find out near optimum layouts within a satisfactory time scale. However, in reality, a typical healthcare layout usually consists of more spatial units than what is presented in case study one; therefore, a more detailed optimisation problem of one grouping zone is shown via the second case study.

[1] The small gap is a construction tolerance which is the allowable deviation from a given dimension, location, line, grade, or other value given in the design documents. Tolerances are necessary in construction because no manufacturing, fabrication, or construction process is perfect. There are only degrees of accuracy.

Figure 6.9: Comparative of generated spatial layout with real hospital plan.

6.3 Effect of crossover and mutation on optimisation performance

Case study one shows the capability of the developed prototype in solving the SLP problem. In order to improve the performance of the programme, a set of comparison tests were carried out testing the most important parameters in the GA algorithms: crossover probability (P_c) and mutation probability (P_m). The comparative tests were carried out based on case study one.

To examine the effect of crossover probability (P_c) on this optimisation problem, the parameters with 9 sets with the P_c values were selected while accordingly 9 sets different mutation probabilities were selected (Table 6.5). For each set, 10 operations are tested to give a average performance of the effect of each pair genetic operators. It is anticipated to find the optimum set of parameters giving the best programme performance via the nine sets tests.

From the results that compared nine sets parameters, it is found the first set has the best performance. Figure 6.10 shows the comparisons of infeasibilities among tested nine sets. Set one has the lowest value of 25% and 75% of generated infeasibilities compared

Table 6.5: Crossover and mutation rates for nine sets of test.

Sets	Crossover probability, P_c	Mutation probability, P_m
1	0.9	0.1
2	0.8	0.2
3	0.7	0.3
4	0.6	0.4
5	0.5	0.5
6	0.4	0.6
7	0.3	0.7
8	0.2	0.8
9	0.1	0.9

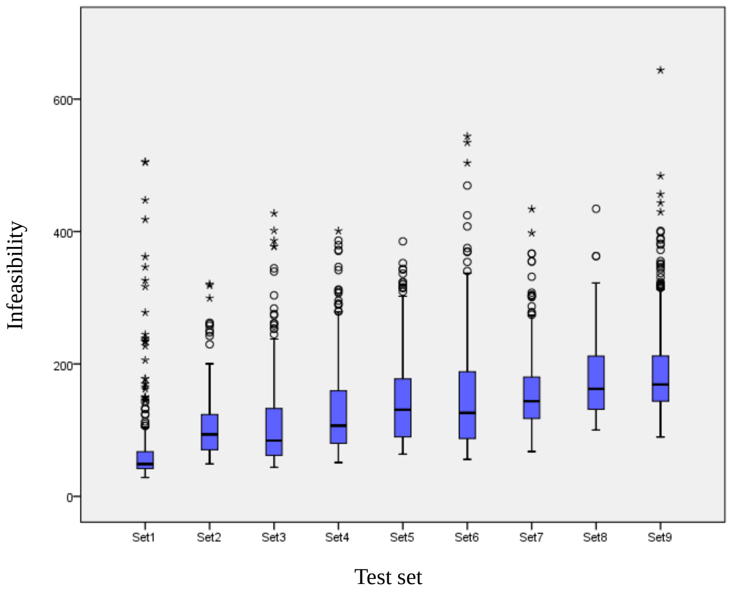

Figure 6.10: Performance comparisons of nine sets with different crossover and mutation rates).

with other sets, which means a better performance of low infeasibilities for most of the generated layouts. It leads to a quicker achievement of near-optimum solution than others. A higher mutation rate didn't help improve the overall performance; in addition, the objective value became negative in set 7, set 8 and set 9 due to the high mutation rate. The reason is because of the high possibility bringing in new offspring often result in violation of first two constraints, leaving the layout out of the building site and completely overlapped with each other. As a result, lower mutation rate is suggested to be used in the optimisation in the future.

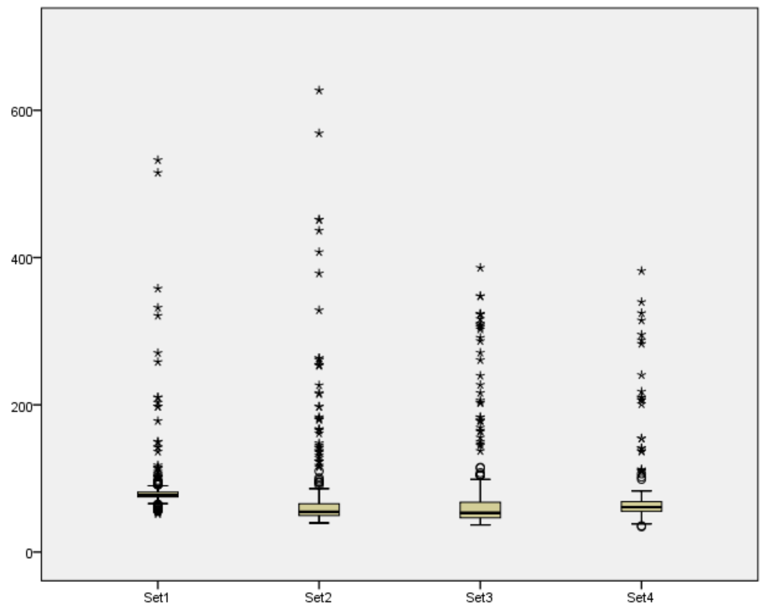

Figure 6.11: Comparison of four sets of different mutation rates).

Comparison of last nine sets of operations indicates a better performance with combination of a relatively high value of crossover rate and a lower value of mutation rate. In the next test, four sets were running, keeping the same crossover value ($P_c = 0.9$) with four different mutation rate ($P_{m1} = 0.02, P_{m2} = 0.04, P_{m3} = 0.06, P_{m4} = 0.08$). Results showed slightly difference within the four sets, set 2 and set 3 have nearly the same effects with regards to the final performance. Therefore, the difference of the mutation rate which is lower than 0.1 has small differences on the final optimisation performance.

6.4 Case study two: detail design

An outpatient department layout optimisation is selected for this problem, the integrated optimisation implements outpatients' perception from the outpatient questionnaire. With more spatial units, this case study tests the efficiency of the integrated SLP optimisation. This section presents the problem specifications, the implementation of the integrated method and a discussion of results is provided in the end.

6.4.1 Problem specifications

The hypothesised outpatient department has ten spatial units, the dimensions and interrelationships between each spatial unit are determined according to hospital design guidelines, integrated with outpatients' perception from previously conducted questionnaire survey. Before the parameters of input file and adjacencies among spatial units were determined, some assumptions were applied to this optimisation problem.

- Shapes of all the spatial unit are set an rectangular. A check-in desk is considered to be located in the waiting room.
- There is enough space for healthcare activity within each spatial unit. Adequate facilities have been installed in each spatial unit.
- Each spatial unit is considered having a door to access to the corridor.
- Each spatial unit is assumed to have the same height with the same envelope material.

A sketched layout is found with department divided into spatial units. The following 10 spatial units are redefined and used throughout the study, which have been assigned with suitable functional names. Outpatients will be waiting in the waiting room after they check in. Nurses and doctors work in the consulting room, treatment room to deliver care and they work in the office to carry out administrative work. Patients are allowed to get access to waiting room, consulting room, treatment room and toilets. Clean and dirty utility room are for care workers only. Nurses and doctors have full accessibilities to all the rooms in this unit.

- SU_1 – Clean utility room (CUR): where drugs, medicines and lotions can be stored and prepared.

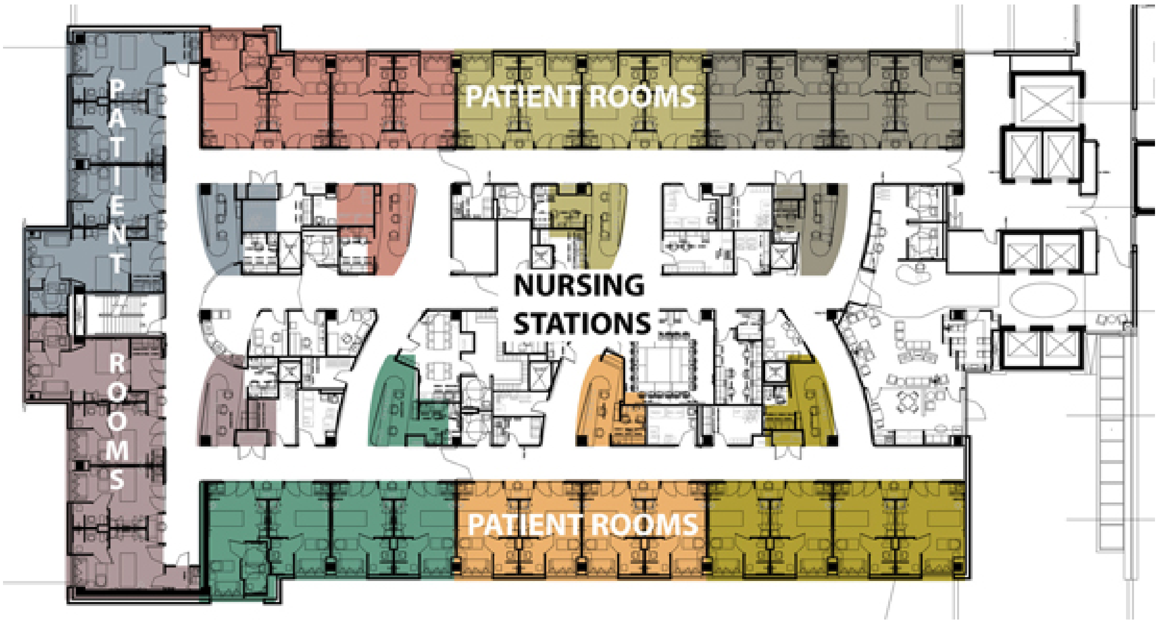

Figure 6.12: Proposed sophisticated healthcare space layout (Source: Triple Corridor Plan at St. John's Mercy Heart and Vascular Hospital).

- SU_2 – Office room (OR): for doctors working when not with patients where administrative work is carried out.
- SU_3 – Operating theatre (OT): where surgical operations are carried out, should be adjacent with doctors working place and with the consulting room.
- SU_4 – Storage room: required for the storage of healthcare supplies. An increasing number of UK hospitals have installed the 'just-in-time' storage system, which involves a large centralised store on each site where all non-specialised clinical equipment is kept for regular distribution for different departments when it is required.
- SU_5 – Waiting room (WR): providing seating for minimum 30 people, with additional allowance for a play area. Easy access to WC and treatment room is required.
- SU_6 – Consulting room (CR): providing facilities for all initial consultations, most clinical examinations, and treatment. Be adjacent to the clean utility room and the dirty utility room.
- SU_7 – Treatment room (TR): generally, it has the same design requirement as the consulting room, except a sound insulation. This is where the outpatients get

further treatment by doctors and nurses.

- SU_8 – Toilet (WC): easy access for both patients' and staff's convenience.
- SU_9 – Dirty utility room (DUR): includes facilities for cleaning dressing trolleys and other items of equipment, should be adjacent to a WC for the collection of specimens.
- SU_{10} – Cafeteria (CF): easy access for facility users.

With clarification of functionality of each spatial unit, the relationship chart is tabulated in Table 6.6. Some adjacencies have been emphasised in the clarifications based on facility users' preference and the results from questionnaire. For example, SU_3 is specified to be located adjacently with SU_2 doctor's working room and SU_6 consulting room. Similar requirement is applied to SU_6 treatment room, which need to be located with SU_1 clean utility room and SU_9 dirty utility room. In the matrix, the weightings of relationships are categorised into five levels: most important, important, ordinary closeness, unimportant, and undesirable. If there is overlapped adjacency requirement on particular spatial unit, this should be coordinated by using the followed relationship chart, the most weighted/important adjacency requirement gains higher priority in the constraint design.

Table 6.6: Relationship matrix of each spatial unit with embedded closeness importance.

From	**To**									Area (sq.ft.)
	SU_2	SU_3	SU_4	SU_5	SU_6	SU_7	SU_8	SU_9	SU_{10}	
SU_1	U	U	I	U	M	I	I	X	X	300
SU_2		I	U	U	I	I	I	X	U	400
SU_3			I	I	I	U	I	I	U	400
SU_4				X	U	I	U	U	X	300
SU_5					I	I	M	U	I	400
SU_6						U	I	M	U	440
SU_7							I	I	X	440
SU_8								M	X	80
SU_9									X	75
SU_{10}										440

Notes:
M: Most important; I: Important; O: Ordinary closeness; U: Unimportant;
X: Undesirable.

6.4.2 Results of the optimisation problem

This optimisation was run for 1800 generations, the variation of degree of infeasibility of the best generated layout of each generation is shown in the Figure 6.13. Similar to case study one, difference between figure 6.14 and 6.15 is evident due to the same reason that all the spatial units are located within the building site and non-overlapping occurs during the whole optimisation process. From Figure 6.13, it can be observed that the degree of infeasibility of best generated solution reduce rapidly during the first 100 generations and the rate of the reduction becomes slow afterwards. It is unlikely that the optimisation will reach an optimal solution within 800th generations, the slight change of the degree of infeasibility from 800th to 1800th generations may suggest the need for further adjustments (e.g. reseeding or change selection methods) of the optimisation to avoid the optimisation getting stuck in the middle of the generations.

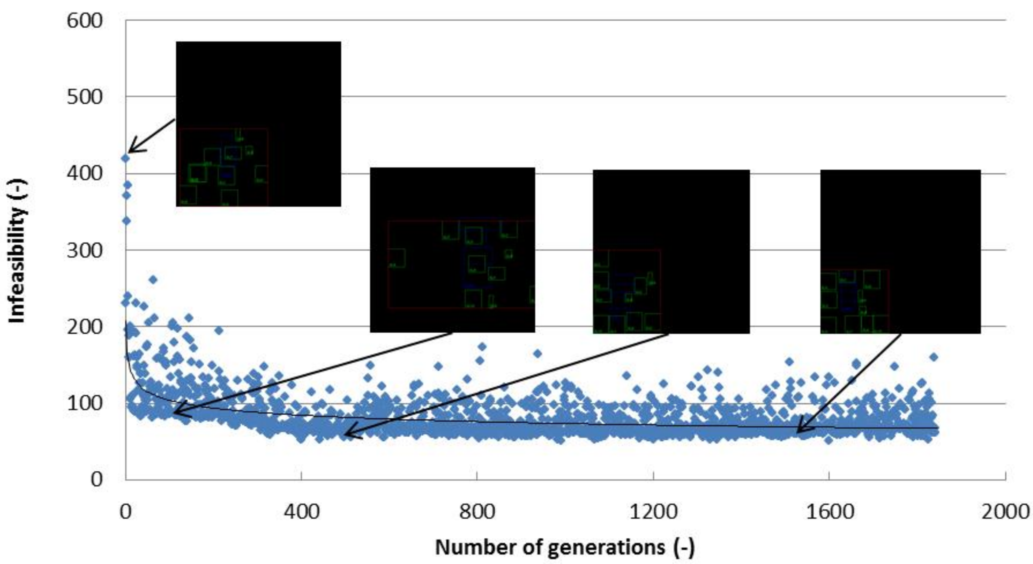

Figure 6.13: Degree of infeasibility of 1st to 1800th generations.

The diagrams in Figure 6.16 show four best layouts selected from different stages of the optimisation to present the improvement of the layout optimisation process over 1800th generations. The first layout is the initial random generated layout with a infeasibility value of 418.87, one spatial unit is out of the boundary and the corridor is overlapped with three other spatial units. After 100 generations, the infeasibility value drops to 120.29

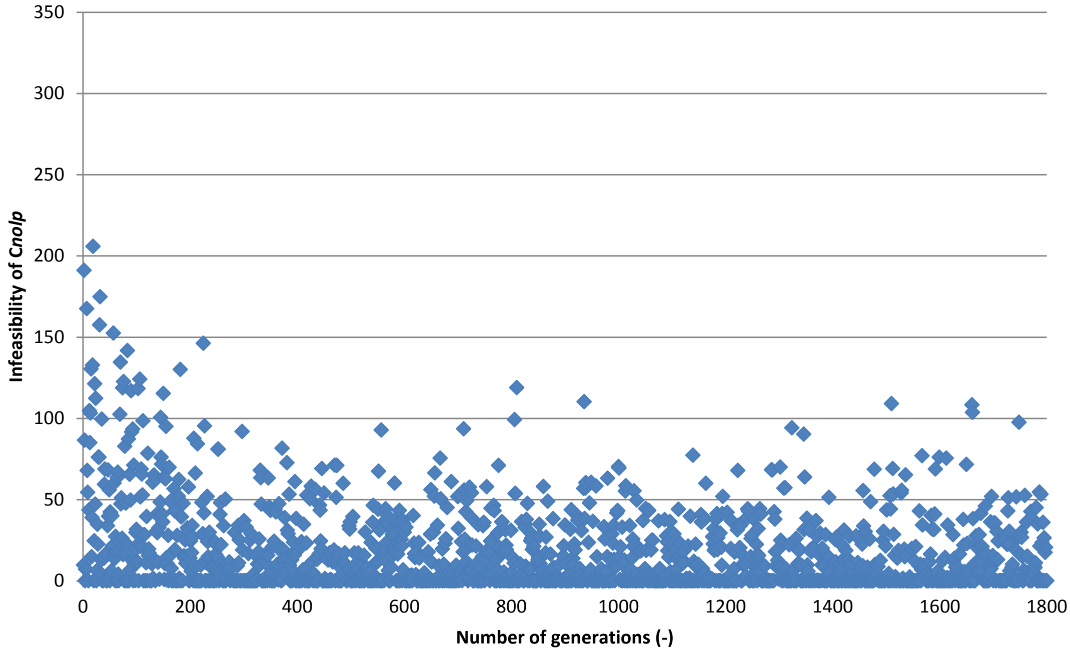

Figure 6.14: Degree of infeasibility for constraint of non-overlapping(C_{nolp}).

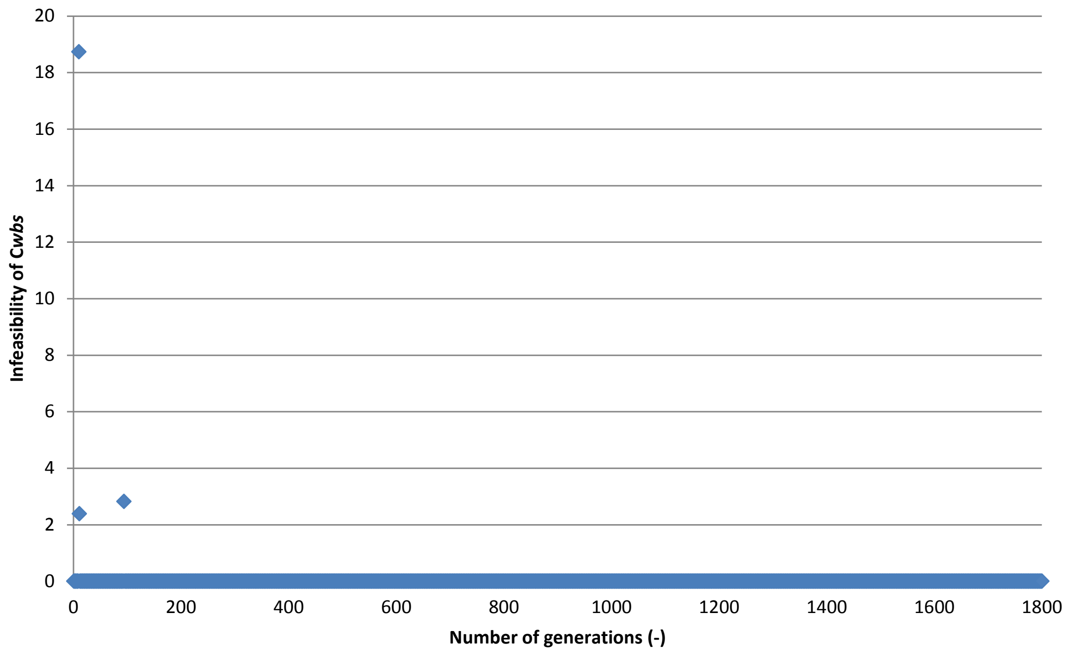

Figure 6.15: Degree of infeasibility for constraint of within building site(C_{wbs}).

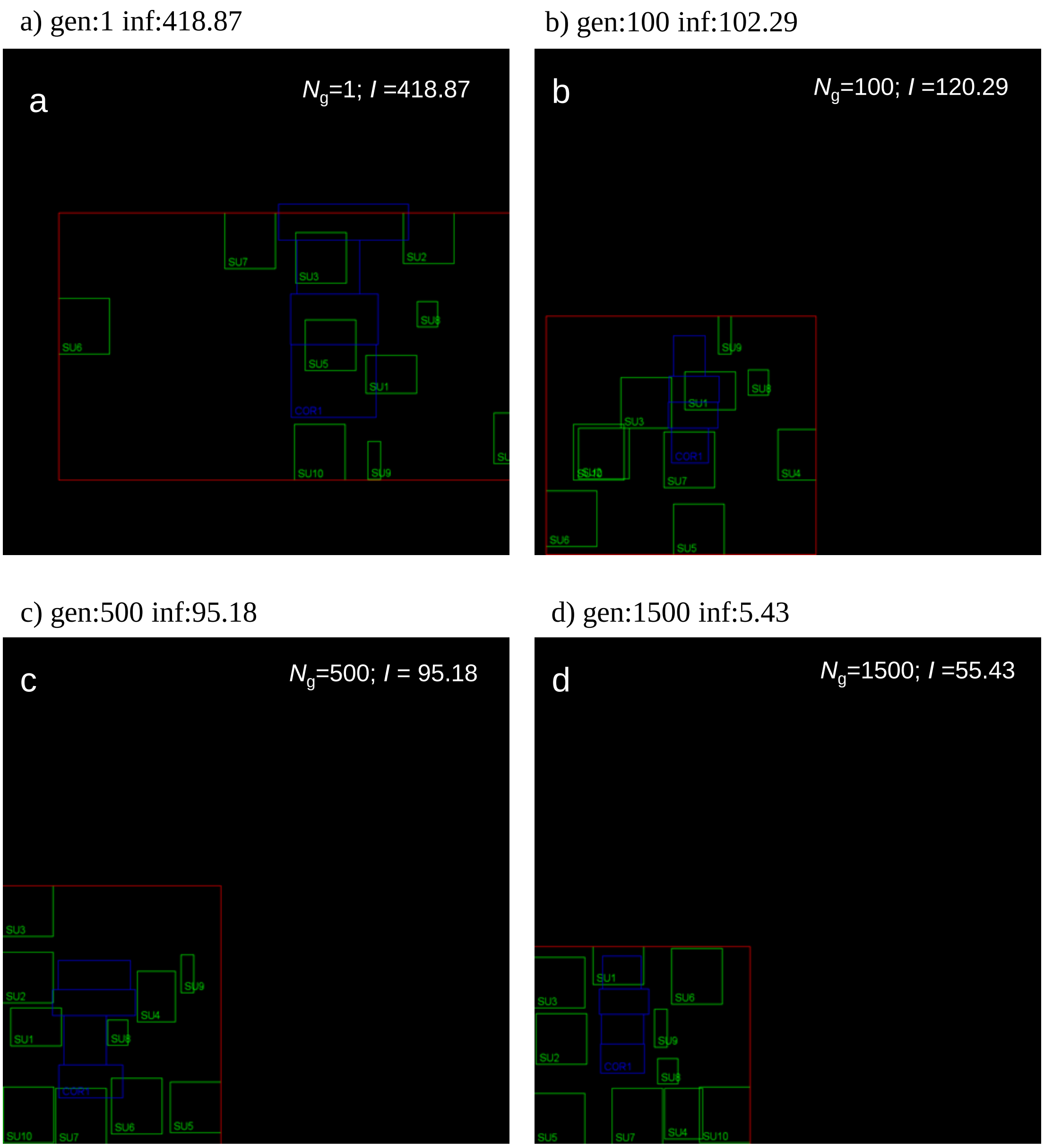

Figure 6.16: Generated spatial layouts (generation 1, 100, 500 and 1500). Green boxes represent spatial units and blue ones represent the corridor.

showing a more compact layout. However, SU_2 and SU_{10} are almost fully occupied, and the corridor are overlapped with SU_1 and SU_7. The third layout is obtained at the 500$^{\text{th}}$ generation, which have better performance in the overlapping constant. There is no overlapping between spatial units, though part of the corridor is slightly overlapped with the corner of SU_6. Nevertheless, there is obvious wasted area between the corridor and the north boundary, which makes the whole layout less compact. Besides, SU_3, SU_9 and SU_5 are found still not accessible to other spatial units. The last produced layout is the best solution with the minimum infeasibility value during the generations. Basically it reflects the proposed real layout with regards to some of the adjacency relationships. But still it appears that the solutions have not converged to a best optimum layout, generated corridor has overlapping part with SU_1, though area of wasted space is reduced down from last layout. Therefore it is also suggested to change parameter values of the genetic operations coupling with reseeding to help improve the performance of the optimisation.

Compared with the proposed layout in reality, the generated layout tried to represent a hospital spatial layout with a centred corridor and surrounded spatial units (Figure 6.17). The Figure 6.16 shows the generated compact layouts, however, it is evident the generated layout is not the optimal solution with regards to objective of compactness. Some gaps between SU_5, SU_2 and SU_7 are not expected and should have been eliminated. Nevertheless, the layout has satisfied the constraint of within building site and there are very few overlaps between spatial units. Comparing with the pre designed relationship chart (Table 6.6), it is found the layout also satisfied some of the adjacency constraints, such as between SU_2 and SU_3, SU_4 and SU_7. The corridor was surrounded by spatial units to form a natural accessibility among each spatial unit. SU_2 and SU_8 are centralised within the layout as they are required to be accessible by many other departments. However, SU_{10} seems inaccessible by most of the spatial unit except SU_4.

The difficulty to reach a satisfactory layout may be due to the scale of the SLP problem compared to the previous one. As described by Harik *et al.* (1999) when the size of the problem increases, the population size also needs to be increased. The analysis shows that all the GA parameters affect collectively for the performance of the optimisation. Thus, values of all other parameters needs to be altered along with population size. Other than this, another reason may due to the performance of GA toolbox, which has no function in reseeding to achieve better performance with lower infeasibility values. Therefore, systematic experiments should be designed and carried out to find the most suitable GA parameter values to solve this problem as discussed in the future work.

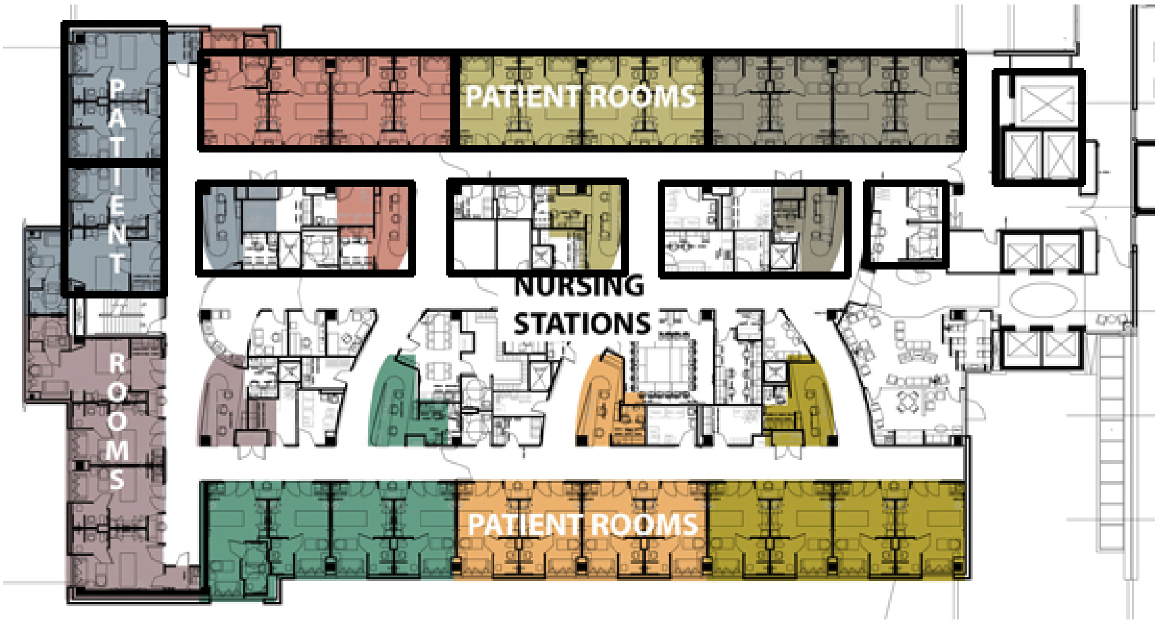

Figure 6.17: Generated spatial units in the proposed layout.

6.5 Discussion and Summary

6.5.1 Performance of using GA toolbox

Various genetic parameters are used to test the optimisation performance, these GA control parameters and their values are: population size (P_s) with two values: 100 and 500; Stochastic fitness ranking probability with one value: 0.45; tournament size (S_t) with two values: 2 and 4; crossover probability (P_c) with two values: 0.85 and 0.9; mutation probability (P_m) with two values: 0.15 and 0.05. The crossover distribution parameter and mutation distribution parameters are 2 and 20 respectively. In addition, 9 sets of experiments were carried out with different pairs of crossover probability and mutation probability.

Performance of GA tool box was evaluated based on the infeasibility value of the best solution produced for a number of generations. Due to the nature of the searching problem, it is unrealistic to find out the optimum solution within a limited generations, which means the pair of GA parameters tested in the experiments only give the best solution for the number of generations.

Results of the figures showed the performance of the optimisation using the parameter set: [P_s=500; P_{rank}=0.45; S_t=2; P_c=0.9 η_c=2; P_m=0.1; η_m=20], which is found is capable to get acceptable solutions. Although this was only based on a limited number of experiments and the most suitable GA parameter will only be tested via different strategies and that has beyond the purpose of this study.

6.5.2 Integrated user perception with spatial layout optimisation

Spatial layout planning is a automated process trying to arrange a number of functional spaces to satisfy a set of requirements and design objectives. There is more than one way of space planning. Previous design requirements are found only focus on the building itself with geometrical and topological constraints, however, it is important to integrate potential building users' preference in the initial design process. As design not only specifies shape and size of the layout, it also take consideration of users' need and reflects in the decision making process.

Two case studies were conducted to implement the developed methodology. The first considered optimising a small scale healthcare building layout, as described in detail in Chapter 6, there are seven spatial units and one corridor in the layout with adjacency and accessibility requirements. The adjacency and accessibility requirements are derived from the hospital user perception and hospital design guidelines. Results from previous user perception questionnaire are implemented to calculate constraints infeasibility of the optimisation. The set of genetic parameters that was selected as described in Chapter 6 was used for the GA toolbox. The second case, explained in Chapter 6, has more spatial units including ten SUs and a more complex corridor, therefore it has more constraint variables. Solutions obtained are quite satisfactory in the first case study compared with the second one. The results are still infeasible after a big number of generations, this is because of the size of the problem and the choice of the suitable parameter set. When previous attempts of SLP that used rectangular SUs such as by Grason (1971) and Arvin & House (2002) it can be observed that, the problems they have chosen are having less than 20 SUs and had not considered the circulation space (HWs). Even in the occasions where, SLP problems have been solved using GA (such as by Jo & Gero (1998)), the researchers have always applied the GA parameters specific to their selected problem without using the same set of GA parameters for a different problem. Therefore, it is necessary to test different parameter sets and utilise the most appropriate ones accordingly in further studies.

6.5.3 Effect of crossover probability (P_c) and mutation probability (P_m)

Nine sets of experiments were carried out to test the effect of crossover probability, a higher value of crossover (set1) indicates a fast convergence to finding the solutions. The higher value of crossover is not supporting the diversity of solutions because rather than searching new space, the generations tend to finding solutions mainly based on the existing search place. It is potentially dangerous to let the search fall into local optima. Based on this experiment, the higher the crossover probability the larger the mean value of infeasibility, therefore, the first pair of parameters was selected since it has the lowest mean value to test the effective of mutation probability.

Four sets of mutation probabilities($P_{m1} = 0.02, P_{m2} = 0.04, P_{m3} = 0.06, P_{m4} = 0.08$)were used in the experiments to test the effectiveness of mutation probability. As the crossover probability is fixed, the comparison result didn't show a huge difference on the selection of different mutation probability. A higher value of mutation rate will increase the diversity of solutions while at the same time it slow down the convergence process. The Figure 6.11 suggests a better combination of GA genetic operators is the third set, however the difference with other pairs is marginal which indicates a little influence in searching the optimum solutions.

6.6 Summary

This chapter proposed a method integrating user preference with SLP optimisation, and investigates the performance of the automated spatial layout programme by carrying out two case studies and experiments that explore effect of parameter values of the genetic algorithm of optimisation.

The first case study consists of a small scale spatial layout with six spatial units and one corridor. The second case study has 10 spatial units and two corridors which represent a larger scale healthcare layout. Conduction of these two case studies showed the potential application of the functional prototype of the spatial layout optimisation. In order to compare performance of the prototyped programme, nine sets were tested with different combination values of crossover and mutation rates. Result shows a lower mutation rate improves better performance. It is suggested a detail test should be carried out to test the variation of mutation rates to justify the influence to the whole performance, keeping the same crossover rate.

Chapter 7

Conclusions and future directions

This Chapter describes the conclusions of the research elaborated in this thesis. The work carried out is briefly explained and the conclusions are stated according to the objectives of the research based on the findings of performance analysis and case studies explained in Chapters 4 to 6.

7.1 Conclusions

A systematic literature review was conducted to investigate the factors influencing the healthcare design. Five main factors were categorised (User satisfaction, safety and well-being, organisational factors, energy and environment and spatial configuration) after the review with each main factor has groups of sub-factors. These generated factors were mainly addressing the need from patients and care providers' perspectives in the healthcare design domain. Aspects need to be considered in building space layout planning (SLP) were also reviewed. Different approaches for space layout planning were analysed with regards to their advantages and disadvantages. Evolutionary algorithms were highlighted for its global searching ability and less possibility getting stuck in local optima. Genetic algorithms were selected to act as optimiser later on in the research. This research then explores the perception of healthcare users on the design of their healthcare environment. This has been achieved by examining the perspectives from care providers, outpatients and inpatients via a questionnaire survey and interviews. Three different types of questionnaire survey were conducted to investigate users' perception of the physical environment in two Chinese hospitals. Through appropriate statistical analysis, findings from the questionnaire revealed the relationships of user demographic information with their perceptions on the design factors. It was found that gender, age, working hours (for care providers) and patients' accommodation experience all have impacts on the user perceptions.

Need for automated layout planning is evident from literature, as human designers are incapable to search and consider each of the SLP solution due to the nature of SLP problem. Therefore, a prototype of an automated spatial layout optimisation was developed to overcome the shortage from human designer's side. This prototype arranges the spatial units in a building site according to various requirements (constraints and objectives). Genetic algorithms were utilised to search the potential solution space since it was found to be the most robust algorithm in solving combinatorial problems. The spatial units were designed in rectangular size with fixed dimensions and the centrally located corridor was designed with flexible length and width. This research integrates the user perception of the design factors that is generated from the questionnaire survey with the developed SLP optimisation by evaluating the infeasibilities of constraints. Constraints of the optimisation were divided into geometrical and topological constraints which include 'non-overlapping', 'within the building site', 'adjacency' and 'travelling distance'. The accessibility of different spatial units was achieved by surrounding the corridor with all the other spatial units. Based on the results of the experiments, the integrated prototype is found to be capable to solve some small scale optimisation problems. Some specific problems can also be solved through the prototype by adding new objective and constraints which need to be mathematically formulated.

7.2 Contribution to knowledge

Three questionnaire surveys were conducted to investigate the user perception of physical environment of the healthcare facilities, which was integrated into an automated spatial layout optimisation in the early design stage. The optimisation prototype was validated through two case studies and the whole research is successful in achieving the aim and objectives stated in Section 1.4.2.

Based on the review of factors influencing the hospital design, three different questionnaire survey were conducted to investigate user perception of the physical environment in two Chinese hospitals. Different perceptions from stakeholders (care providers, inpatients and outpatients) were assessed with regards to different design factors on working environment, waiting areas and patient wards. The methods applied to analyse the survey:

descriptive analysis, principal component analysis and non-parametric tests can be used to analyse similar perception questionnaires. The relationships between respondents' personal information and their perception of design factors are revealed and could be considered as evidence from healthcare building users to integrate into decision making in building design process. This research implemented the integration of user perception with SLP optimisation, which is novel to evaluate the infeasibilities of optimisation constraint from contextualised evidence.

The optimisation prototype was tested through two case studies, one is a design problem typically found in concept design stage where groups of spaces are located in one layout, and the other one represents a design problem typically found during detail design stage, including ten spatial units and one corridor with 4 components. The optimisation prototype produce satisfactory results for both studies, but the research shows that optimisation parameters need to be altered to reach an optimum result. Different optimisation parameter settings suit different SLP problems and GA has been tested to solve the problem properly. Evaluations of the constraints (non-overlapping spatial units, layout within boundary of the site, adjacency and accessibility) can be used to solve other SLP problems, such as in the office building or industrial facilities.

Also the research methodology can be altered to fit in study of other type of built environment. This need to be based on the investigation of the corresponding facility users' perception and the methods to evaluate the specified layout problems. The design objectives and optimisation constraints need to be translated into mathematical formulation and the way this research presents to integrate perception with SLP optimisation could also be used.

7.3 Limitations and future directions

Certain limitations of this research need to be pointed out. The questionnaire survey was conducted in two Chinese hospitals in Qingdao, a major city in Shandong province in Eastern China. The responses are, therefore, inherently the Chinese healthcare users' perception of design factors and their relative importance. However, it should be noted that the difference in perception between respondents from China and the rest of world would be minimal, except for a few design factors that are culturally significant. This is primarily because of the fact that the design and operation of major healthcare facilities such as general or medical college hospitals are more universal than other types of buildings. Also, there is evidence that contemporary developments in Chinese architecture, in particular in urban areas, have had considerable influences from globalization (Ren, 2008) and in a sense Western architectonic philosophies during the second half of the 20th century. The end-product was a rather universal urban fabric, with little difference in spatial organization and manifestation of form and space between urban buildings in China and the rest of the world. The contextual bias from buildings themselves may, therefore, be low. Also, the selected city where the questionnaire survey were conducted has a four–season monsoon–influenced climate, that lies in the transition between the humid subtropical and continental regimes. During the surveyed period, it is milder than inland areas in Shandong province and the weather basically has no influence to patients' accessibilities to the hospital.

Further research may be needed for universal applications of some of the research findings. For example, the relationship between working hours and perception may be affected by average hours worked per week by healthcare providers in a country. Chinese healthcare workers typically worked more hours per week than their counterparts in the West: e.g., American physicians worked 53.9 h (Dorsey *et al.*, 2003) while their Taiwanese counterparts worked 65.6 h per week (Chen *et al.*, 2010). Therefore, the effect of work pattern may be different, the detailed understanding of which requires further research. Another aspect of the study is the proportion of female respondents (63.8%), which may appear high but is demographically representative of healthcare staff in China and the rest of the world. Female nurses make up the majority of the healthcare workforce, which reflects a traditional career trend in healthcare labour markets in most countries (Zurn *et al.*, 2004). Although the research did not find significant differences in perception between administrators and managers vs. physicians and nurses; i.e., non-medical vs. medical e there may be differences between sub-categories.

In terms of the spatial layout planning, it is found that calculation of overlapped areas for evaluating non-overlapping constraint is very difficult as there are a number of combinations in the corner of each spatial units due to its shape and position. Therefore, we use spatial units all in rectangular size to eliminate the problems as previous researchers. There is an avenue for future research applying non-rectangular spatial units in non-rectangular size of layouts. Other operations to enhance the solution quality, such as reseeding, are also suggested in the future study.

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Appdx A Sample of questionnaire survey

Photocopy of a questionnaire survey sample used in the research is provided here.

关于门诊病患人员对医院空间布局认知的问卷

(Patients' perception of hospital space layouts in China)

引言

此调查问卷为拉夫堡大学医疗保健基础设施研究和维护翻新中心**(HaCIRIC)**而设计。我们正在对新建医院或者主要维修医院的相关设计理念进行评估。此问卷的目的是评估医疗保健设施的空间布局图设计情况。

目前，在建筑领域建筑师/设计师可以采用的信息数据有限。我们非常感谢您能填完该问卷并且返回给发卷者，这将有助于我们对空间布局图优化的研究。

参与回答问卷完全是自愿的，我们理解您们或许不能回答这里列出的所有问题。如果您们对一些问题不确切/不知道或者不想回答，请对该项内容不予答复。

如有任何问题请与负责该研究课题的博士生 赵铁嵩 联系，联系地址：英国 拉夫堡大学土木建筑工程系 **LE11 3TU**，电子邮箱：**Y.Zhao2@lboro.ac.uk**

Introduction

This questionnaire is designed for use by the Health and Care Infrastructure Research and Innovation Centre (HaCIRIC) in Loughborough University. We are investigating the factors affecting the design of hospital space layouts for new-build and refurbishment projects. This questionnaire is designed to understand the stakeholders' perception of hospital space layouts.

Available information on various aspects of hospital space layouts and their impact on health and care delivery is limited. Your input will assist us in compiling an evidence base that can be used by design and healthcare professionals to create a better healing environment.

Participation in this questionnaire is strictly voluntary. We understand that you may not be able to answer all the questions asked here; if you are unsure or do not know the answer or would prefer not to answer, please leave the relevant section blank.

Data collected through this questionnaire will be solely used for purposes described here and will be treated as anonymous and confidential.

Thank you for taking time to complete this questionnaire. Please return the completed questionnaire to: Yisong Zhao, Dept. of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, United Kingdom

If you have any questions on how to complete this form, or would like more information, please contact the responsible research student via email:Y.Zhao2@lboro.ac.uk

注：此问卷旨在了解你对医院建筑布局图的看法，他们在患者康复的环境中起到哪些作用，此问卷不针对正在做此问卷的医院。

Please note: This survey seeks your perception/opinion of the aspects that can contribute to a better healing environment; not the existing conditions of the hospital being surveyed.

第一部分：调查时间和地点 Section 1: About this survey

医院名称 Name of the hospital	青岛大学医学院附属医院			
日期 Date	__ / __ / 2009	地点 Location		
时间（调查时间打钩） Time (tick that apply)	☐ 上午 **8** 点**-12** 点 8 AM-12PM	☐ 下午 **12** 点**-4** 点 12 PM-4 PM	☐ 下午 **4** 点**-**晚 **8** 点 4 PM-8 PM	☐ 晚 **8** 点**-**次日早 **8** 点 8 PM-8 AM

第二部分：整体环境 Section 2: The overall environment

1. 请评估以下各方面在医院整体环境中的作用（**1=**最不重要；**2=**不太重要；**3=**一般；**4=**重要；**5=**非常重要）。请在下面方框中打 √

Q1. Please rate the following aspects on their contribution to **the overall environment** in a hospital. (1 = least important, 3 = neither important nor unimportant and 5 = very important)

	1	2	3	4	5
医疗人员业务水平 Professionalism of staff	☐	☐	☐	☐	☐
医院的护理设施（例如，实验室、设备等） Care facilities provided in the hospital (e.g. labs, equipments)	☐	☐	☐	☐	☐
医院的附属设施（如自助餐厅，小卖部等） Ancillary facilities provided in the hospital (e.g. cafeteria)	☐	☐	☐	☐	☐
清洁和维护 Cleanliness and maintenance	☐	☐	☐	☐	☐
传染控制 Infection control	☐	☐	☐	☐	☐
各种辅助设施的可达性以及在医院中步行的路程 Accessibility of the required facilities and travelling distance within the hospital	☐	☐	☐	☐	☐
残疾人通道 Access for the disabled	☐	☐	☐	☐	☐
个人隐私和尊严 Privacy and dignity	☐	☐	☐	☐	☐
有效的医院空间布局图设计 Efficient design of the hospital space layout	☐	☐	☐	☐	☐
医院环境的视觉感官 Visual characteristics of the hospital environment	☐	☐	☐	☐	☐
医院的环境舒适度 Thermal comfort in the occupied spaces	☐	☐	☐	☐	☐
合适的光线 Adequate lighting in all areas	☐	☐	☐	☐	☐
晚上环境的安静度 Quiet environment at night	☐	☐	☐	☐	☐
室内外环境（包括花园、雕塑等） Interior and/or exterior landscape (including gardens, sculptures, etc.)	☐	☐	☐	☐	☐
亲友探视的条文规定 Provision for frequent visits from family and friends for patients	☐	☐	☐	☐	☐

第三部分：普通区域 Section 3: Waiting and other areas

2. 根据医院对患者康复比较理想的环境需求，评估除了病房以外其他区域相关的各个方面（**1=**最不重要；**2=**不太重要；**3=**一般；**4=**重要；**5=**非常重要）。请在下面方框中打 √

Q2. Please rate the following aspects related to the **waiting or other areas** (except in-patient rooms) in a hospital, according to their importance in creating a better healing environment in hospitals. (1 = least important, 3 = neither important nor unimportant and 5 = very important)

	1	2	3	4	5
空间的建筑设计 Architectural design of the space	☐	☐	☐	☐	☐
家具的摆放 Furniture layouts	☐	☐	☐	☐	☐
环境赏心悦目的颜色设计 Pleasant colour scheme	☐	☐	☐	☐	☐
宽敞度 Spaciousness	☐	☐	☐	☐	☐
室内花草以及室内外景观 Indoor plants, interior/exterior landscaping	☐	☐	☐	☐	☐
合适的艺术作品摆放（如画、雕塑等） Presence of coordinated art objects (e.g. painting, sculpture, etc.)	☐	☐	☐	☐	☐
提供足够的座位（合适数量的座位）Seating sufficiency (adequate number of seats)	☐	☐	☐	☐	☐
座位的舒适度 Seating comfort	☐	☐	☐	☐	☐
外部景观 Exterior view	☐	☐	☐	☐	☐
室内采光 Availability of daylight	☐	☐	☐	☐	☐
提供合适充足的光线（包括灯光和自然光线） Adequate illumination (artificial and natural lighting combined)	☐	☐	☐	☐	☐
舒适的环境温度 A thermally comfortable environment	☐	☐	☐	☐	☐
噪音 Noise	☐	☐	☐	☐	☐
空气清新（没有异味）Air freshness (absence of unpleasant smell)	☐	☐	☐	☐	☐
清洁度 Cleanliness	☐	☐	☐	☐	☐
娱乐设施 （如广播、电视等）Entertainment facilities (e.g. radio/television broadcast, etc.)	☐	☐	☐	☐	☐

第四部分：普通区域 Section 4: Corridors

3. 根据医院对患者康复比较理想的环境需求，评估与走廊有关的各个方面（1=最不重要；2=不太重要；3=一般；4=重要；5=非常重要）。请在下面方框中打 √

Q3. Please rate the following aspects related to the **corridors** in a hospital, according to their importance in creating a better healing environment in hospitals. (1 = least important, 3 = neither important nor unimportant and 5 = very important)

	1	2	3	4	5
寻路系统（包括合适的标志、标志颜色等） Wayfinding system (includes proper signposting, colour coordination, etc.)	☐	☐	☐	☐	☐
走廊宽度 Spaciousness of corridors	☐	☐	☐	☐	☐
走廊不作其他用途（如等诊）Elimination of other uses (e.g. waiting) in the corridors	☐	☐	☐	☐	☐
外部景色 Exterior view	☐	☐	☐	☐	☐
室内采光 Daylight	☐	☐	☐	☐	☐
提供合适充足的光线（包括灯光和自然光线） Adequate illumination (artificial and natural lighting combined)	☐	☐	☐	☐	☐
环境赏心悦目的颜色设计 Pleasant colour scheme	☐	☐	☐	☐	☐
悬挂、摆放艺术品（包括画和雕塑） Presence of painting including painting and sculpture	☐	☐	☐	☐	☐
摆放花草 Presence of plants	☐	☐	☐	☐	☐
路过有异味的地方 Passing through areas with unpleasant smells	☐	☐	☐	☐	☐
路过治疗区 Passing through treatment areas	☐	☐	☐	☐	☐
走廊里的噪音 Noise level in the corridor	☐	☐	☐	☐	☐
清洁 Cleanliness	☐	☐	☐	☐	☐

第五部分：您的情况 Section 5: About you and your stay

您的年龄。Please select your age.

☐ **18-25** 岁 18-25 years	☐ **26-35** 岁 26-35 years	☐ **36-50** 岁 36-50 years	☐ **50** 岁以上 Over 50 years

您的性别。Please select your gender.

☐ 男 Male	☐ 女 Female

来此医院次数？How many times have you been to this hospital?

☐ **1-2** 次 1-2 times	☐ **3-4** 次 3-4 times	☐ **5-10** 次 5-10 times	☐ **10** 次以上 >10 times

此次来医院是急诊还是非急诊？
Is your current visit to the hospital an emergency or pre-arranged?

☐ 急诊 Emergency	☐ 非急诊 Pre-arranged

请标明此次来访的病房或科室 Please indicate wards/ unit areas you are visiting

☐ 急诊科 A & E	☐ 胃肠 Gastrointestinal	☐ 手术室 Operating theatres
☐ 行政 Administration	☐ 普通外科 General surgery	☐ 矫形科 Orthopaedics
☐ 烧伤 Burns	☐ 妇科 Gynaecology	☐ 门诊 Outpatients'/ clinics
☐ 心脏 Cardiac	☐ 血液学, 血液病 Haematology	☐ 儿科/新生儿科 Paediatrics/ neonatal
☐ 中医 Chinese medicine	☐ 传染病科 Infectious diseases	☐ 临终关怀 Palliative care
☐ 临床药物学 Clinical pharmacology	☐ 心理健康 Mental health	☐ 呼吸科 Respiratory
☐ 社会关怀 Community care	☐ 产科 Midwifery	☐ 泌尿科 Urology
☐ 临床护理（重点护理组/需要医疗及监护组）Critical care (ICU/HDU)	☐ 神经科 Neurosurgery/ neurology	☐ **X** 光室/病理科 X-Ray/ Pathology
☐ 老年看护 Elderly care	☐ 护士工作站 Nursing station	☐ 其他(请说明)_______________ Other: (Please specify)
	☐ 肿瘤学 Oncology	

请写出您对医院治疗环境的设计的看法。（例如，布局，光线以及其他。）Please feel free to write any comments you have on the design of healing environments in a hospital (e.g. layout, lighting, etc.)

非常感谢您填完该问卷。Thank you for your time in completing this survey.

Appdx B Table of data extraction from Chapter 2

Table of data extraction from Chapter 2.

Table B.1: Data extraction from literature review of factors affecting hospital design

Focus area	Author	Year	Methodology	Contribution to knowledge
Patient dignity	Baillie	2009	Qualitative, triangulated single case study	A single case study explore that how the environment, staff behaviour and patient factors impacted on patient dignity.
	Dvoskin *et al.*.	2002	Cross sectional design	Describe how to design a secure forensic state psychiatric hospital.
	Matiti & Trorey	2008	Phenomeno-logical hermeneutic approach-interview	Identified six key themes that contribute to the preservation of patient dignity.
	Thrall	2005	Case study	Focus on the efforts of patients accommodation in hospital that encourage more space around the bed.
Patient falls	Fortinsky *et al.*	2004	Cross-sectional study using a structured interview	Determine how the healthcare providers address fall risk factors in older patients and determine the educational levels to be the barriers.
	Hendrich *et al.*	1995	A case-control study	Logistic regression was used to develop a multi-variate risk factor model with seven risk factors.
	Hendriks *et al.*.	2005	Two-group randomised controlled trial	Three types of evaluations (effect, econom-ic and process) of a multidisciplinary intervention programme to prevent falls.

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Focus area	Author	Year	Methodology	Contribution to knowledge
Patient safety	Krauss *et al.*	2007	Retrospective cohort study	The study collected data of patient fall from nine hospitals from 2001 to 2003 and use logistic regression to determine relationship between fall circumstances and hospital types.
	Hartmann *et al.*	2009	Case study	Data collected from 30VA hospitals over 6-month period to measure safety climate and organizational culture.
	Joseph & Rashid	2007	Literature review	Noise, air quality, lighting conditions and unit layout, patient room design and other features were identified to be linked with patient safety.
	Olden & McCaughrin	2007	Pre-test and post-test	Offer a framework by integrating multiple organizational factors and using well-accepted organization theory to reduce medical errors and enhance patient safety.
	Reiling	2006	Case study	Introducing safety-driven innovations into the facility design process.
	Reiling *et al.*	2004	Pre-test of new design for safety	Innovative design elements were reflected by safety-driven design principles.
	Sari *et al.*	2007	Two stage retrospective review	Evaluate the performance of a routine incident reporting system in identifying patient safety incidents.
Patient satisfaction	Veillard *et al.*	2005	Literature review and pre-test	PATH was developed to assess the hospital performance.

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Focus area	Author	Year	Methodology	Contribution to knowledge
	Douglas & Douglas	2005	Case study including questionnaire survey	Explore patients' perceptions of health-care built environments and develop a set of patient-centered indicators.
	Janssen *et al.*	2000	Case study	Single room care was found to be a significant improvement in client satisfaction.
	Mroczek *et al.*	2005	Quantitative study	Analysis from a survey shows that the physical environment is necessary in influencing how the staff views their workplace as well as how they might fare with regard to their own health.
Positive distraction	Joye	2007	Case study	Adverse effects of lack contact with natural contents on psychological and physiological well-being.
	Uding *et al.*	2007	Case study	Articulates specific ways parents were involved in the quality program and the role of the parent co-investigator.
Spatial arrangement	Alalouch & Aspinall	2007	Case study(using Space Syntax)	Explore the relationship between plan configuration of buildings and subjective judgments on spatial locations for privacy.
	Alalouch *et al.*	2009	Case study (using Space Syntax)	Explore preference for privacy among different people in multi-bed wards.
	Chaudhury *et al.*	2006	Pilot study	Majority of respondents prefer single rooms over double-occupancy rooms.

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Focus area	Author	Year	Methodology	Contribution to knowledge
	Kibbler *et al.*	1998	Case study using survey	Examine the effect of adding a fifth bed to four-bedded bays in three acute medical wards on colonization.
	O'Connell & Humphreys	2000		Examine the design and layout of ICU for better reduction of infection.

Appdx C Publication list and selected publications

A list of publications is provided in appendix.

- **Zhao,Y.** and Mourshed,M. (2013) Outpatients perception on the design of waiting areas in healthcare facilities. Indoor and Built Environment. (in process)
- **Zhao,Y.** and Mourshed,M.(2012) Design indicators for better accommodation environments in hospitals: inpatients perceptions. Intelligent Buildings International 4, 199-215.
- Mourshed,M. and **Zhao,Y.** (2012) Healthcare providers perception of design factors related to physical environments in hospitals. Journal of Environmental Psychology, 32(4), 362-270.
- **Zhao,Y.**, Mourshed,M. and Wright,J. (2009) Factors influencing the design of spatial layouts in healthcare buildings. In: Dainty, A. (Ed) Procs 25th Annual ARCOM Conference, 7-9 September 2009, Nottingham, UK, Association of Researchers in Construction Management, 1041-49.
- Lu, J. and **Zhao, Y.** (2009), Health Space Design, Evidence Based Design of Built Healing Environment, HaCIRIC BHE Final Study Report, Health and Care Infrastructure Research and Innovation Centre (HaCIRIC), Loughborough University, Loughborough, UK, pp.32-52.

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Healthcare providers' perception of design factors related to physical environments in hospitals

Monjur Mourshed*, Yisong Zhao

Building Energy Research Group, School of Civil and Building Engineering, Loughborough University, Loughborough LE11 3TU, United Kingdom

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ABSTRACT

Research indicates that staff wellbeing, productivity and satisfaction are linked with a hospital's physical environment, in particular the aspects that are determined during early design stages of a building's lifecycle. Incorporating healthcare providers' perspectives during the design of a facility is, therefore, essential to create an effective therapeutic environment. Past research on physical environments in hospitals focused mostly on user satisfaction and was linked with service delivery in a specific setting. Research findings seldom provided useful insights into user perspectives on design related aspects that had the potential to affect their interaction with the environment. This research was aimed at filling this gap by exploring healthcare providers' perception of physical environment design factors in hospitals. A 16-item questionnaire was used to gather perspectives of nurses, doctors and administrative staff in two Chinese hospitals, with a response rate of 77.3% ($N = 304$). Descriptive, principal component analysis and statistical tests were applied on the responses to investigate the relationship between perceptions of design factors and demographic and work related variables. Three principal components were identified, namely spatial, maintenance and environmental design. The identified components had good correspondence with previous research on behavioral and environmental psychology. Female healthcare providers were found to be more perceptive about factors related to sensory environments such as visual, acoustic and olfactory, compared to their male counterparts. The working pattern and length of service had associations with perceptions of maintenance and environmental design factors. Respondents ranked abstract and more subjective design factors such as aesthetics and the presence of coordinated art objects lower than the factors generally associated with the safe and efficient delivery of service.

1. Introduction

Research suggests a strong association between health outcomes and the physical environment in which a person lives or receives treatment (Gesler, Bell, Curtis, Hubbard, & Francis, 2004; Rollins, 2004; Ulrich et al., 2008; Whitehouse et al., 2001). Consequently, attention has recently been turned on the actual architectural design of a healthcare facility (Reiling, 2007). The idea of 'place making' or the provision of an optimum psychological fit between people and their physical surroundings has received renewed interests among the design community (Sime, 1986), in particular from healthcare designers (Prasad, 2008). Place making can be seen as a move away from the mere geometric design of spaces toward a more holistic consideration of user perception and behavior in the physical context. Examples of place making by integrating research-based evidence in hospital design can be found in the idea of 'sense sensitive design' (Mazuch, 2005). The need for integrating user perception and preference of their physical surroundings in buildings has also been highlighted, directly or indirectly, in past research on post occupancy evaluations of buildings (Dinç, 2009), user satisfaction (Crow et al., 2002) and indoor thermal comfort (De Dear, 2004).

There is also a growing body of evidence on the impact of the working environment on healthcare providers' efficiency, productivity and satisfaction that contribute to patient outcomes. In a recent research on the effect of work environments on hospital outcomes across nine countries, Aiken et al. (2011) have concluded that poor hospital work environments were common and were associated with negative staff outcomes and poor quality of care. Staff turnover, in particular nursing staff turnover, has been found to be a growing risk in many developed countries. Determinants of turnover are found to be multifaceted and dependent on the context of the study and points of view of the researcher (Hayes et al., 2006). However, work environments are found to be commonly associated with staff turnover (Hayes et al., 2006; Jones, 2005), in addition to leadership and management approaches (Cummings et al., 2010). Physical environments are also linked with

* Corresponding author. Tel.: +44 1509 228792.
E-mail address: m.m.mourshed@lboro.ac.uk (M. Mourshed).
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staff wellbeing issues such as injury rates and stress (Trinkoff, Johantgen, Muntaner, & Le, 2005). Ulrich et al. (2008) have discussed physical environment factors that affect staff outcome in a review article. They identified that well designed hospital environments had the potential to increase staff effectiveness and satisfaction; reduce medical errors and hospital acquired infections; and decrease staff stress and injuries.

Improving the quality of care and efficiency of service delivery while reducing costs have become increasingly important because of the greater budgetary pressure in recent years. Healthcare expenditure accounts for a significant share of the national budget in most countries (Garrett, Chowdhury, & Pablos-Méndez, 2009). There is, therefore, a growing need for transparency in decision-making that is based on the evidence of the impact of physical environments on healthcare quality. Assessments of healthcare quality were typically based on professional practice standards and seldom incorporated aspects related to physical environments (Devlin & Arneill, 2003). However, the opinion of healthcare facility users is increasingly being accepted as an important indicator for measuring healthcare quality and as a critical component of performance improvement and clinical effectiveness (Woodring et al., 2004). Healthcare providers constitute the most frequent facility user group who spend most of their working time in hospital indoor environments. Their opinion on the design of a hospital provides valuable information and expertise to hospital designers, as healthcare providers are familiar with the physical aspects of the environment, as well as its relationship with the requirements of their work.

Most aspects of the physical environment having an impact on staff outcome are determined during early design stages of a building's lifecycle. Subsequent modifications at later stages are expensive and sometimes difficult to achieve due to the multidisciplinary nature of design decision-making. An understanding of users' perception of design factors is, therefore, essential for informed decision making during early design stages. Past research on physical environments in hospitals focused mostly on staff satisfaction and was linked with service delivery in a specific context (see Vischer, 2007, for a discussion). User satisfaction studies provided an indication of some relevant physical environment features that could be considered during design. Nevertheless, they were mere proxies, which needed translating into design factors before use and not without some loss of semantics. Moreover, physical environment factors were not studied in an integrated way in a single study to generate a comprehensive evidence base, upon which decisions could be made.

This study was aimed at filling this gap by contributing to the evidence base on factors related to physical environments in hospitals. Healthcare providers' perceptions of 16 design factors, identified through a review of existing literature, were explored by conducting a questionnaire in two Chinese hospitals.

The rest of the paper is organized as follows. The methods for the development of the instrument and the conduct of the questionnaire are discussed. Descriptive and statistical analyses of the obtained data are discussed next, followed by a contextual discussion. Research limitations are discussed next. The article ends with a summary of findings and concluding remarks.

2. Methods

2.1. Questionnaire development

The questionnaire instrument was developed in four stages.

First, the items of the questionnaire were identified based on a review of literature and industry guidelines, conducted between January and May 2009. The purpose of the review was to identify the design factors that:

- Modify physical environments in healthcare facilities;
- Affect users' perception and satisfaction of the physical environment; and
- Affect the delivery of service and clinical outcome.

Table 1 lists the investigated design factors, identified from the review of literature and industry guidelines. Key sources are also listed to contextualize the inclusion of the factors with previous research findings.

Second, one of the authors visited the two participating hospitals four times and interviewed members of staff to explore their perspectives on the physical environment, in particular the factors that can be addressed during design/refurbishment of hospitals.

Third, a draft questionnaire was developed by incorporating the findings from the first two stages. The questionnaire was first produced in English and then translated to Chinese. Two healthcare professionals and two administrators reviewed the draft for accuracy and content validity. The draft questionnaire was then evaluated in a pilot study to analyze the comprehensibility and clarity of the items and features related to the psychometric properties of the instrument. The participants ($N = 21$) of the pilot study included head nurses, physicians and administrators. All participants were asked to state any deficiencies of the content of the questionnaire, other potential sources of perceptions and significance of each item. The pilot study resulted in an amended final questionnaire with improved content validity.

Fourth, the final questionnaire included 16 structured questions to rate the perception of the importance of the dimensions of the physical environment in healthcare facilities. Respondents were asked to rate their perception of an item on a 5-point scale, ranging from 1 to 5 (1 = Least important; 2 = Unimportant; 3 = Neither important nor unimportant; 4 = Important and 5 = Very important). The questionnaire also contained an open-ended question to enable respondents to communicate their ideas on how to improve the physical environment. Demographic information such as age and gender were included. Data regarding the length of service in the hospital and weekly working hours were recorded as well.

2.2. Study participants

The study was conducted among healthcare providers that included doctors, nurses, technicians, and administrative/managerial staff in two Chinese hospitals in Qingdao, a coastal city in Eastern China. The hospitals were chosen for this research because of their size, reputation, world-standard facilities and the relatively large number of staff and patients. One of the hospitals is affiliated with a medical college and the other one is a general hospital, which is also the largest in the city. Combined, these two hospitals employed approximately 5900 staff and had around 4000 beds at the time of the study. Respondents were selected at random to participate in the questionnaire. All of the respondents were at least 18 years old and had worked in the respective hospitals for at least 6 months prior to the questionnaire being administered. Probationer doctors and nurses were also included in this study, in particular in the hospital affiliated with the medical college. Respondents were communicated in writing that the participation in the questionnaire was voluntary and that the confidentiality of the data would be maintained.

2.3. Ethical considerations

A two-stage ethical approval was obtained for this questionnaire. In the beginning, an ethical approval was obtained from the authors' academic institution in the UK. Furthermore, the research committees of the two participating hospitals gave approval to the study.

Table 1
Design factors identified from the literature review.

Design factor	Impact
Adequate illumination	Adequate illumination, artificial and natural lighting combined, is required to perform visual tasks (Shikder, Mourshed, & Price, 2012). Adequate illumination on work surfaces lowers rates of medication-dispensing errors (Buchanan, Barker, Gibson, Jiang, & Pearson, 1991).
Air quality and freshness	Defined as the absence of unpleasant smell. Poor and insufficient ventilation decreases work efficiency and productivity (Seppänen et al., 2006). Poor air quality increases the risk of nosocomial infection (WHO, 2002).
Architectural design of the space	Architectural design of a space is more than just the geometric organization; it influences users' sensory perceptions. Spatial architectural designs affect staff recruitment and retention, as well as efficiency and productivity (Guenther & Vittori, 2008).
Availability of daylight	Light, especially daylight impacts on visual performance and psychological state of a person by regulating the circadian rhythm. It impacts on patient outcome, as well as provide restorative benefits to medical staff and office workers (Ulrich et al., 2008). The lack of daylight has also been associated with job burnout (Alimoglu & Donmez, 2005) and medication errors (Roseman & Booker, 1995).
Cleanliness and ease of maintenance	The design of the building and constituent spaces are linked with cleanliness (PwC, 2004). Surface characteristics affect infection control (Dancer, 2011).
Exterior view from the space	Views to the outside are manifested as positive emotional and physiological changes leading to stress reduction or restorative benefits (Ulrich, 1984).
Furniture layout	Ergonomic characteristics of furniture and equipment can cause long-term muscular or nerve injury due to poor bodily positioning or muscle use (Vischer, 2007). Furniture layout has been identified as the primary concern for patient falls (Tzeng & Yin, 2009).
Indoor plants and landscaping	Contribute to positive distraction and a pleasant working environment. Views of natural settings are found to influence patient recovery (Ulrich, 1999).
Location and orientation of the space	Linked with site specific thermal, visual, auditory and olfactory environments. In terms of physical settings, poor location and orientation of a space may result in a poor wayfinding system and may contribute to increased staff stress and time wastage (Zimring, 1990).
Noise level	The level of ambient noise has strong links with patient outcomes. Staff effectiveness increase in quiet settings (Dubbs, 2004). Healthcare providers perceive higher noise levels as stressful and sufficiently high to interfere with their work (Bayo, García, & García, 1995).
Pleasant color scheme	Color, an inherent property of all materials and surfaces, is considered an inseparable element of design. Together with lighting, color has an impact on people's responses to the environment and affect staff morale and quality of healthcare (Dalke et al., 2006).
Presence of coordinated art objects	Art-based interventions are found to be effective in reducing adverse physiological and psychological outcomes (Stuckey & Nobel, 2010). There is potential to enhance staff morale and satisfaction by integrating them in arts initiatives that have a positive healing effect on patients. However, Ulrich et al. (2004) found that not all art was suitable for healthcare spaces.
Proximity to wards	Long distances between different working areas have a negative impact on nursing performance (PwC, 2004) and quality of care.
Provision for hand hygiene	Hands of healthcare staff are the principal cause of nosocomial or hospital acquired infection (HAI) (Pittet et al., 2000). The lack of hand hygiene provisions such as availability of washbasins is perceived as a factor contributing to HAI (Lankford et al., 2003).
Spaciousness	The lack of spaciousness has been seen as a strong ambient stressor (Stamps III, 2007). Perception of room spaciousness has effects on user satisfaction and performance (O'Neill, 1994).
Thermal comfort	Thermal discomfort is associated with inadequate work ability among nurses (Fischer et al., 2006) and decreased productivity by influencing their ability to think (Witterseh, Wyon, & Clausen, 2004).

2.4. Data collection

Data for this study were collected between 12 and 26 August 2009, a time period in which there were not any special holidays in China that could create a possible bias from the use of seasonal decorations in the hospital physical environments. Two different data collection strategies were applied.

First, some of the respondents were randomly selected from each floor. In the outpatient departments, the timing for selection was between 8 am and 5 pm, Monday–Friday, which was representative of usual work practices in most departments, including outpatients. Respondents from the inpatient departments were selected during the day and evening to account for various work patterns. The researcher introduced him and the objectives of the study before handing out the questionnaires.

Second, administrative/managerial staff (e.g., head of a department) was selected during their regular meetings on Wednesday and Thursday afternoons in the two hospitals respectively. Visual aids (PowerPoint) were used to introduce the researcher and the objectives of the study to the attendees as a group, before handing out the questionnaires.

An informed consent was obtained from each participant in the study. Some of the completed questionnaires were collected as soon as they were finished, if both the respondent and the researcher happened to be available at that moment. Otherwise, the researcher went back to collect questionnaires filled in by the respondents who were occupied when they got the questionnaires.

A total of 304 members of staff from the two Chinese hospitals completed the questionnaires in full, out of the 400 distributed and the results were included in the study. The response rate was 77.3%.

2.5. Data analysis

Most statistical analyses have been performed with PASW Statistics version 18.0 for Windows (IBM-SPSS, 2010). Nevertheless, the researchers have carried out the test for differences in dependent correlations. Descriptive statistics on the item and scale frequencies, percentages, means and standard deviations (SD) were computed. Demographic and work related data were also analyzed descriptively by computing frequencies and percentages. Internal consistency reliability was assessed via Cronbach's coefficient alpha (Cronbach, 1951). $\alpha \geq 0.70$ was used as the recommended value, as this study involved the comparison of groups of respondents (Nunnally & Bernstein, 1994).

In order to reduce random sources of error and be able to assess the reliability and validity of a particular questionnaire the use of multi-item scales has been suggested by Nunnally and Bernstein (1994). This study employed Principal Component Analysis (PCA), a mathematical technique to identify the underlying structure characterizing a set of highly correlated variables. The PCA analysis showed that fewer items in the main study had a factor loading $\geq$0.30 in more than one factor, compared to the pilot study. The factors from the main study were easier to label and had good correspondence with other studies. Variance maximization (varimax), an orthogonal rotational strategy has been chosen for this study. PCA was performed for the 16 individual items at a significance level $p = 0.001$. Three summated indices were extracted from the 16 question items of the physical environment: spatial design, environmental design and design for maintenance.

2.6. Interviews to validate research findings

Twelve questions were initially designed to obtain healthcare providers' perception of design factors in one of the above-mentioned hospitals. These questions evolved from the literature review, initial questionnaire findings and through discussions with members of staff at the surveyed hospitals. In order to ensure that the questions were directed, simple and specific while avoiding double-barreled questions, a senior member of staff was asked to answer all of the questions and give feedback for improvement. Finally, seven key questions were formulated for the interview.

Interview participants were selected from the questionnaire respondents. There was a section in the questionnaire on whether the respondent would be interested in participating in a further interview. Only nine nurses opted in, of which six were randomly selected for interview. The interview questions focused on the assessment of the perception of building design factors and their impact on healthcare providers and patients. The interviewees were informed beforehand that the interviews would be recorded and the confidentiality of the information would be maintained.

3. Results and analysis

3.1. Respondents' characteristics

Demographic and work related characteristics of the respondents are given in Table 2. Among 304 respondents, 110 (36.2%) were male and 194 (63.8%) were female. Almost half of the respondents (46.1%) were aged between 26 and 35 years whereas the percentages of respondents at either end of the population were 17.1% and 3.9% for age groups 18–25 and above 50 years respectively. At the time of the survey, 31.5% and 34.9% of the respondents had been working in respective hospitals for periods 1–5, and 6–10 years respectively. Majority of them (72.4%) worked between 41 and 60 h per week while only 4.6% of the respondents worked more than 60 h per week. The department of general surgery represented the highest number (13.8%) of returned questionnaires. Other respondents came from the remaining 26 departments across the hospitals. The diversity of different working areas ensured that a wide range of respondents was represented in this study. A descriptive analysis of the questionnaire items is given in Table 3.

3.2. Principal component analysis

A principal component analysis (PCA) was conducted on the 16 questionnaire items with varimax rotation. The Kaiser–Meyer–Olkin (KMO) (Kaiser, 1974) measure verified the sampling adequacy for the analysis, KMO = 0.883, which can be considered high (Field, 2009). Bartlett's test of sphericity yielded a statistically significant value ($\chi^2 = 2255.424$; $p = 0.000$). These indices implied that the matrix was well suited for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Three components had eigenvalues over Kaiser's criterion of 1 and in combination explained 58.4% of the variance. Given the large sample size, the convergence of the scree plot and Kaiser's criterion on three components, this is the number of components that were retained in the final analysis. Factor loadings after rotation are given in Table 4. The PCA result suggested that components 1, 2 and 3 represented spatial design, environmental design and the design for maintenance aspects, respectively.

Table 2
Background information of the respondents.

Variable	Scale/category	*N*	%
Age (yr)	18–25	52	17.1
	26–35	140	46.1
	36–50	100	32.9
	>50	12	3.9
Gender (–)	Male	110	36.2
	Female	194	63.8
Working hour (hr)	<20	2	0.7
	20–40	68	22.3
	41–60	220	72.4
	>60	14	4.6
Length of service (yr)	<1	33	10.9
	1–5	96	31.5
	6–10	106	34.9
	>10	69	22.7
Department	Accident and emergency	14	4.6
	Administration	35	11.5
	Burns	5	1.6
	Cardiac	17	5.6
	Chest surgery	9	3
	Chinese medicine	6	2
	Clinical pharmacology	12	3.9
	Critical care (ICU/HDU)	10	3.3
	Dermatology	3	1
	Elderly care	2	0.7
	Gastrointestinal	11	3.6
	General surgery	42	13.8
	Hematology	15	4.9
	Hepatology	6	2
	Incretion	1	0.3
	Infectious diseases	3	1
	Management	12	3.9
	Midwifery	11	3.6
	Neurosurgery/neurology	6	2
	Operating theaters	6	2
	Orthopedics	17	5.6
	Ophthalmology	3	1
	Pediatrics/neonatal	4	1.3
	Respiratory	24	7.9
	Stomatology	2	0.7
	Urology	14	4.6
	X-Ray/pathology	14	4.6

Table 3
Descriptive analysis.

Item	Response[a] (%)					Mean	SD
	1	2	3	4	5		
Cleanliness and ease of maintenance	0	0	2.3	29.6	68.1	4.66	0.522
Air quality and freshness[b]	0.3	0.7	6.3	45.4	47.4	4.39	0.666
Noise level	0.3	1	9.2	43.4	46.1	4.34	0.713
Thermal comfort	0	1	10.2	48	40.8	4.29	0.685
Proximity to wards	0	1.6	9.9	46.7	41.8	4.29	0.709
Provision for hand hygiene	0	3.3	10.9	49	36.8	4.19	0.757
Adequate illumination[c]	0	0.7	13.2	55.6	30.6	4.16	0.663
Availability of daylight	0	1	17.1	57.2	24.7	4.06	0.675
Spaciousness	1.1	1.1	20.4	52	25.7	4.00	0.769
Location and orientation of the space	0.3	2.6	27	51.6	18.4	3.85	0.754
Architectural design of the space	0	5.3	27.3	50	17.4	3.80	0.786
Pleasant color scheme	0	5.3	33.6	48.7	12.5	3.68	0.757
Exterior view from the space	1.3	4.9	32.2	49.3	12.2	3.66	0.804
Furniture layout	1	5.6	39.1	47.7	6.6	3.53	0.744
Indoor plants, interior/exterior landscaping	0	7.6	39.5	46.7	6.3	3.52	0.726
Presence of coordinated art objects	1	11.5	42.1	41.4	3.9	3.36	0.775

[a] 1: Least important; 2: Unimportant; 3: Neither important nor unimportant; 4: Important; 5: Very important.
[b] Defined as the absence of unpleasant smell.
[c] Overall lighting: artificial and natural lighting combined.

Table 4
Rotated component matrix of questionnaire items.

Item	Component		
	Spatial	Environmental	Maintenance
Indoor plants, interior/exterior landscaping	0.729	–	–
Furniture layout	0.715	–	–
Exterior view from the space	0.713	–	–
Presence of coordinated art objects	0.699	–	–
Pleasant color scheme	0.699	–	–
Architectural design of the space	0.658	–	–
Location and orientation of the space	0.647	–	–
Adequate illumination	–	0.753	–
Availability of daylight	–	0.737	–
Thermal comfort	–	0.726	–
Noise level	–	0.694	–
Air quality and freshness	–	0.682	0.408
Provision for hand hygiene	–	–	0.746
Proximity to wards	–	–	0.643
Cleanliness and ease of maintenance	–	0.449	0.522
Spaciousness of working areas	0.475	–	0.487
Percentage of explained variance (58.4)	40.83	11.12	6.4
Cronbach's α coefficient (0.901)	0.863	0.852	0.736

The reliability of each attribute was examined by Cronbach's alpha coefficient. The reliability estimates of all three components were greater than 0.70, as shown in Table 4, indicating a strong internal reliability among items with similar attributes. The internal consistency reliability of the overall scale was 0.901 that exceeded Nunnally's criteria, suggesting little measurement error in the instrument. According to the results, nearly half of the total variance (40.837%) was explained by component 1 (spatial design). The rest of the variance was explained by the remaining two components.

Three of the 16 items had dual loadings on two factors. The item, 'air quality and freshness' had loadings of 0.682 and 0.408 on environmental and maintenance factors respectively. 'Cleanliness and ease of maintenance' had loadings of 0.449 and 0.522 on environmental and maintenance factors respectively. The item, 'spaciousness of working areas' had loadings of 0.475 and 0.487 on spatial and maintenance factors respectively. To investigate further, Cronbach's α, if the item was deleted, was examined for each item. The value for α decreased if any of the items were deleted, except for 'cleanliness and ease of maintenance'. The increase in Cronbach's α for 'cleanliness and ease of maintenance' was marginal ($0.902 - 0.901 = 0.001$). On the other hand, with a mean score of 4.66 out of 5.00, cleanliness was ranked as very important by the respondents. Considering the above, the 3-factor solution was retained along with the original loadings of the items.

3.3. Relationship between personal information and perception of design factors

Before investigating the relationship between respondent characteristics and perception of design factors, respondents were regrouped to simplify data analysis and interpretation. A small number of staff worked less than 20 h per week; therefore, the variable 'working hours' was rescaled to have the ranges: less than 40 h, between 40 and 60 h and longer than 60 h. The rescaled 'working hours' variable corresponded to short, medium and long periods of working time. Similarly, the variable 'age' was re-categorized to indicate the ranges: young (18–35 years), middle aged (36–50 years) and senior staff (older than 50 years). To investigate the effect of job roles, the respondents were categorized into two groups: administrative/managerial and physicians/nurses/technicians.

The distribution of the data was not normal; hence, non-parametric tests were carried out on 16 questionnaire items and reported in Table 5. Mann–Whitney *U*-test was carried out on 'gender' and 'role', whereas Kruskal–Wallis test was carried out on 'age', 'working hours' and 'length of service'. Results show that there is a significant difference in perception between male and female healthcare providers for items: cleanliness and ease of maintenance; air quality and freshness; noise level; and provision for hand hygiene. Age has a significant effect on the perception of the following design factors: noise level; spaciousness; location and orientation of the space; and architectural design of the space.

The perception of the factors: thermal comfort, proximity to wards, adequate illumination, availability of daylight and spaciousness is significantly influenced by working hours per week. This translates to 5 out of 9 items in components 2 (environmental design) and 3 (maintenance design), demonstrating the importance of the number of hours worked per week on perceptions of maintenance and environmental design factors.

There is also a significant difference in the perception of factors: indoor plants, interior/exterior landscaping; furniture layout; and proximity to wards between different groups of respondents, based on their length of service. The design factor, proximity to wards has a high level of significance, $p < 0.001$.

No significant difference in perception was found due to respondents' job roles.

4. Discussion

4.1. Perception of design factors

Healthcare providers are key stakeholders and critically important informants in the process of design and refurbishment of healthcare facilities. Their perception of physical environment features are based on their observation of and interaction with hospital spaces over their working life. All of the 16 investigated design aspects were ranked relatively high with mean scores ranging between 3.36 and 4.66, from the lowest to the highest, on a scale of 1–5. Overall, 'cleanliness and ease of maintenance' was considered to be very important and had the highest mean score (=4.66) and lowest standard deviation (=0.522). The item, 'presence of coordinated art objects' was considered to be the least important of the analyzed design aspects. In terms of constructed dimensions, the respondents appear to be more concerned about the environmental and maintenance design factors, compared to spatial design. This is evident in Table 3, where all of the nine items under environmental and maintenance design dimensions topped the list with a minimum mean score of 4.00.

The overall findings agree with conventional wisdom and results from past research on quality of care and user satisfaction, the closely aligned topics of research to the present study. Cleanliness is routinely reported in literature as one of the most important attributes of a healthcare environment and has the potential to influence care quality and staff and patient wellbeing. Although, there exists a greater need for cleanliness in departments such as surgery, emergency and intensive care units where patients are more vulnerable to the risk of infection (Lavy & Dixit, 2010), it is also important in lower risk areas such as care homes. In a review of service users' expectations of inpatient mental healthcare, Hopkins, Loeb, and Fick (2009) identified cleanliness as an important aspect along with comfort. In a recent article, Dancer (2011) noted the

Table 5
Non-parametric test result.

Factor and questionnaire item	*p*-value				
	Gender[a]	Age[b]	Working hours[b]	Length of service[b]	Role[a]
Spatial					
Indoor plants, interior/exterior landscaping	0.529	0.258	0.297	0.047*	0.117
Furniture layout	0.111	0.075	0.726	0.038*	0.207
Exterior view from the space	0.904	0.355	0.471	0.115	0.358
Presence of coordinated art objects	0.672	0.890	0.593	0.694	0.119
Pleasant color scheme	0.222	0.060	0.118	0.642	0.241
Architectural design of the space	0.684	0.047*	0.835	0.064	0.159
Location and orientation of the space	0.251	0.028*	0.079	0.052	0.326
Environmental					
Adequate illumination	0.979	0.123	0.020*	0.332	0.986
Availability of daylight	0.839	0.116	0.033*	0.619	0.620
Thermal comfort	0.141	0.334	0.027*	0.991	0.428
Noise level	0.037*	0.047*	0.326	0.494	0.980
Air quality and freshness	0.038*	0.623	0.089	0.688	0.900
Maintenance					
Provision for hand hygiene	0.036*	0.868	0.259	0.155	0.875
Proximity to wards	0.130	0.346	0.025*	0.001*	0.151
Cleanliness and ease of maintenance	0.030*	0.833	0.087	0.062	0.656
Spaciousness	0.987	0.005*	0.028*	0.367	0.885

*$p < 0.05$.
[a] Mann–Whitney *U*-test.
[b] Kruskal–Wallis test.

emergence of evidence on the importance of the clinical environment in encouraging hospital infection. Given the wide-ranging surfaces, equipment and building design, the article argued for a tailored approach toward cleanliness. Cleanliness in the hospital environment has also been linked with the recruitment, retention and performance of nurses in the UK National Health Service (NHS) (PwC, 2004).

In terms of mean response scores, 'air quality and freshness' was ranked as the second most important item. Air quality has previously been associated with user satisfaction (PwC, 2004), staff performance (Seppänen, Fisk, & Lei, 2006) and the prevention of nosocomial infections among staff and patients (Leung & Chan, 2006). Gosden, MacGowan, and Bannister (1998) discussed the importance of air quality in infection control by citing examples of how small numbers of organisms could cause orthopedic implant infections, giving rise to a considerable degree of morbidity and mortality. Leung and Chan (2006) noted that parameters of indoor air quality (IAQ) were well understood in commercial and public buildings and how these could adversely affect occupant health, with conditions ranging from sick building syndrome (SBS) to building related illnesses (BRI) such as pneumonitis and cancers. IAQ, to a large extent, depends on the rate of outdoor/fresh airflow, a higher rate of which is more efficient in diluting the concentration of odor and volatile organic compounds (VOC). In a review of published sources that investigated the link between ventilation rates and staff performance, Seppänen et al. (2006) noted that in all of the reviewed cases higher ventilation rates resulted in higher performance.

The respondents have rated 'Noise level' as the third most important design aspect. The impact of noise pollution on both the patient and healthcare providers has been extensively studied in critical care units and other healthcare areas. Patients' wellbeing and their health outcomes are found to be affected by higher levels of noise because of poor sleep quality (Freedman, Kotzer, & Schwab, 1999) and increased stress. In the case of healthcare providers, noise pollution increases the probability of errors and is one of the risk factors for provider burnout (Tijunelis, Fitzsullivan, & Henderson, 2005). It is widely acknowledged that sound levels higher than 55 dBA brings disturbing effect (Beranek, 1971). The Environmental Protection Agency (EPA) in the United States recommends that the ambient noise level in a hospital should not exceed 40 dB. However, many studies suggest that this recommended threshold of ambient sound is routinely exceeded (Busch-Vishniac et al., 2005; Souter & Wilson, 1986).

'Thermal comfort' is considered by the respondents to be the fourth most important aspect. The sensation of comfort is dependent on many physical and psycho-physiological variables such as indoor air temperature, metabolism, clothing insulation, ability to modify/control the indoor environment, etc. (De Dear, 2004). The effect of physical environment aspects on thermal comfort is more pronounced for naturally ventilated buildings, compared to fully air-conditioned buildings. Thermal comfort is also indirectly linked with indoor air quality in the sense that increased ventilation helps in diluting odor and VOC, as well as in bringing down indoor temperatures to a comfortable level.

The order of importance of the remaining environmental and maintenance design factors is as follows: 'proximity to wards', 'provision for hand hygiene', 'adequate illumination', 'availability of daylight' and 'spaciousness'. All of the architectural design aspects were ranked lower than environmental and maintenance design aspects, with mean scores ranging from 3.36 for 'presence of coordinated art objects' to 3.85 for 'location and orientation of the space'. The fact that mean scores for all spatial design aspects were lower than 4.00 indicates that the respondents considered them to be important but not as important as environmental and maintenance design factors. Aspects related to various environmental stimuli such as art objects, indoor plants and interior/exterior landscaping were considered to be of low importance, as shown in Table 3. The effect of such stimuli on staff and patient wellbeing and patient recovery has been found to be positive in past research (Dijkstra, Pieterse, & Pruyn, 2006; Golden et al., 2005; Ulrich, 1984; Ulrich, Zimring, Quan, Joseph, & Choudhary, 2004). However, their relatively low ranking in this research may be due to the fact that previous research looked at individual aspects, rather than the integrated whole, as is the case in this research. Another reason may be that the respondents did not make a strong connection between abstract environmental stimuli and staff performance and/or patient outcomes. Further research is, therefore, necessary to investigate the low mean scores of spatial design aspects.

4.2. Perception and demographic characteristics

Of the four demographic and work related variables investigated in detail in this study, working hours per week explained significant differences in perception of several of the maintenance and environmental design factors. Women were found to be more perceptive of sense-sensitive (Mazuch, 2005) design factors such as the ones related to five senses: smell, taste, sight, feel and hearing. Mean scores by female staff were higher than their male counterparts on cleanliness and ease of maintenance (mean score of 4.71 vs. 4.56); indoor air quality and freshness (4.44 vs. 4.30); noise level (4.40 vs. 4.23); and provision for hand hygiene (4.27 vs. 4.05). This result is in accordance with previous research, which indicated that females showed greater sensitivity and/or physiologic responsiveness to stimuli in a number of sensory modalities, in particular in olfactory sensitivities, than males (Velle, 1987). Women are also reported to suffer from sick building syndrome (SBS) more often than men (Brasche, Bullinger, Morfeld, Gebhardt, & Bischof, 2001). In Chinese culture, women take more responsibility for environmental cleanliness at home, which may account for and translate into them having a higher expectation of cleanliness than men. In other words, females expect cleaner and quieter environments to focus on work. Nursing stations and patient rooms are their primary working locations where a minimum level of noise and better air quality and freshness are highly demanded. All six interviewed nurses expressed their preference for design for cleanliness that eliminates clutter and helps them care for patients more effectively.

In addition, the research has identified different perceptions of design factors between respondents who worked less than or equal to 40 h a week ($N_{\leq 40} = 220$) than the staff who worked more hours per week ($N_{41-60} = 70$ and $N_{>60} = 14$). Respondents working less than or equal to 40 h represent the working pattern of the majority of the staff in the two hospitals. They considered 10 out 16 investigated design factors to be more important than the other groups. The 10 design factors came from all three principal components: spatial, maintenance and environmental design and included both the highly ranked ones (e.g., proximity to wards) as well as the factors with low mean scores (e.g., presence of coordinated art objects). In comparison, respondents who worked 41–60 h per week considered the following design factors to be more important than the others: cleanliness and ease of maintenance (mean score of 4.68); Noise level (4.35); Adequate illumination (4.18); Pleasant color scheme (3.7); Indoor plants, interior/exterior landscaping (3.55) and Furniture layout (3.54). Exterior view from the space had an equal mean score of 3.68 from the respondents who worked less than or equal to 40 h per week and the respondents who worked between 41 and 60 h per week. Findings related to 'working hours' can be used for designing departments with varying work patterns; e.g., inpatients vs. outpatients.

Among the spatial design factors, 'location and orientation of a space' was rated higher by the respondents than most of the other factors in the category. This may be due to the cultural preference of the Chinese for coordinated location and orientation of a space and furniture within. Evidence of locational preference can be seen in the ancient Chinese wisdom called *Feng Shui*, which was based on the observation of astronomical phenomena, natural phenomena and human behavior (Mak & Ng, 2005). These three aspects were combined with Chinese astronomy, geography and philosophy to devise rules for the design of spaces, buildings and cities. Interviewed nurses also stated their preferences for a better orientation of the space they worked in. Some of the comments in the returned questionnaires also support this finding; e.g., one responded commented "...[I] prefer to work in a south-faced room with more natural light...".

Nurses described their preferences for the design of nursing stations in both the questionnaire and interview. They noted that the design of nursing stations could be such that there was a degree of acoustic separation between their working areas and adjoining corridors and patient areas. In essence, they referred to the ambient noise level, which could be brought down through careful design. The preference for better acoustic design was mentioned often by nurses working in departments such as accident and emergency where there were increased interactions with patients and families. This is an interesting finding, which illustrates the multi-dimensional and multi-objective nature of architectural design. From a spatial design perspective, visual and auditory links need to be maintained between nursing stations and patient areas for effective care delivery, which may contribute to an increased noise level. At the same time, staff working in these areas needs a quiet space to concentrate on work. The use of hard surfaces (for easy cleaning and better control of infection) adds to this problem as they reflect sound and, therefore, contribute to the ambient noise level. The 'push and pull' between the aforementioned design objectives: efficient care delivery, reduction of noise and cleanliness serve to illustrate the challenges in design decision making.

4.3. Integrating user perception in healthcare facility design

One of the advantages of research focusing on physical environments is that findings can be applied more easily in evidence-based design decision-making. Indices of factors and their relative ranking can be identified based on user characteristics and use patterns of the space. The indices can then be used for prioritizing design factors for heuristics based decision-making, typically found in early design stages. However, with the increase in the number of design variables (i.e., factors or aspects) and goals, the reconciliation between conflicts becomes complicated, rendering the conventional 'cognitive' and 'trial and error' approach inefficient for effective decision-making (Mourshed, 2006). To overcome the limitations of cognitive or heuristics based approaches, design automation such as numerical optimization (Caldas, 2008; Mourshed, Shikder, & Price, 2011) can be applied where the indices of design factors and their relative ranking are converted into proportional weights on design goals and the solution space is searched algorithmically.

5. Limitations

Certain limitations of this study need to be pointed out. The questionnaire was conducted in two Chinese hospitals in Qingdao, a major city in Shandong province in Eastern China. The responses are, therefore, inherently the Chinese healthcare providers' perception of design factors and their relative importance. However, the differences in perception between respondents from China and the rest of the world may be minimal, in particular for universal design factors that are not culturally significant; e.g., adequate illumination and daylight availability. Factors related to building services and systems such as thermal comfort is another example of such variable. This may be due to the fact that the design and operation of major healthcare facilities such as general or medical college hospitals are more universal than other types of buildings. Also, there is evidence that contemporary developments in Chinese architecture, in particular in urban areas, have had considerable influences from globalization (Ren, 2008) and in a sense western architectonic philosophies during the second half of the 20th century. The end product was rather a universal urban fabric, with little difference in spatial organization and manifestation of form and space between urban buildings in China and the rest of the world. The contextual bias from buildings themselves may, therefore, be low.

Further research may be needed for universal applications of some of the research findings. For example, the relationship between working hours and perception may be affected by average hours worked per week by healthcare providers in a country. Chinese healthcare workers typically worked more hours per week than their counterparts in the West: e.g., American physicians worked 53.9 h (Dorsey, Jarjoura, & Rutecki, 2003) while their Taiwanese counterparts worked 65.6 h per week (Chen, Lee, & Chang, 2010). Therefore, the effect of work pattern may be different, the detailed understanding of which requires further research. Another aspect of the study is the proportion of female respondents (63.8%), which may appear high but is demographically representative of healthcare staff in China and the rest of the world. Female nurses make up the majority of the healthcare workforce, which reflects a traditional career trend in healthcare labor markets in most countries (Zurn, Poz, Stilwell, & Adams, 2002). Although the research did not find significant differences in perception between administrators and managers vs. physicians and nurses; i.e., non-medical vs. medical – there may be differences between sub-categories.

6. Conclusion

Past research on physical environments in hospitals focused mostly on user satisfaction, linked with service delivery in a specific setting. Research on satisfaction typically explored users' (staff and patients) perception of the quality of care and analyzed the impact of some tangible dimensions such as salary, work pattern, presence/absence of certain facilities, etc. Findings from such research are convenient for use in financial and efficiency related strategic planning and management. They seldom provide useful insights into facility design aspects that are critical for creating a therapeutic environment.

Using a 16-item structured questionnaire, this research explored healthcare providers' perception of design aspects related to physical environments in hospitals. Aspects related to the design for maintenance were perceived to be more important by healthcare providers than those related to spatial design. Environmental design aspects related to sensory perceptions were also ranked as very important by the respondents. There were significant differences in perception of the body-contact and sensory aspects among males and females. Of other demographic and work related variables, the length of service had an effect on spatial design aspects such as landscaping and indoor plants that had an indirect association with the healing environment. Working pattern; i.e., 'hours worked per week' had significant associations with the perception of maintenance and environmental design aspects.

In addition to contributing to the growing body of knowledge on users' perception of physical environment aspects, this paper shed light on the use of the findings in architectural design.

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C.2 Journal paper 2

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Design indicators for better accommodation environments in hospitals: inpatients' perceptions

Yisong Zhao [a] & Monjur Mourshed [a]
[a] Loughborough University, Civil and Building Engineering, New Ashby Road, Loughborough, LE11 3TU, UK

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RESEARCH ARTICLE

Design indicators for better accommodation environments in hospitals: inpatients' perceptions

Yisong Zhao and Monjur Mourshed*

Loughborough University, Civil and Building Engineering, New Ashby Road, Loughborough, LE11 3TU, UK

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Several studies have found an association between the physical environment and human health and wellbeing that resulted in the postulation of the idea of *evidence-based and patient-centred* design of healthcare facilities. The key challenge is that most of the underpinning research for the evidence base is context specific, the use of which in building design is complex, mainly because of the difficulties associated with the disaggregation of findings from the context. On the contrary, integrating patients' perspectives requires an understanding of the relative importance of design indicators, which the existing evidence base lacks to a large extent. This research was aimed at overcoming these limitations by investigating users' perception of the importance of key design indicators in enhancing their accommodation environments in hospitals. A 19-item structured questionnaire was used to gather inpatients' views on a 5-point scale, in two Chinese hospitals. A principal component analysis (PCA) resulted in five constructed dimensions with appropriate reliability and validity (Cronbach's alpha=0.888). The item, *design for cleanliness*, was ranked as *most important*, closely followed by environmental and safety design indicators. The item, *entertainment facilities*, was ranked lowest. The item, *pleasant exterior view* had the second-lowest mean score, followed by the item, *ability to customise the space*. Age, accommodation type and previous experience of hospitalization accounted for statistically significant differences in perceptions of importance of various constructed design dimensions.

Keywords: design indicator; evidence-based design; healthcare design; user perception

Introduction

Healthcare expenditures represent a significant share of a nation's gross domestic product (GDP). For example, the overall healthcare spending in the United States in 2009 was close to US$ 2.5 trillion and accounted for 17.6% of GDP, 31% of which was spent on hospital care (CMS 2011). The figure in 2008 was 16.0, 11.2, 8.7 and 8.1% for the United States, France, United Kingdom, and Japan, respectively (OECD 2010). It is projected that healthcare spending will continue to rise and will outpace the growth in the general economy of some countries (Belohlav *et al*. 2010). Greater budgetary pressure, ageing population and increased expectations of quality of care call for a rethinking in the way care is delivered. Physical environments comprising buildings and ancillary facilities, in which care takes place, are a major part of this healthcare regeneration process.

*Corresponding author. Email: m.m.mourshed@lboro.ac.uk

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Research has found strong association between human health and wellbeing and the physical environment, in which a person lives or receives treatment (Fottler *et al*. 2000, Diez Roux 2001, Whitehouse *et al*. 2001, Devlin and Arneill 2003, Chu *et al*. 2004, Douglas and Douglas 2005, Dijkstra *et al*. 2006, Ulrich *et al*. 2008). It is generally acknowledged that patients' accommodation should provide a safe environment where they spend most of their time during their stay in a hospital. An increasing body of research on accommodation environment sought to enhance patients' experience and the delivery of care. This includes but is not limited to, the explorations of relationships between healthcare design and patient safety (Clarkson *et al*. 2004, Reiling *et al*. 2004, Joseph and Rashid 2007, Birnbach *et al*. 2010) and adverse effects of the physical environment on various healthcare indicators. Such indicators included: job satisfaction (Tyson *et al*. 2002), staff turnover (Aiken *et al*. 2008, Applebaum *et al*. 2010), patient satisfaction (Stern *et al*. 2003, Douglas and Douglas 2005) and patient privacy and dignity (Thrall 2005). A well-designed, well laid-out, spacious and well-decorated accommodation environment is considered to significantly benefit both patient wellbeing and staff performance (Pattison and Robertson 1996, Mroczek *et al*. 2005, Lorenz 2007).

The acknowledgement of this link by the wider community has resulted in the postulation of the idea of *evidence-based and patient-centred* design of healthcare facilities (Ulrich *et al*. 2008). The cornerstone of evidence-based design (EBD) is the *evidence-base*, which is generated from credible research in architecture, environmental psychology, neuroscience and behavioural economics. The key challenge for integrating EBD in the design and operation of healthcare buildings is that much of the underpinning research is contextual, that is, related to the quality or effectiveness of care in a specific setting such as a hospital or a treatment. The applications of such findings in buildings are challenging, mainly because of the difficulty in disaggregating the findings from the contexts of care or physical setting. In addition, the effects of the physical environment in the existing evidence base are hidden behind various physical, physiological and psychological variables, which need to be translated to design indicators or variables before using for decision-making. Such translations are not always straightforward and not without the loss of semantics and utility.

On the contrary, the *patient-centred* approach of care delivery requires that patients' perspectives are considered in all aspects of care – from care planning and treatment (Robinson and Thomson 2001) to the design and operation of buildings (Smith *et al*. 1995). This is partly because of the role physical environments play on patient healing outcomes and partly because of the market-oriented nature of the healthcare sector where organizations are now in a position to attract patients, resulting in a much greater emphasis on the provision of patient-centred care (Stern *et al*. 2003) and architectural design of the facilities (Reiling 2006). Patients' perception and feedback about the physical environment include what they think are important to them, what matters to them and what supports their healthcare experience. Such source of information is very important in screening for problems and in developing an effective plan of action for quality improvement in healthcare organizations (Stern *et al*. 2003). Patients' participation also provides meaningful information for healthcare designers and architects to go beyond their own limited experience with the built environment of a particular healthcare facility. They can accordingly make an effort to shape and/or reshape the healing environment to realize the desired outcomes of perceived service quality (Fottler *et al*. 2000).

The pre-condition for the patient-centred design and operation of healthcare buildings is that patients' perception of the importance of various design indicators are captured in a usable format. In most countries, patients' views are collected using *quality of care* questionnaires and are often linked to a care or treatment they received beforehand. The physical design of healthcare environments is recognized as important (Hutton and Richardson 1995) in these evaluations but often only a few dimensions, if any, related to physical environments are considered. Patients' perceptions of physical environment dimensions relevant to the design and operation of buildings are thus less explored in the existing literature.

Recognizing the above gaps, this research was aimed at investigating patients' expectations in the building design process and their perception of the relative importance of design indicators. A 19-item structured questionnaire was conducted among inpatients in two hospitals in Qingdao, China. In terms of the user group, hospital inpatients were considered in this research. This is because of the fact that there is a greater impact of the physical environment on inpatients' health and wellbeing than other patient groups such as outpatients who experience the healthcare environment occasionally. In addition, the number of admission episodes is significant in most countries. For example, between July 2010 and June 2011, there were 14.8 million finished admission episodes (FAEs) in the United Kingdom, of which 5.3 million were emergency admissions (HES 2011). The surveyed hospitals in Qingdao had more than 100,000 inpatients admitted during 2009, the year in which the reported survey took place.

Hospital design has traditionally focused on the needs of staff and care providers, accommodating little needs of patients (Sweeney 2008). The other objective was, therefore, to develop an inpatient questionnaire that could reliably and validly assess and represent inpatients' expectations in the building design process.

The rest of the article is organized as follows. The methods applied in this article for the development of the instrument and survey administration are discussed. Descriptive and statistical analyses of the obtained data are discussed next, followed by a contextual discussion. The article ends with a discussion on the limitations of this research, future directions and concluding remarks.

Methodology

Questionnaire development

The development of the questionnaire was based on an extensive review of literature. The review was conducted on the aspects related to: the design of patient accommodation environments; patients' opinions on physical environments in *quality of care* surveys; and the research on environmental psychology that looked at the relationship between physical environment and patient health and wellbeing, in particular patient outcomes. Keyword searches were conducted on the following databases: Pubmed, ScienceDirect, Web of Science, Scopus, Ovid MEDLINE, the Cochraine Library, and Design and Applied Arts Index. This enabled the first-step filtering of literature, which were refined further with keyword searches that were related to the scope and methods; for example inpatient accommodation, questionnaire, survey, physical environment, perception, opinion, and perspective. Non-electronic sources were also consulted to identify potential sources for inclusion in the review. The filtered sources, from both electronic and non-electronic, were first categorized based on their adopted methods and findings. Relevant design indicators were identified from this systematic review of literature.

Nine inpatients were interviewed to explore their general perception of the accommodation environment in one of the participating hospitals. A focus group (one-hour session) involving two inpatients, two care providers (nursing staff) and one administrative staff was conducted. In both the focus group and the interviews, the objective was to compare the findings of the literature review with participants' perception of the impact of the accommodation environment on patient health and wellbeing. Finally, a draft questionnaire was designed based on the identified design factors from the extensive literature review and consultations with patients and staff.

The draft questionnaire was then piloted among 18 inpatients to analyse the appropriateness and comprehension of the items and testify the validity of the questions. Participants were asked to complete the questionnaires and give comments on any deficiencies of the content of the questionnaire, other potential sources of perceptions and significance of each item. The pilot study resulted in the final questionnaire with improved content validity.

The final structure of the questionnaire included 19 questions to rate the importance of design indicators for the accommodation environment. Respondents were asked to rate their perception of an item on a Likert-type response balanced scale, ranging from 1 to 5 (1 = least important, 2 = unimportant, 3 = neither important nor unimportant, 4 = important, and 5 = most important), a higher score indicating a higher level of perception of the importance of the item. Demographic variables such as age, gender, and inpatient status were requested from the participants. Data regarding admission times and familiarity of the environment were also recorded. Design factors that were translated into 19 questions are given in Table 1, along with brief descriptions of their impacts and sources.

Ethical consideration

A two-stage ethical approval was obtained for this study. First, an ethical approval was obtained from the UK academic institution where the authors were based. Second, the research committees of the two participating hospitals gave approval to the study.

Sampling and data collection

The study was conducted among inpatients admitted in two Chinese hospitals (Figure 1) in Qingdao, a coastal city in East China. At the time of the survey, the two hospitals employed approximately 5900 staff and had around 4000 beds in total. One of the hospitals is affiliated with a medical college and the other one is the largest general hospital in the city. Owing to their size, facilities, volume of staff and patients, the two participating hospitals can be considered as representative of Chinese public urban hospitals. Respondents were selected at random from different departments to participate in the survey. Some inpatients were excluded from participation because of their physical and psychological state resulting from the illness for which they were admitted in the hospital. All participants were over 18 years old and they were communicated in writing, through an *introduction to the survey* section, that this survey was voluntary and the confidentiality of the data would be maintained. In this section, the purpose of the questionnaire is clearly outlined and all participants were asked to answer the questions based on their perception of general healthcare environment rather than the surveyed hospital they were staying at.

Festive decorations during particular holidays such as the Chinese New Year have the potential to create bias in the responses. Therefore, the data for this study were collected between the 12 and 26 August 2009, a time period in which there were no special holidays in China. Help from nurses were sought to distribute the questionnaires among inpatients. Informed consent was obtained from each participant in the study. A total of 400 copies of the questionnaire were distributed and 369 were returned after 2 weeks. Eighty-two responses were incomplete and were excluded from the analysis. Finally, 287 returned copies were accepted for analysis. Therefore, the valid response rate was 71.75%.

Statistical analysis

Descriptive statistics on the item and scale frequencies, percentages, means, and standard deviations (SD) were computed first. Demographic and other related data were also analysed descriptively by computing frequencies and percentages. Internal consistency reliability of the scale was then measured using Conbach's coefficient alpha (Cronbach 1951), which is a test reliability

Table 1. Design factors, their description and key sources.

Design factor	Impact
Ability to customise the space	Space has been suggested as more than a static passive vessel for actions to take place; its characteristics impose limitations (e.g. degrees of privacy) whereas also facilitating interactions (González-Santos 2011).
Adequate illumination	Adequate illumination, artificial and natural lighting combined, is required to perform visual tasks and for patient safety (Shikder *et al*., in press).
Adequate sitting area for visitors	Involvement or interaction with family during a patient's hospitalization can affect patient outcomes (Powers and Rubenstein 1999); hence the need for adequate sitting area for visitors.
Availability of natural light	Light, especially daylight impacts on visual performance and psychological state of a person by regulating the circadian rhythm, which has impacts on patient outcomes (Ulrich 1984).
A thermally comfortable environment	A thermally comfortable environment helps maintain normothermia and decrease patient anxiety (Wagner *et al*. 2006).
Cleanliness	The design of the building and constituent spaces are linked with cleanliness (PwC 2004). Surface characteristics affect infection control (Dancer 2011).
Entertainment facilities	Supplement of entertainment facilities will help to build a patient-centred environment that increases patient satisfaction (Schweitzer *et al*. 2004).
En-suite bathroom	En-suite bathroom is better for privacy (van de Glind *et al*. 2007) and hygiene (Tyson *et al*. 2002), as well as for better isolation and lower infection risk (Panagea *et al*. 2005).
Location and orientation of the room	Poor location and orientation of the room may result in a poor way-finding system and may contribute to increased patient stress and dissatisfaction (Zimring 1990).
Measures to prevent patient falls	Environmental and organizational factors have links with patient falls (Hernandez and Miller 1986).
Noise	The level of ambient noise has strong links with patient outcomes. High levels of noise have been found to hinder patients' recovery and influence their physical and psychological health (Wiese and Wang 2011).
Number of patients in a room	Roommate assignment can affect patient anxiety and stress (Chaudhury *et al*. 2005).
Pleasant exterior view	Views to the outside are manifested as positive emotional and physiological changes leading to stress reduction or restorative benefits (Ulrich 1984).
Privacy from other patients and staff	Patient privacy is an essential guiding principle of the staff–patient relationship (Flegel and Lant 1998). If conversations are overheard, patients may perceive it to be a breach of privacy (Karro *et al*. 2005).
Proximity to nursing staff	Proximity to nursing staff impacts on patient–provider communication (Johnson *et al* 2004), which influences patients' satisfaction.
Proximity to service delivery points	Proximity to nurses' station is essential for patients' safety and wellbeing as it saves nurses' walking time. Long distance has a negative impact on nursing performance (PwC 2004).
Proximity to social facilities	Studies have indicated that social support reduces stress and improves patient recovery outcome (Ulrich *et al*. 2004).
Spaciousness and furniture layout	Perception of spaciousness has effects on patient satisfaction and staff performance (O'Neil 1994).
Unpleasant smell	Defined as poor air quality and freshness, which may increase the risk of nosocomial infection (WHO 2002).

technique that requires only a single test administration to provide a unique estimate of the reliability for a given test (Gliem and Gliem 2003). This enabled the assessment of the overall correlation between items within a scale. $\alpha \geq 0.70$ was recommended as the criteria for one scale to be considered sufficiently reliable for use in groups of respondents (Nunnally and

Figure 1. Interior and exterior views of one of the surveyed hospitals.

Bernstein 1994). The coefficient $\alpha \geq 0.70$ was regarded as acceptable, $0.70 < \alpha \leq 0.80$ as respectable and $\alpha > 0.80$ as very good.

As scale dimensionality could be determined by factor analysis, a principal component exploratory factor analysis was carried out to identify the underlying structure, characterizing a set of highly correlated variables. The importance of a component was evaluated by examining both scree plots and the contribution of each component to total variance (>5%). Varimax rotation was applied with the principal component analysis (PCA) results, guiding the number of factors to be extracted. Items were included in the factors if there were substantial loadings ($\geq$0.40). In the case of multiple loadings of an item on different factors, it was included in the factor with which the item had more conceptual relationship. The factors from the main study were easier to label and had good correspondence with other studies. After this stepwise development phase, good construct validity and internal consistency were established for the questionnaire. Bartlett's test of sphericity was used to identify the significant correlation between items. Kaiser–Meyer–Olkin (KMO) procedure for measuring sampling adequacy was applied. The KMO level of 0.7 generally assures the usefulness of factor analysis for a given sample (Tuluca and Zwick 2001). A higher KMO (maximum 1.0) indicates that sampling data are more likely to factor well because correlations between variables can be explained by low partial correlation coefficients (other variables) (Leung *et al*. 2005). In order to analyse demographic effects and relationships among constructed dimensions, χ^2 and non-parametric tests were employed. Statistically significant differences in perception based on gender, admission/patient type and the requirement of a chaperon were tested via Mann–Whitney U-test. Kruskal–Wallis test with $p<0.05$ was used to analyse the differences between age groups (18–25, 26–35, 36–50, and >50 years), number of hospitalization times (1–2, 3–4, 5–10, and >10 times), number of wards previously stayed (0, 1, 2, 3, and >3) and number of visits to the hospital (1–2, 3–4, 5–10, and >10 times). Mann–Whitney *U*-test with a reduced *p*-value ($p<0.01$) was used as a post-hoc test to avoid the risk of finding significant differences by chance (Bland and Altman 1995). Statistical analyses have been performed with PASW Statistics version 18.0 for Windows (IBM 2010).

Results and findings

Respondents' characteristics

Table 2 summarizes demographic and other admission related data from the respondents. Among 287 accepted respondents, 145 (50.5%) were male and 142 were female (49.5%). A total of 72%

Table 2. Demographic information of the respondents.

Variable	Scale	Male	Female	p-Value[†]	Total (%)
Age (yr)				0.084	
	18–25	15	26		14.3
	26–35	22	17		13.6
	36–50	56	60		40.4
	>50	52	39		31.7
Inpatient type				0.706	
	Short-term	96	91		65.2
	Long-term	49	51		34.8
Accommodation type				0.387	
	Single-bed	25	23		16.7
	Multi-bed (2–4)	96	103		69.3
	Multi-bed (4–8)	24	16		13.9
Number of wards stayed				0.117	
	0	27	15		14.6
	1	59	67		43.9
	2	31	37		23.7
	≥3	28	23		17.8
Number of previous hospitalizations				0.816	
	1–2	73	68		49.1
	3–4	34	39		25.4
	5–10	21	17		13.2
	>10	17	18		12.2
Admission type				0.034*	
	Emergency	23	37		20.9
	Pre-arranged	122	105		79.1
Chaperon				0.860	
	Yes	134	132		92.7
	No	11	10		7.3

[†] χ^2 table test.
*$p<0.05$.

of inpatients were older than 36 while most of them were aged between 36 and 50 (40.4%). Patients older than 50 years accounted for 31.7% of the respondents. Fifteen males and 26 females were aged between 18 and 25 years while there were 22 males and 17 females for the age group 26–35. Only 65.2% (N=187) of the inpatients were short-term patients who stayed at the hospital for less than 2 weeks; the remaining 34.8% were long-term patients and stayed at the hospital for more than 2 weeks, prior to responding to the survey.

A total of 69.3% of the patients (199) were staying in a multi-bed ward with a capacity of 2–4 persons. Single occupancy was at 16.7%, while 13.9% of the respondents stayed at multi-bed wards with a capacity of 4–8 persons. About 14.6% of the respondents were first time inpatients, that is, they did not stay at a different ward previously. Patients, who stayed at one or two different wards previously, accounted for 67.6% of the respondents. In contrast, 17.8% of the respondents had stayed in three or more wards in the hospitals prior to being at the surveyed ward. Nearly half of the respondents (49.1%) were hospitalized in the hospital only once or twice. However 25.4 and 13.2% inpatients were hospitalized between 3–4 and 5–10 times, respectively. A total of 12.2% of the inpatients were quite familiar with the accommodation environment as they had been to the hospital for more than 10 times. Most of the inpatients (92.7%) welcomed chaperons during their stay at the hospital. Only 7.3% of the respondents said no to a chaperon. Majority of the admissions were pre-arranged at 79.1%, while 20.9% were emergency.

A descriptive analysis of the design indicators is given in Table 3, which shows the percentage of response at each choice of the 5-point scale. Mean and SD of responses are computed for each design indicator. The questionnaire items are sorted in a descending order, based on the mean response score. SD are generally small for higher mean response scores (e.g. cleanliness; mean = 4.41, mode = 4 and SD = 0.583) and relatively greater for lower mean scores (e.g. entertainment facilities; mean = 3.46, mode = 3 and SD = 1.063).

Principal component analysis

Principal component analysis, followed by an orthogonal rotational solution (varimax), was conducted on the final 19 items at a significance level, $p < 0.001$. No item was removed from the scale as all of them had substantial factor loadings greater than 0.40. The factor solution was based on Bartlett's test of sphericity, showing a significant correlation between items ($\chi^2 = 2340.39$; $p < 0.001$) and the KMO test for sampling adequacy, measuring 0.852, which can be considered *great* (Field 2009). These indices implied that the matrix was well suited for factor analysis. An initial analysis was run to obtain eigenvalues for each component in the data. Five summated indices from the 19 question items had eigenvalues greater than 1.0. The total variance extracted was 64.5%. Factor 1 was clustered by six items, representing the largest percentage of explained variance (33.4%). Both factors 2 and 3 contained three items, accounting for 11.1 and 8.99% of the variance, respectively. Factor 4 had four items and factor 5 had three items, accounting for 5.58 and 5.45% of the variance, respectively. Given the large sample size, and the convergence

Table 3. Descriptive analysis of the design factors.

	Response† (%)							
Questionnaire items	1	2	3	4	5	Mean	Mode	SD
Cleanliness	0.0	0.0	4.9	49.5	45.6	4.41	4	0.583
A thermally comfortable environment	0.0	0.3	10.1	44.9	44.6	4.34	4	0.670
Measures to prevent patient falls	0.0	0.0	13.6	40.1	46.3	4.33	5	0.703
Unpleasant smell	0.0	0.0	14.3	46.0	39.7	4.25	4	0.691
Adequate illumination§	0.0	1.7	13.2	46.7	38.3	4.22	4	0.735
Noise	0.0	0.0	14.6	50.5	34.8	4.20	4	0.675
Proximity to nursing staff	0.3	2.8	13.9	44.9	38.0	4.17	4	0.796
En-suite bathroom	0.0	2.8	14.6	46.0	36.6	4.16	4	0.774
Availability of natural light	0.0	1.4	16.7	47.7	34.1	4.15	4	0.738
Proximity to service delivery points	0.0	3.1	14.3	48.4	34.1	4.14	4	0.770
Privacy from other patients and staff	0.3	3.5	16.0	50.2	30.0	4.06	4	0.793
Number of patients in a room	0.0	1.0	19.2	55.1	24.7	4.03	4	0.694
Adequate sitting area for visitors	1.0	4.9	24.7	35.9	33.4	3.96	4	0.934
Location and orientation of the room	1.0	3.1	21.6	55.1	19.2	3.88	4	0.784
Spaciousness and furniture layout	0.7	5.6	22.6	52.6	18.5	3.83	4	0.818
Proximity to social facilities	1.7	6.3	35.5	34.5	22.0	3.69	3	0.942
Ability to customise the space	2.8	7.3	34.1	35.5	20.2	3.63	4	0.977
Pleasant exterior view	1.7	10.1	32.4	39.0	16.7	3.59	4	0.941
Entertainment facilities	4.9	11.1	35.2	30.7	18.1	3.46	3	1.063

†Response scales are as follows:
1 = Least important.
2 = Unimportant.
3 = Neither important nor unimportant.
4 = Important.
5 = Most important.
§Overall lighting: artificial and natural lighting combined.

of the scree plot and Kaiser's criterion on five factors, this is the number of factors that were retained in the final analysis. The interpretation of the factors was based on the loadings of each item on each factor. In one instance of dual loading, the item, *proximity to nursing staff*, was placed with the factor with the highest loading (0.521) (e.g. Capra 2005). Table 4 shows the factor loadings after rotation. These five factors were identified as architectural design; sensory and hygiene design; lighting and thermal design; design for privacy and safety; and dimensional design. Note that the factor 'dimensional design' refers to physical design aspects that relate to size of space, distance between spaces etc.

Internal consistency reliability

Generated factors were examined for reliability using Cronbach's coefficient alpha (α) estimate. The obtained values of the reliability estimates were all greater than 0.70, as shown in Table 4,

Table 4. Rotated component matrix of questionnaire items.

	Components				
Questionnaire items	Architectural	Sensory and hygiene	Lighting and thermal	Privacy and safety	Dimensional
Ability to customise the space	0.795	–	–	–	–
Pleasant exterior view	0.746	–	–	–	–
Adequate sitting area for visitors	0.720	–	–	–	–
Entertainment facilities	0.716	–	–	–	–
Spaciousness and furniture layout	0.544	–	–	–	–
Location and orientation of the room	0.454	–	–	–	–
Noise	–	0.847	–	–	–
Unpleasant smell	–	0.846	–	–	–
Cleanliness	–	0.731	–	–	–
Adequate illumination	–	–	0.795	–	–
Availability of natural light	–	–	0.793	–	–
A thermally comfortable environment	–	–	0.694	–	–
Measures to prevent patient falls	–	–	–	0.620	–
Privacy from other patients and staff	–	–	–	0.766	–
Number of patients in a room	–	–	–	0.542	–
En-suite bathroom	–	–	–	0.473	–
Proximity to nursing staff	–	–	–	0.505	0.521
Proximity to service delivery points	–	–	–	–	0.807
Proximity to social facilities	–	–	–	–	0.754
Cronbach's alpha coefficient (0.888)	0.822	0.817	0.788	0.749	0.762
Percentage of explained variance (64.5)	33.419	11.052	8.990	5.583	5.453

indicating a strong internal reliability among items with the same attributes (Nunnally and Bernstein 1994). The Cronbach's α coefficient for the overall scale was 0.888. Table 4 also shows the internal consistency reliability level (Cronbach's α) for each generated factor. The value of α was 0.822 for architectural design; 0.817 for sensory and hygiene design; 0.788 for lighting and thermal design; 0.749 for design for privacy and safety; and 0.762 for dimensional design.

Relationship of personal information and perception of design factors

Non-parametric tests were carried out on 19 questionnaire items since the analysed data follow a non-normal distribution (Callao *et al*. 2007), as shown in Table 5. Results show that there is no

Table 5. Comparison of mean scores between demographical variables.

		Components				
Demographic variables	Range/scale	Architectural	Sensory and hygiene	Lighting and thermal	Privacy and safety	Dimensional
Gender	Male	3.79(0.68)	4.31(0.54)	4.23(0.61)	4.16(0.56)	4.06(0.68)
	Female	3.65(0.66)	4.26(0.58)	4.24(0.59)	4.14(0.51)	3.94(0.68)
	p-value†	0.363	0.677	0.760	0.056	0.948
Age (yr)	18–25	3.79(0.54)	4.23(0.59)	4.27(0.60)	4.20(0.47)	3.93(0.70)
	26–35	3.55(0.72)	4.46(0.61)	4.36(0.62)	4.24(0.53)	3.91(0.72)
	36–50	3.71(0.69)	4.24(0.54)	4.19(0.58)	4.13(0.53)	4.02(0.65)
	>50	3.78(0.68)	4.30(0.54)	4.21(0.62)	4.10(0.57)	4.04(0.71)
	p-value§	0.056	0.909	0.039*	0.316	0.058
Admission type	Emergency	3.71(0.65)	4.31(0.48)	4.28(0.63)	4.11(0.57)	4.00(0.69)
	Pre-arranged	3.72(0.68)	4.28(0.58)	4.22(0.59)	4.16(0.52)	4.00(0.68)
	p-value†	0.956	0.620	0.779	0.591	0.645
Number of previous hospitalizations	1–2	3.78(0.62)	4.29(0.60)	4.23(0.59)	4.14(0.55)	4.03(0.65)
	3–4	3.72(0.69)	4.24(0.51)	4.22(0.56)	4.14(0.49)	3.98(0.66)
	5–10	3.68(0.66)	4.32(0.54)	4.21(0.69)	4.13(0.52)	4.01(0.78)
	>10	3.59(0.83)	4.35(0.48)	4.30(0.63)	4.19(0.58)	3.92(0.76)
	p-value§	0.363	0.493	0.417	0.449	0.285
Inpatient type	Short-term	3.75(0.72)	4.31(0.55)	4.24(0.62)	4.16(0.55)	4.03(0.67)
	Long-term	3.68(0.57)	4.24(0.57)	4.22(0.57)	4.12(0.50)	3.93(0.70)
	p-value†	0.196	0.909	0.603	0.159	0.457
Accommodation type	Single-bed	3.83(0.65)	4.35(0.59)	4.30(0.64)	4.23(0.49)	4.14(0.67)
	Multi-bed (2–4)	3.77(0.61)	4.31(0.52)	4.25(0.57)	4.18(0.52)	3.99(0.68)
	Multi-bed (4–8)	3.40(0.89)	4.08(0.67)	4.08(0.69)	3.89(0.58)	3.86(0.67)
	p-value§	0.298	0.030*	0.633	0.826	0.081
Number of wards stayed	0	3.66(0.74)	4.23(0.59)	4.21(0.62)	4.18(0.50)	4.04(0.63)
	1	3.74(0.57)	4.25(0.57)	4.19(0.56)	4.11(0.52)	3.97(0.69)
	2	3.70(0.69)	4.25(0.55)	4.22(0.57)	4.08(0.58)	3.94(0.68)
	≥ 3	3.76(0.82)	4.47(0.48)	4.39(0.69)	4.31(0.51)	4.12(0.71)
	p-value§	0.832	0.340	0.011*	0.419	0.011*
Chaperon	Yes	3.71(0.68)	4.29(0.56)	4.24(0.60)	4.14(0.54)	4.00(0.69)
	No	3.90(0.57)	4.22(0.48)	4.17(0.59)	4.17(0.49)	4.00(0.62)
	p-value†	0.316	0.670	0.272	0.791	0.245

†Mann–Whitney U-test.
§Kruskal–Wallis test.
$^{*}p < 0.05$.

significant difference in perception between male and female inpatients in the five summated indices of design indicators. Similarly, no significant difference in any of the constructed dimensions is present for the variables: admission type, number of previous hospitalization, inpatient type, and chaperon. Age has a significant effect on the perception of *lighting and thermal design* dimension. Significantly, different perception of the *sensory and hygiene design* dimension can be seen among patients staying at different types of accommodation. Previous experiences of accommodation affect patients' perception of two dimensions: *lighting and thermal* and *dimensional* design.

Discussion

Among the design indicators of the accommodation environment evaluated by 287 inpatients, *Cleanliness* (mean = 4.41) was ranked as the most important indicator, followed by *a thermally comfortable environment* (mean = 4.34) and *measures to prevent patient falls* (mean = 4.33). The item, *entertainment facilities* (mean = 3.46), was rated as the least important design indicator, whereas the items: *pleasant exterior view* (mean = 3.59) and *ability to customise the space* (mean = 3.63) were second and third least important indicators. This result suggests that inpatients are more concerned about environmental and safety aspects such as cleanliness, thermal comfort, and prevention of falls, than subjective ones such as views to the exterior or entertainment facilities. The overall responses generally agree with previous findings in the sense that all design factors, which were initially identified through extensive literature reviews, had reasonably high mean scores – indicating their importance to inpatients. Twelve of 19 items had mean scores higher than 4 (important) and the remaining 7 had mean scores higher than 3 (neither important nor unimportant).

There were greater percentages of older inpatients among the respondents (see Table 2). Patients aged 36–50 years and older than 50 years accounted for 40.4 and 31.7% of the respondents, respectively. This distribution, although appears biased towards older patients, is representative of hospitalization patterns in most countries. As an example, hospitalization rates for patients of age 65 years and older in the United States were significantly higher than the rates for the younger groups. Patients aged 65 and older accounted for 37% of hospitalizations and 43% of hospital days (Hall *et al*. 2010). No significant difference in perception based on age was found for the constructed dimensions, except for lighting and thermal design. Respondents aged between 26 and 35 thought that lighting and thermal design factor was important (mean score = 4.36), more than the other age groups. Evidence suggests that as we grow older, our visual abilities decrease – so does our tolerance to variations in the luminous environment (Shikder *et al*., in press). Designing thermal and luminous environments for older people, therefore, need to consider various physical and psychological factors.

Admission type and number of previous hospitalization did not significantly affect inpatients' response on the importance of design factors. However, short-term (<2 weeks of hospitalization) patients considered all constructed design dimensions to be more important than the long-term (>2 weeks of hospitalization) patients. It may be due to the fact that long-term patients had more time than short-term patients to adapt themselves with the hospital environment, resulting in differing perceptions.

There is a significant difference in perception based on accommodation type for the *sensory and hygiene design* factor, comprising three design indicators: cleanliness, noise, and unpleasant smell. Inpatients who stayed in single-patient rooms considered these three design indicators to be more important than those in multi-bed wards. This correlation between accommodation type and *sensory and hygiene design* factor is an important finding because of the fact that single-patient accommodation has become a popular option in the domain of hospital design in recent times

(Lawson and Phiri 2000, NHS Estates 2001, Chaudhury *et al*. 2005). Patients' preference for single rooms may be due to their wish to be close to their partners and family while being hospitalized or may simply be due to their own preference for privacy. Other interesting observation is that mean scores on all constructed PCA factors by patients staying at single-bed accommodation were higher than patients in other accommodation types. In the Chinese context, patients who stay in single-patient rooms are often more financially able than those who choose to stay in multi-bed wards. This may contribute to their higher expectations from the physical environment in hospitals and the significant correlation with *sensory and hygiene design* factor. Other feature of single-patient rooms is that the isolation from other patients contributes to the reduction in nosocomial infections, compared to multi-bed wards (van de Glind *et al*. 2007). On the contrary, single-patient accommodation is not appropriate for all types of patients, in particular for those who need an opportunity to interact and communicate with others for their recovery.

Opportunity for adaptation may be another contributing factor in differing perceptions. Single-patient rooms are better in creating an isolated environment by reducing the ambient noise level. Patients in multi-bed wards are subjected to more noise than those in single-patient rooms; therefore, their tolerance levels may be higher. However, it should be noted that research has found links with higher noise levels in wards and poor sleep quality and sleeplessness in daytime, affecting patients' health outcomes (Freedman *et al*. 1999). It is widely acknowledged that sound levels higher than 55 dB_A brings a disturbing effect (Beranek 1971). Many studies suggest that the exceeding of the recommended level of ambient sound levels is common (Souter and Wilson 1986, Busch-Vishniac *et al*. 2005), resulting in increased stress among patients. However, the relationship between accommodation type and perception is complex, involving many social and psychological parameters. Further research is needed to fully understand this.

Significant difference was found in patients' perception of both the *lighting and thermal design* and *dimensional design* factors, based on their previous hospitalization experience. Patients, who previously stayed at three or more wards, thought that the *lighting and thermal design* factor was more important (mean score = 4.39) than others who previously stayed at less than three wards. They also considered the *dimensional design* factor to be more important (mean score = 4.12) than others. One such *dimensional design* indicator is the *proximity to service delivery points* such as nursing stations, which is important for ensuring the quality of care and patients' wellbeing. Nurses are frontline caregivers in a hospital, and depending on the design of a healthcare facility they may be required to walk considerable distances during their shifts. An investigation into the nursing practices in 36 hospital surgery units has found that individual nurses travelled between 1 and 5 miles per 10-hour daytime shift (Hendrich *et al*. 2008). General consensus is that this travelling needs to be reduced through careful hospital design. In short, this research has found statistically significant difference in perception of the importance of design factors based on patients' previous experience of hospitalization.

Mean scores from male inpatients were higher than females in most of the PCA factors, except for *lighting and thermal design*, in which mean score from male participants was 4.23, compared to 4.24 by females.

The results of the principal component analysis showed that the five constructed factors generally had good internal consistency, even if those factors comprised only three items. This multidimensional structure matches the findings from previous investigations on patient satisfaction, the closely related topic of research to the one described here (Hutton and Richardson 1995, Douglas and Douglas 2004). This research also confirms the hypothesis, from a Chinese perspective, that there exists a positive relationship between patients' perception and their overall evaluation of the role of physical environments in their care. This points towards greater criterion validity within this instrument.

This study also explored inpatients' perception of design factors related to privacy and safety. Principal component analysis suggested that five items (see Table 4) contributed to this constructed factor: measures to prevent patient falls; privacy from other patients and staff; number of patients in a room; en-suite bathroom and proximity to nursing staff. The last item, *proximity to nursing staff*, was the only item with dual loading of 0.505 and 0.521 in two factors, *privacy and safety* and *dimensional*, respectively. In both cases, the loadings were significant and higher than 0.40, indicating the importance of the item. However, considering the differences in loadings, the item was clustered with the *dimensional design* factor, leaving the *privacy and safety* factor with four items. The reason the item is kept is because of the fact that the item is a very important dimensional design aspect for efficient and safe delivery of care.

Research limitations and future directions

First, there are differences in healthcare in urban and rural communities in China, because of the unbalanced development of healthcare infrastructure. This study focused on urban hospitals and research findings may not be representative of the overall Chinese situation in every aspect. The differences, if any, or similarities can be the subject of future investigations.

Second, the study did not include respondents younger than 18 years. The views presented by inpatients in this study are, therefore, of adults. This is not so much a limitation but a conscious decision, primarily because of the cognitive and attitudinal differences between children and adults, and also because of the differences in interior design and decoration in children and adult accommodations, which have the potential to introduce bias. Future studies can investigate children's perception and compare findings with this study.

Third, further demographic variables such as income, educational background etc. could have been incorporated, even though the literature did not suggest a strong association between these variables and the perception of or satisfaction with the built environment. In this study, the questionnaire was conducted among inpatients who were already in a vulnerable condition due to their illness. Therefore, the research team decided to keep the questionnaire succinct and relevant. Also, because of the cultural preferences, some respondents would have felt that the answers to questions on income were too private to give.

Fourth, it is necessary to point out that differences may exist in perception between Chinese respondents and the rest of the world, although such differences may be minimal because the design and operation of major healthcare facilities such as medical college hospitals are more universal than other types of buildings. Nevertheless, validation is a continuous process and further studies are required to confirm these results in different countries and contexts. So, there is a need to replicate findings using confirmatory statistical methods.

Fifth, responses may be different among currently hospitalized patients and respondents who were hospitalized some time ago. The reason may be due to the fact that while currently hospitalized patients can respond from experiences in the immediate past (days or weeks), previously hospitalized patients, however, have to recall their experiences from a distant past, which may as well affect their perception.

Sixth, this research did not explore why cleanliness was perceived highly by the respondents. The general environment in both hospitals appeared clean and discussions with the management suggested that infection control in both hospitals were well within national and World Health Organisation (WHO) guidelines. Qingdao (where the surveyed hospitals are based) residents are well aware of the link between pollution and its atmospheric effects through increased occurrences of acid rain, which led to several successful policy interventions to reduce the concentration of ambient particles and SO_2, ultimately resulting in a significant reduction of harmful particles such as $PM_{2.5}$ in the urban atmosphere (Hu *et al* 2002). This awareness may have led to higher expectation of the physical environment by the residents. A high expectation of cleanliness may be linked with the culture and aspiration of the Chinese for better air quality in indoor and outdoor environments.

Conclusion

Previous attempts at generating evidence base on the association between physical environments and patients' health and wellbeing focused mostly on patient or user satisfaction from the perspective of quality of care in a specific context. The dimensions of these contexts, such as patient experience, interaction with care providers etc., made it challenging to use the evidence base in design decision-making. This research was aimed at addressing this gap by exploring context-neutral perspectives of inpatients on the importance of key design indicators for the design of accommodation environments.

On the basis of the opinions of sample patients and care providers, and an extensive literature review of design indicators that were linked with patient health and wellbeing, this study developed a 19-item self-completed questionnaire to explore inpatients' views on a 5-point scale. Descriptive and principal component analyses were conducted on the collected questionnaire data. Non-parametric tests were conducted to identify if there were any significant differences in perception of the constructed PCA factors based on demographic information. A relatively good response rate indicates that this questionnaire can be used for extracting inpatients views on the importance of design indicators. The instrument has undergone a rigorous process of testing for reliability and validity, supporting its application as a measure of patient perception. The core scales are supported by the results of the factor analysis. PCA confirmed the hypothesized dimensional structure of the questionnaire yielding five factors. The high levels of internal consistency reliability suggest that the items comprising these hypothesized scales are sufficiently related.

Among the investigated design indicators, *design for cleanliness* was ranked as the most important, followed by *a thermally comfortable environment*, *measures to prevent falls*, *unpleasant smell*, *adequate illumination* and *noise* – all with mean scores above 4.20, indicating that they are high on the agenda for inpatients. All of these six factors were part of the two constructed dimensions: *sensory and hygiene* and *lighting and thermal*. In other words, respondents considered conventional environmental design factors to be highly important, more than *architectural* or *dimensional* design factors. The lowest ranked item was *entertainment facilities*, followed by *pleasant exterior view* and *ability to customise the space*. All three had mean scores above 3.46 and were part of *architectural design* factor, indicating that although the factors were at the bottom of the list, the respondents considered them to be important, but not as important as the environmental design factor.

The study highlighted the importance of environmental design indicators to hospital inpatients. However, there were significant differences between perceptions of different groups of inpatients. Inpatients, aged between 26 and 35, considered lighting and thermal to be more important than the other age groups. Patients, who stayed at single-patient accommodation considered *sensory and hygiene design* indicators (cleanliness, noise and unpleasant smell) to be more important than the patients from multi-bed accommodations. Previous experience of hospitalization resulted in differences in perception. Mean summated scores by patients who previously stayed at 3 or more wards were higher in *lighting and thermal* and *dimensional* design factors than the patients who had less hospitalization experiences.

The findings from this research are important for integrating patients' perception in the design process. However, further research is needed to validate and confirm these results in different geographic regions.

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C.3 ARCOM conference paper

FACTORS INFLUENCING THE DESIGN OF SPATIAL LAYOUTS IN HEALTHCARE BUILDINGS

Yisong Zhao[1], Monjur Mourshed[2] and Jonathan Wright[3]

1 Department of Civil and Building Engineering, Loughborough University, LE11 3TU, UK

2 Department of Civil and Building Engineering, Loughborough University, LE11 3TU, UK

3Department of Civil and Building Engineering, Loughborough University, LE11 3TU, UK

There has been a significant increase in capital building programmes in the National Health Service (NHS) since the publication in 2000 of the Government policy on modernisation of health and care delivery in the UK. With regard to physical capacity, the target was to create over 100 new hospitals by 2010 and 500 new one-stop primary care centres. The initiative was seen as a way to modernise the physical facilities as well as the key health and care delivery activities that take place in and around them. Space layout design is considered as one of the primordial activities in a building's lifecycle and impacts on the 'human to environment' and 'human to human' interactions. It is, therefore, essential to understand the factors that influence the design and outcome of space layouts, in particular in healthcare buildings because of the complex functional relationships that exist between the activities. A comprehensive review of the factors related to space layout design in healthcare facilities have been undertaken in this research. The findings suggest that the developments in healthcare and allied fields have implications for the design of space layouts and the resulting buildings and are as important as some of the functional aspects such as efficiency and productivity. The other notable factors can be attributed to the need to mitigate the impacts of, as well as adapt to, the global climate change.

Keywords: Healthcare buildings, space layout planning.

INTRODUCTION

The National Health Service (NHS) is free at point of use and paid for out of taxation, delivering local service by 1.3 million staff in more than 300 organisations and through approximately 5200 GP practice premises as well as other primary care services (DOH 2008). The core of the services is the physical infrastructure that have been built mostly after its inception in 1948; more are still required and is now challenged by issues such as reducing economic growth, ageing population (Hosking and Jarvis 2003) and the need to conserve energy. There are also issues such as the greater accountability of public funding and increasing expectations from the stakeholders, mainly the patients regarding the service they receive. The NHS is also under pressure to reduce the cost of service delivery. Therefore, it is necessary to rethink the process of design and construction of new hospitals and adaptation of existing ones, in particular the decision-making during early stages. Decisions

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[1] Y.Zhao2@lboro.ac.uk

regarding the physical characteristics of a building such as layout, form, fenestration are made at an early stage and it is difficult to alter or reverse them later without significant financial involvements. Space layout design is considered as one of the primordial activities in architectural design for new construction and in most cases of building adaptation. Layout design is a process of locating activity spaces or objects in a container space to maximise or minimise design goals while satisfying the required spatial relationships among component spaces or objects. Design of space layouts in healthcare buildings is challenging due to its strict and complicated relationships among component spaces and/or functional units. The relationships can be in the form of preferred adjacencies and accessibilities. However, little research has been carried out on determinants of space layout plans in healthcare buildings. The aim of the research reported here is to investigate the factors that influence the design of space layouts in healthcare buildings.

METHODOLOGY

The research is based on a critical review of the state-of-the art in current practices in healthcare building design, healing aspects of the built environment, advances in space layout design and relevant policies and strategies of the NHS and Department of Health (DoH). Several strategies were employed to identify potential studies/articles for the review. Metalib, an information portal has been used to identify relevant catalogs, reference databases, citation databases, journals and conferences through semantic meta search. Keyword search was conducted in the identified databases which included but not limited to: the Online Computer Library Center (OLLC), Construction Information Service (CIS), the American Institute of Architects (AIA), British Library's Electronic Table of Contents (Zetoc), ScienceDirect, IngentaConnect, DoH portal, etc. Relevant journals, magazines and newspapers in the topics of healthcare design, patient safety and patient recovery were identified as well. A detailed review was conducted on the 51 of the 150 literatures, screened and identified through the method described above. The objective was to understand the factors that can influence the design of space layout in healthcare buildings.

FACTORS INFLUENCING THE DESIGN OF HEALTHCARE SPACE LAYOUT

Design of healthcare facilities has, in the past, concentrated mostly on accommodating the physical requirements of space and service delivery. The consideration of non-tangible benefits to the users such as patients, staff and visitors was mostly ad-hoc. Advances in our understanding of the therapeutic impacts of the built environment have led to a better appreciation of users’ needs and their relevance to patient wellbeing and recovery. The focus is now on patient-centred design of healthcare facilities while considering the advances in recovery technology and changes in the organisation and service delivery. Studies have indicated that the physical environment, composed of how various activities are laid out, is linked with all indicators described earlier. Factors that influence the design of space layouts in healthcare facilities are described in the following sections and summarised in Figure 1. Various stakeholders, their expectations from spatial configurations and the impact of the factors on the outcome is summarised in Table 1.

Table 1: Stakeholders, their expectations from spatial configurations and impacts on the outcomes.

Stakeholders	Specific requirements	Impacts
Patients	Isolation from other patients (when required)	PD, IC
	Company of other patients (when appropriate)	PS
	Easy access to lighting, bed and television controls	PS
	Easy access to phone	PS
	Interesting area for ambulation	PS
	Outside view	PS
	Easy access to nurse's call signal	PS, PR
	Access to bathroom and shower	PS, PSa
	Pleasant indoor light	PS, PR
	Aesthetic, pleasing environment	PS, PR
	Ability to accommodate differing approaches to staffing	SP
	Ability to deal with shift in severity index	SP
	Ability of all care providers to confer in privacy	SP
Nursing staff	Ability to work effectively in day or night shifts	SP, SS
	Access to office and conference space	SP, SS
	Access to information retrieval and input	SP, PR
	Access to high-urgency/frequent-use items	SP, PR
	Access to supplies and disposal of used supplies	SP, PR
	Access to equipment storage in designated spaces	SP, PR
	Access to medication	SP.PR
	Staff lounge facility	SS
	Security- personal and for property items	SS
Visitors	Easy access to patient's room	PS
	Private space for communication with staff	PD
	Accommodation with patients	PS, PR

Legends:
SP: staff productivity, SS: staff satisfaction, PS: patient satisfaction, PSa: patient safety, PR: patient recovery, PD: patient dignity, IC: infection control.

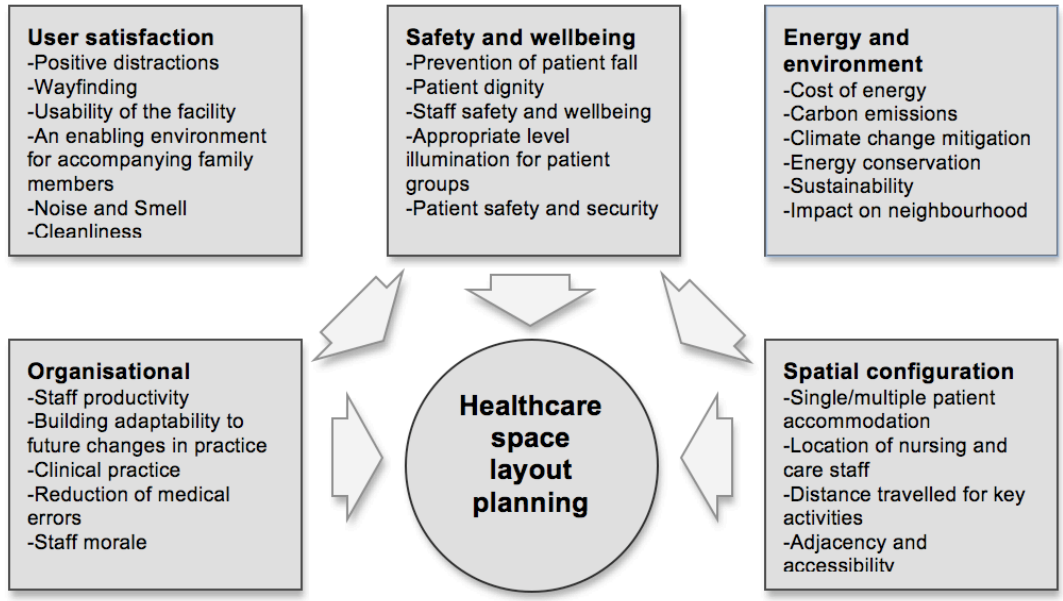

Figure 1 Factors that influence space layout design in healthcare facilities.

SAFETY AND WELLBEING

Patient safety. Patient safety has been considered as one of the most important aspects in the hospital design process and it relates to staff, patients and visitors. For patients, a safe environment is essential for successful recovery for staff safety relates to the working environment and their wellbeing. Evidence on the link between the facilities design and patients' safety can be found in the literature (Reiling et al, 2004; Barach and Dickerman et al. 2006; Rashid 2007). Safety of staff and patient is of particular importance in the design of behavioural health facilities, as discussed by Sine and Hunt (2009) and summarised in the following five-level form:

- Level 1: Restrictions on accessibility; e.g. staff and service areas where patients are not allowed;
- Level 2: Highly supervised areas; e.g. corridors, counselling rooms, interview rooms and smoking rooms where patients are highly supervised and not let alone for periods of time;
- Level 3: Generally supervised areas; e.g. lounges and activity rooms where patients may spend time with minimal supervision;
- Level 4: Minimal or no supervision areas; e.g. patient rooms (semi-private and private) and patient toilets where patients spend a great deal of time alone with minimal or no supervision; and
- Level 5: Administrative or initial assessment areas; e.g. admissions rooms examination rooms and seclusion rooms where staff interact with newly admitted patients that may present potential unknown risks and/or where patients may be in a highly agitated condition.

The levels of safety, described above depends on the amount of supervision that the patients get from the staff during their stay. Hospital layout designs based on an assessment of staff and patient safety will aid the staff offer better supervision and reduce potential medical errors. The aspects of health and safety legislations and the management's desire to minimise risk from litigations also contribute to the safety aspects of design.

Patient falls. Another aspect related to patient safety is patient falls. Findings from literature suggest that most patient accidents take place in their rooms. Hendrich, et al. (1995), for example, discovered through a case study at a teaching institution that most falls occur when the patients would like to get to the bathrooms from their rooms. Pullen et al. (1999) reported that 74 out of the 444 patient falls in their study happened when the patients were alone in the bathrooms. The issue of patient fall have implications in the desired occupancy of patient areas. Multi-occupancy areas have higher concentrations of staff visit and therefore more safe with regard to falls, but it conflicts with other design goals such as patient satisfaction, etc. Another way to approach the issues to would be to increase the monitoring of patients by staff members (Hendrich et al. 1995), which may not necessarily be preferred due to the desire to drive down cost of service delivery. Allowing family members to accompany the patient has also been suggested (Ulrich 2004) to reduce the risk of fall. All of these approaches have bearings on the design of the hospital layout as activities, spaces and users are interrelated in a complex web of interaction.

Current practices related to patient safety has been criticised by the DoH, which concluded that contemporary facilities design is out of step with the thinking and practice in the NHS and is not as up-to-date as other safety critical industries or organisations (DoH 2003).

USER SATISFACTION

Patient satisfaction

Evidence from recent literature indicates that patients expect more from the hospital in addition to a high quality of health service, such as spacious single bedroom with bathroom, pleasant lighting, ability to have outside views, access to phone and television controls, etc. There is a strong link between patient outcome and what patient want in a building, further discussed in Ulrich (2004) and Lawson and Phiri (2004). Some of the features of patient satisfaction are discussed below:

Accommodating visits from family members. Visits from family members will provide social support to the patient, which may help to alleviate the physical pain and stress. It has been found that the involvement or interaction of family during hospital stay affect patient outcomes (Powers and Rubenstein 1999).

Occupancy. Barlas (2001) argues that the noise disturbance increases stress levels and disturbs sleep patterns among patients and slows down patient recovery as a result. Single rooms are, therefore, preferred to multi-bed wards as they provide the patients a more quieter environment as well as increased privacy and confidentiality. Frequent family interactions is more acceptable in single rooms.

Positive distractions. Positive distractions have been defined as "environmental-social conditions marked by a capacity to improve mood and effectively promote restoration from stress” by Ulrich (1991). Aspects such as outside views, pleasant lights, music and art will all enhance the patient wellbeing. Positive distractions are also known to improve staff morale and satisfaction.

Patient privacy

A survey by Jones and Bullard (1993) of 140,000 hospital patients showed privacy to be of primary concern to patients. Healthcare providers have a duty to treat patients with respect and autonomy and to protect their personal data and the physical person from the invasion of privacy.

Single-sex accommodation. Being with other patients of the same gender is an important component of privacy and dignity. This type of accommodation can take a number of different forms, for instance, the single-sex wards, single-sex bedded bays and single rooms. The hospital should provide a combination of these different types of accommodation. Recognising the importance of the aspect, the DoH has been slowly replacing mixed wards with single-sex wards over the past years. 97% of NHS trusts provide single-sex wards with segregated bathroom facilities.

Dignity on the ward. In addition to the segregation based on sex, the patients prefer to have the ability to make their personal space private as and when necessary. The image of a hospital ward featuring a line of beds with no physical separation between them, also known as a ‘Nightingale’ ward fails to provide the essential levels of privacy. 98% of these wards for older people have now been replaced as part of a wider hospital building programmes. Over 350 other Nightingale wards have also been replaced (DoH 2001).

ORGANISATIONAL

Reducing errors. Research has shown that people are likely to make mistakes when busy, tired or at worse body conditions. Errors may occur at the ill-designed nursing stations, disorganised and/or filled storage rooms. Cortvriend (2005) has found that the nursing staff pick up a wrong bottle or put the bottle at the wrong place because of the non-distinguishable storage design for medicines.

Clinical practice. The drive to reduce costs of service delivery and the advances in clinical practice have implications on the way hospital layouts are designed and constructed. The design of layouts also need to be adaptable to future changes in practice, in particular because of the integration of information technology (IT) and virtual activities such as virtual surgery, telemedicine, etc.

Nurse station. The impacts of hospitals on the staff are studied extensively, in particular the aspects related to nurses’ productivity. Nurses’ station is regarded as the primary determinant of the architectural form and character of hospital buildings (Kazanasmaz 2006).The function of the nursing unit is the organisational hub of the patients ward where the nurse-call is registered, paperwork is done and staff report at change of shift. A good design of the nursing unit will help to improve patient care and staff satisfaction (McCarthy 2004). This aspect is discussed further in the next section.

SPATIAL CONFIGURATION

Infection control

Hospital design should make sure that the inpatients, especially those vulnerable and weak, are away from the infection within the hospital. Several studies indicate that the effectiveness of frequent hand washing and after each activity with associated risks of infection. Spatial configuration with single-patient accommodation have also been found to the effective in containing infection and reduce the risk of spreading (Chaudhury et al. 2006, Dowdeswell et al. 2006, Saxon 2004, Ulrich et al. 2004).

However, it needs to be mentioned that the degree of effectiveness of single-patient accommodation in reducing levels of hospital infection is not based on any large scale longitudinal study. Contrasting findings also exist; e.g. Vietri et al. (2004) investigated the effects on MRSA infection rates of moving from a hospital with open bay wards to a new facility with single or double rooms. No significant change of MRSA infection rate was found; this is interesting but it covers only one hospital that includes a relatively small group of patients. Lawson and Phiri (2004) argue that it is easier to detect and manage infection outbreaks at single-patient rooms because:

- Single-patient rooms act as isolated units in the hospitals;
- It is relatively easy to carry out deep cleanings in single-patient rooms;
- Monitoring of single patients with infection is more manageable;

Evidence concerning the efficacy of treatment of patients in single rooms mainly concerns quite specific categories of patients such as SARS infected patients (McManus et al. 1994; Thompson et al. 2002; Farquharson and Baguely 2003; Schwarz and Dulchavsky 2002).

Space considerations

Bed space. The provision of sufficient space in clinical areas, in particular around each bed, is one of the most important aspects of the design of acute in-patient accommodation for allowing for key activities as well as to reduce infection risks. The relationship between the bed spacing and infection carriage has been examined by many researchers (Kibbler et al. 1998, Williams 1966, Saxon R 2004).They argue that if adequate space around a single bed is not provided, the equipments may become contaminated and may lead to cross-infection if they are relocated elsewhere. Lawson and Phiri recommended that the minimum area of single-patient rooms should be 20 m2, with dimensions of 5m by 4m, excluding en-suite facilities; similar to what has been suggested in the Health Building Notes (HBN 1997).

Nurses' station. The location and configuration of the nurses' station impacts on patient observation and safety, efficiency of service delivery, travelling time and to some extent staff satisfaction. Visibility of the Nurses' station to the patients have been found to be important in maintaining a good level of service. Figure 2 depicts popular types of nursing stations and their impact on the layout and architectural form.

ENERGY AND ENVIRONMENT

Energy consumption cannot be overlooked when design the healthcare layout as the health care sector is one of the public sector's largest energy consuming sectors with an annual energy bill of £400m and emissions of 3.3MtCO_2/yr (Carbon Trust 2007). The sector has mandatory energy targets for new and existing buildings, which seek to deliver a 15% reduction in energy consumption from 2001-2010. Well thought-out layout design may prevent unreasonable energy consumption to enhance the overall sustainability of the building and contribute to climate change mitigation. Attempt has been made by the NHS in recent years to decrease the amount of energy consumed within their premises and, consequently, greenhouse gas (GHG) emissions.

DESIGN PROCESS CONSIDERATIONS

This paper addresses the general issues that influence the design and in some case, the operation of healthcare buildings. The findings in this research suggest that the developments in health and care delivery and in the allied fields have implications for the design of space layouts and resulting buildings, which are sometimes as important as some of the functional aspects such as efficiency and productivity. Apart from the factors described above, the design of healthcare buildings is much influenced by the dynamic developments in the changing healthcare sector, from the financing of the sector to the perception and/or satisfaction of the key stakeholders. Adaptability to future changes, both organisational and technological, is therefore the key to the design and construction of sustainable healthcare buildings. Typically, the design of healthcare buildings is driven by their function and the type of services that they provide to the public. The wider recognition of the healing aspects of the built environment translates to the fact that the design of a hospital, from layout planning to the detailed design of its services, need to be holistic in its approach.

The consideration of the wide range of factors that may affect the outcome of a healthcare building is challenging in an industry setting. Therefore, a strong collaboration among the stakeholders at the earliest in the process is essential to maximise the positive outcomes and to enhance sustainability. Integration of multi-disciplinary simulation and modelling tools for analysis and optimisation methods for an effective search of the design solution space may assist designers and other stakeholders in making effective decisions.

CONCLUSION

The influence of a hospital's design on patient wellbeing has been subject to much debate throughout the past 150 years (Gidney 2008). As more patient-focused healthcare facilities are being built, ensuring patients' wellbeing is not the only standard a modern hospital should aim for. Besides the clinical aspects, the healthcare environment around a patient plays a very important role during their stay. A well-designed/refurbished hospital is, therefore, the cornerstone of the high standard the government is aiming to achieve. The consideration of the factors identified in this research are essential in the process of design/refurbishment. The complex and often conflicting interrelationship that exist between some of the factors may require the stakeholders to work collaboratively during all lifecycle stages, starting from inception or concept development.

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