The Hong Kong Polytechnic University

Department of Building and Real Estate

A BIM-based Pre-occupancy Evaluation Platform (PEP) for Facilitating Designer-Client Communication in the Early Design Stage

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A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy

August, 2011

Declaration

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

Signed

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Abstract

The architectural design process may vary according to different situations, but the common ground of this process generally starts from a briefing stage and ends up with design drawings. During the briefing and design process, communication between designers and clients is usually intensive and significant. Such communication is mainly based on client's requirements and solutions proposed by designers. Consequently in practice, there are constant interactions between these two groups of people.

As documented in literature, there are some gaps between the designers and clients during these interactions. First, unlike designers, inexperienced clients may find difficulties in reading 2D drawings and imagining how the design will be emerged after construction stage. This will affect the process and outcome of requirement specification and design review. It is also not easy for them to understand how their organization daily activities will be accommodated in the new built environment (such as movement patterns). This would also affect them to effectively evaluate the design solutions. On the other hand, although some requirement models were established, there is still demand for a platform to manage both of the client requirements and feedback, and facilitate them to review design solutions against those requirements during the communication with designers, especially in the context of a virtual environment.

In order to address the problems mentioned, objectives of this research are (1) to review the literature about the early architectural design process, discover the problems affecting effectiveness of the designer-client communication, and find the approaches of improvements; (2) to design and develop a Pre-occupancy Evaluation Platform (PEP) by

integrating building information modelling, user activity simulation and requirements management techniques, so as to narrow the gaps between designers and clients; (3) to validate the effectiveness of this platform in enhancing client understanding of the design solutions, and improving their performance during requirement specification and design review process.

To achieve these objectives, different research methods were used. Literature review was conducted to understand the background of this research, define problems need to be solved by the PEP, and review relevant techniques for solving these problems. An applied research method named research and development was applied to establish this new platform. This PEP contains three modules: (1) building information module; (2) user information module; and (3) pre-occupancy evaluation module. In the first two modules, virtual prototyping technology is applied to improve client understanding of their built environment. A virtual environment is built based on Building Information Modelling (BIM) tools for demonstrating both building models and end-user activities in the built environment. In the pre-occupancy evaluation module, a specification of client requirements and feedback is complied, which contains requirements of building projects (mainly in spatial factors) and related questionnaires for collecting client feedback. An interface is also designed to facilitate the clients to manage requirements and review design solutions. Both of the requirements and feedback are recorded and saved in a database during the design process. In addition, a guideline of implementing the PEP in practice was developed. During the validation process, experimental research, action research and questionnaire survey were employed to validate the impact of PEP in improving participant’s understanding of the design solutions and their satisfaction of the design review process. This validation process was also intended to test the effectiveness of PEP in facilitating participants to generate feedback. In this process, the conventional communication methods supported by 3D building models were used for comparative study.

The results of this validation indicated that, compared with the conventional communication process, the simulation of end-user activities can improve client understanding of the building design mainly in terms of spatial factors and increase their willingness and confidence to work collaboratively with the designers. The application of requirements and feedback specification and related interface also help them to generate larger number of suggestions for improving the design solutions, especially in terms of the spatial factors. These suggestions include further developed requirements and unsatisfied requirements discovered during the design review process. Therefore, the PEP is considered to provide an effective tool to facilitate the designer-client communication.

The main contributions of this research include (1) this research has lead to new knowledge on establishing a Pre-occupancy Evaluation Platform (PEP) for improving designer-client collaborative working efficiency during the early design stage; (2) this research has provided new insights into building up a *user activity simulation model* which contains both information about the building design and user organization in a project; (3) this research also provides new knowledge on creating and implementing a client requirements and feedback specification, which supports clients in conducting a systematic pre-occupancy evaluation during the design stage.

Publications

The following is a list of publications by the candidate on matters relating to this thesis.

Refereed Journal Papers:

1. Shen, W.L., Shen Q.P. and Sun, Q.B. (2012) Building Information Modeling-based user activity simulation and evaluation method for improving designer–user communications. Automation in Construction, 21(1), 148-160.
2. Shen, W.L., Shen Q.P. and Zhang X.L. (2011) A user pre-occupancy evaluation method for facilitating the designer-client communication. Facilities, In Print.

Refereed Journal Papers Under Review:

3. Shen, W.L., Shen Q.P. and Zhang X.L. (2011) The user pre-occupancy evaluation method for supporting designer-client communication in early design stage: a case study. Journal of Construction Engineering and Management, Under Review.

Conference Papers:

4. Shen, W.L. and Shen, Q.P., (2011) BIM-based user pre-occupancy evaluation method for facilitating the designer-client communication in design stage. In Management and Innovation for a Sustainable Built Environment. Amsterdam, Netherlands.
5. Shen, W.L. and Shen, Q.P., (2011) Case study of using user pre-occupancy evaluation method in facilitating designer-client communication. In International

Postgraduate Conference on Infrastructure and Environment. Hong Kong, pp. 653-660.

6. Shen, W.L. and Shen, Q.P., (2010) User Activity Simulation and Evaluation Model for the Improvement of Space Planning in Office Buildings. In CIB World Congress. Salford, United Kingdom, pp. 62-73.
7. Shen, W.L. and Shen, Q.P., (2009) User Activity Simulation Model for the Improvement of Space Planning in Office Buildings. In International Conference on Construction and Real Estate Management. Beijing, China, volume 1, pp. 699-704.

Acknowledgements

First of all, I would like to express my deepest gratitude to my supervisor, Prof. Geoffrey Qiping Shen, for his continued guidance, support and encouragement during these years.

I would like to thank the Building and Real Estate Department of the Hong Kong Polytechnic University, for the provision of research funding and high quality facilities. I should also thank the academic and administrative staff in my department, because my research cannot be conducted smoothly without their help.

I also owe my gratitude to my team member Dr. Luo Xiaochun, for his technical support and encouragement during my research. In addition, sincere thanks should be given to Dr. Lin Gongbo and Dr. Fan Shichao, for their kind help during my research and daily life. I would also like to express my thanks to other team members Wang Hao, Chen Qing, Yuan Zhao, Yang Jing, Tang Liyaning and Wang Danlu, for their sincere help.

During my stay in England, I am indebted to the colleagues from the Think Lab of Salford University. I would like to thank Prof. Terrence Fernando for his invitation. Many thanks go to Ms. Hanneke Van-Dijk, Sun Quanbin, Dr. Wu Kuo-Cheng; Dr. Yao Jialiang, Dr. Zhang Yufan and other friends in Thank Lab, for their help during my stay.

I would like to show my gratitude to other colleagues and friends: Dr. Jorge Ochoa, Dr. Zhang Xiaoling, Dr. Ann Yu, Dr. Derek Drew, Miss Zhong Xian and Ms. Elaine Anson, for their help and support. Thanks also go to Mr. Eric Tam and Alfred Wong from the Campus Develop Office, without the provision of the project drawings and their active participation, organization of these workshops in this research would not be possible.

Last but not least, I would like to thank my parents, Prof. Shen Weifeng and Ms. Hu Ronghua, for their support and understanding all the time. This thesis is dedicated to them.

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Chapter 1 Introduction

1.1 Research Background

Although there are varieties of architectural design processes, the common ground is that, the building design process usually starts with a briefing stage, and ends with completed design drawings. Archer (1968) defined the design process as four intertwined phases: (1) Problem analysis, (2) Solution synthesis, (3) Evaluation and (4) Communication. Communication between the different participants is necessary throughout the whole design process. In a typical architectural design process, participants from a variety of disciplines, such as, designers, clients, and consultants, are involved in the different stages. During the briefing and design solution development processes, communication between designers and clients is particularly intensive and significant. In this study, “designers” refer to architects mainly, and “clients” can include stakeholders as well as end-users that have set up the design requirements. In addition to preparing the design drawings and demonstrating alternative designs to the clients, the designer’s duties may include: (1) consulting the client about significant design issues; (2) investigating the feasibility of the requirements; (3) advising on the initial brief; (4) advising on the development of the brief based on the employer’s requirements and so on (RIBA, 2000). The client, for his part, need to communicate requirements to the designers during the briefing and design stage. This process may include: (1) specifying and developing the planned intentions with respect to the building to be constructed; and (2) reviewing design solutions proposed by designers.

Communication between client and designer is usually based on the client's requirements and the designer's solutions (Shown in Figure 1.1). A Brief is a formal document containing the written instructions and requirements of a client in a construction project (Yu, 2006). In practice, there is constant interaction between the brief and design proposals (RIBA, 2000).

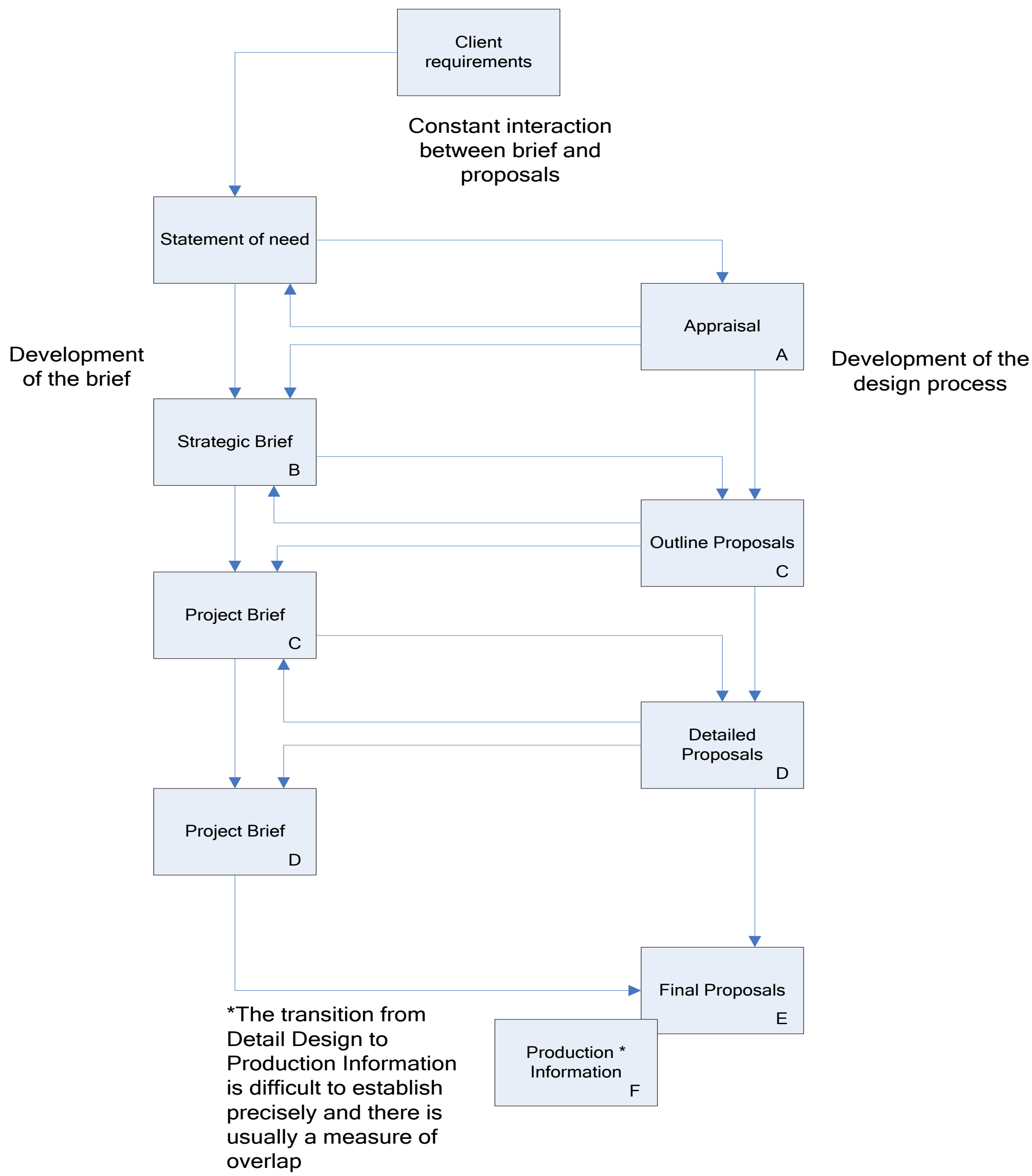


Figure 1.1 The process of briefing and design development (Source: RIBA, 2000)

As documented in literature, there are some gaps between the designers and clients during these interactions. Unlike designers, clients (including end-users) are usually untrained in reading architectural drawings, hence their understanding is limited. This would affect the efficiency and effectiveness of design brief specification (Barrett, 1999). Problems also stem from the fact that clients cannot imagine how the design will be emerged after construction (Lertlakkhanakul et al., 2008). In addition, it is difficult to imagine, during the design stage, how the client organization's daily activities (such as movement patterns) will be accommodated in the future built environment. Such problems may reduce the effectiveness of designer-client communication, and result in dissatisfaction of the design solutions after construction.

To facilitate the designer-client communication, in the building industry, varieties of computer-based techniques such as virtual prototyping and building performance simulation techniques are developed (Li et al., 2008). Building Information Modelling (BIM) is one of the emerging techniques (Eastman et al., 2008). Apart from its advantages in enhancing designer's efficiency, it also provides a platform facilitating the understanding of complex building by inexperienced clients due to its 3D virtual reality representation of the final built environment. On the other hand, because buildings play a role of accommodating user's organizations and equipment, and enable their activities (Ekholm and Fridqvist, 2000), many building analysis tools take occupant's activities into account. For example, crowd behaviour simulation (Ulicny and Thalmann, 2001; Braun et al., 2003; Pelechano et al., 2007) and emergency evacuation simulation (Santos and Aguirre, 2004; Shen, 2005; Ruppel and Abolghasemzadeh, 2009). The simulation of occupant activity has also been considered in research aiming to simulate control-oriented user behaviour, namely interaction between the occupants and environmental controls, e.g. windows, lights, and heating systems for energy saving purpose (Hunt, 1979; Fritsch and Kohler, 1990; Nicol, 2001; Zimmermann, 2006; Mahdavi and Mohammadi, 2008; Zimmermann, 2010).

For supporting the normal architectural design process, user activity simulation techniques were applied in relatively less studies. Ekholm and Fridqvist (2000) emphasised the significance of analyzing end-user's activities and stated that, in the space planning process, to some extent, the activities are considered as the criteria to define the size and relationship between these spaces, but not the building's spaces themselves. Ekholm (2001) then developed an occupant activity add-on for integrating the user activity with the ArchiCAD environment, which can define user activity by time and space and add users into the ArchiCAD in terms of design objects. However, this prototype cannot demonstrate the activity scenarios of the end-users (e.g. movement of users), and has no further illustration of how to apply this user activity modelling method for supporting the briefing and design process, particularly in the aspect of designer-client communication. For the purpose of predicting more accurate occupant usage data (e.g. occupancy time per day) in office buildings, Tabak (2008) developed a system called User Simulation of Space Utilization (USSU) to mimic the real behaviour of office building occupants when scheduling activities. However, the USSU needs a large amount of user input data and focused on user activity scheduling methods mainly. There was also no demonstration of user activity scenarios in virtual environment for enhancing client understanding of the design solutions.

Consequently the significance of integrating user activity with building designs to support the designer-client communication in the early design stage was insufficiently explored, and there is no systematic method or guideline to guide the application of user activity simulation techniques in facilitating designer-client communication.

Additional to the problems about limited experience of client in understanding design, another factor which lowers the efficiency of designer-client communication is related to the management of client requirements and feedback. The communication between designers and clients is an interactive and dynamic process. During this process, clients will continually generate requirements and feedback as the development of the design, especially when they obtain further understanding. The feedback of the design is significant to further development of the design. Although some requirement models of building projects have been established (Kamara, 2002; Kiviniemi, 2005), there is still a lack of a comprehensive mechanism which can not only manage the requirements, but also guide the clients in reviewing design solutions against requirements and collecting feedback during the communication with designers, especially in the context of the virtual environment.

In order to address the problems above and narrow the gaps mentioned, it is necessary to set up a platform which can not only demonstrate the building information of the design solutions, but also how the organization will be accommodated in the future built environment, so as to enhance the client understanding of the design provided by designers. This platform should also provide the functions as facilitating designers to manage both of the requirements as well as the feedback generated from the client. It is also necessary to test to what extent, this platform can improve the efficient and effectiveness of the designer-client communication in real project.

1.2 Research Problems and Objectives

1.2.1 Research Problems

Based on the background provided, this study is aiming to address the following research problems:

1. **What are the specific gaps which exist between designers and clients during the briefing and design stages?**

These gaps identified from the literature and practice can determine the objectives and functions of this proposed platform, as well as the test criteria for the validation component of this research project

2. **What are the techniques suitable for establishing a platform for narrowing the gaps?**

Numerous tools which can be used to optimize the designers and client performance during the briefing and design stages are now on the market. For example, more virtual prototyping and building simulation techniques have been developed and applied in many projects to solve design and construction problems. Suitable techniques to help client understand the design solutions and communicate with designers are a significant feature of this research.

3. **What guideline or process can guide the application of this platform during the briefing and design stages?**

When certain suitable techniques have been selected to build the platform, a guideline or process is needed to combine these techniques serving also as an implementation instruction when supporting designer-client communication on a real project.

4. **What methods and indicators are required to validate the effectiveness of the platform on a real project?**

The implementation of a validation process is an essential step in proving the effectiveness of the proposed platform. Problems which have to be addressed before the validation process include a) how to measure the effectiveness of client performance during communication, b) what validation hypothesis to adopt, and c) what kind of experiment would be suitable for the validation.

1.2.2 Research Aim and Objectives

Following the research problems raised, the aim of this research is specified as: to investigate to what extent a Pre-occupancy Evaluation Platform (PEP) can improve the effectiveness and efficiency of designer-client communication in the early design stage. The following three specific objectives are designed to achieve this aim:

1. To review briefing and design processes presented in the literature to identify the problems, areas of improvement as well as suitable techniques which can be used to address these problems;

2. To design and develop a Pre-occupancy Evaluation Platform (PEP) which integrates techniques such as building information modelling, user activity simulation and requirements management, in order to facilitate the process of design review and requirements specification;

3. To validate the effectiveness of PEP in facilitating designer-client collaboration on real projects, based on the validation methods developed and indicators for measuring the performance of PEP.

1.3 Research Methodologies

1.3.1 Introduction

Research methods can be classified into basic research and applied research depending upon the purpose of the research. Basic research is conducted solely for the purpose of "theory development and refinement", while applied research is mainly concerned with applying and testing theory and evaluating its usefulness in practice. To be more specific, applied research emphasizes what works best rather than why it works (Gay and Diehl, 1992) . Gay and Diehl also classified applied research into three types as follows:

- Evaluation research, which is intended to support decision making by collecting and analyzing data according to one or more criteria. More objective criteria would make the decision more reliable.
- Research and development, which is designed not to directly formulate or test theory but to develop new products or processes. The process of research and development aims to meet specific needs along with detailed specifications. Once this process is

completed, constant field-tests and revisions are made until a specified level of effectiveness is achieved.

- Action research, which is set to solve “a local problem and is conducted in a local setting”. The result of action research may not be generally applicable or characterized by the same kind of mode in other settings.

In addition, Gay and Diehl (1992) specified five research categories in a classification scheme for research: historical, descriptive, co-relational, causal-comparative, and experimental:

- Historical research, which includes “studying, understanding, and explaining past events”. The aim of historical research is “to arrive at conclusions concerning reasons, effects, or trends of past occurrences for explaining present events and predicting future events”.
- Descriptive research, which includes “collecting data for testing hypotheses or answer questions relating to the current status of the subject of the study”. The purpose of descriptive research is to illustrate and present the way things are. Typically descriptive data is collected by conducting questionnaire surveys, interviews, and observation(s).
- Co-relational research, which attempts to “determine whether, and to what extent, a relationship exists between two or more quantifiable variables”. The goal of co-relational research is to establish the relationship, or testify to the lack of it, or to use existing relationships in making predictions. Generally, variables believed to be related to a major, complex variable are investigated during co-relational research. Those found not to be highly related are eliminated from further consideration. For

those variables that are highly related, it is suggested that causal-comparative or experimental studies are conducted to determine if the relationship is indeed causal.

- Causal-comparative research，both “causal-comparative research and experimental study are intended to establish cause-effect relationships and involve group comparisons”. In casual-comparative research, the “cause”, or the independent variable is not manipulated, and is already in existence.
- Experimental research, within which “the researcher manipulates one independent variable at least and controls other relevant variables”, so as to “observe its influence on one or more dependent variables”. The cause in experimental research is regarded as an active independent variable and the one in causal-comparative research already existing, as above, is an attribute independent variable.

1.3.2 Research Framework and Methods

The framework of this research project is shown in Figure 1.2. Among others, the main components of the research method in the framework include:

- Literature review;
- Research and development;
- Experimental research;
- Action research;
- Questionnaire survey.

These methods were selected to achieve the research objectives and address the research problems mentioned in Section 1.2.

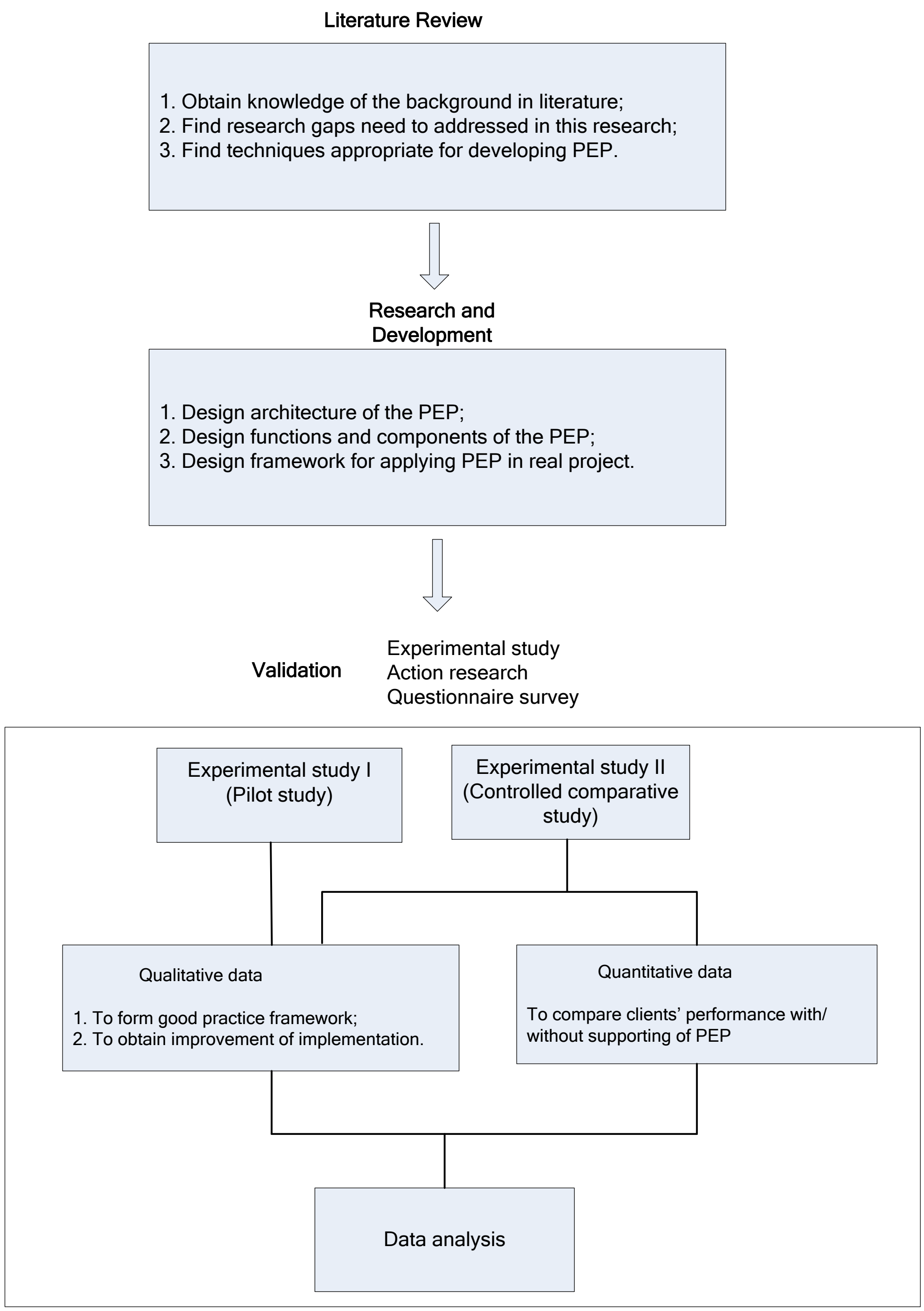


Figure 1.2 Research framework

1.3.2.1 Literature Review

Ridley (2008) pointed out the six purposes of a literature review as follows: (1) to provide a historical background to the research; (2) to give an overview of the current context including contemporary debates, issues and questions in the field; (3) to discuss the relevant theories and concepts supporting the research; (4) to introduce relevant terminology and definition in the context of the work; (5) to find a gap in the field, or describe related research and show how this work extends or challenges previous studies; and (6) to provide evidence for a practical problem or issue addressed by the research so as to emphasize its significance. In this project, the literature review focused on the following two aspects:

1. Literature review of the background to the briefing and architectural design stages as well as communication problems between designers and clients. These problems both defined the research scope and indicated the functions required of PEP. The main problems which had to be addressed in this research are the difficulties encountered by inexperienced clients in communicating with designers, which lower communication effectiveness and client satisfaction with the design solutions.
2. Literature review of the techniques which can address the problems discovered. Since different techniques are used within PEP for improving inexperienced client performance, the review was intended to introduce the terminologies and definitions of the relevant techniques used in the PEP development process. In addition, the reasons for the application of certain techniques were also explained.

1.3.2.2 Research and Development

As mentioned in Section 1.3.1, research and development is one of the applied research methods used to develop new products and processes meeting specific needs. The PEP developed during this research study is a new four step process for enhancing communication efficiency and effectiveness between designers and clients. There were also specific requirements for designing and developing the three modules of the PEP. The PEP was tested for improvement after its development, and its effectiveness studied and validated by two experimental studies. Therefore the research and development method was selected in this study.

1.3.2.3 Experimental Studies

Since the PEP uses techniques which aim to improve client understanding of design solutions and directs the design review process, the primary hypothesis behind this research is that the PEP can improve the efficiency and effectiveness of design-client communication. Since experimental study "is the only method of research that can truly test hypotheses concerning cause-effect relationships" (Gay and Diehl, 1992), experimental studies were selected as a means of testing the hypothesis.

1.3.2.4 Action Research

In addition to the definition given by Gay and Diehl, other definitions also have been provided. The term, "action research" was first coined by Kurt Lewin in about 1944 and appeared in his paper "Action Research and Minority Problems" in 1946. He described action research as comparative research on the "conditions and effects" of different forms of social action, taking the form of “a spiral of steps, each of which is composed of a circle of planning, action, and fact-finding about the result of the action” (Fan, 2009).

Scott and Davidson (2002) stated that action research depends on the involvement of the researcher in a problem situation, enabling direct learning. Waser and Johns (2003) also emphasised the participation of the researcher in a practical situation during action research, and that observations when in this situation can lead to lessons for improvement. A similar definition of action research was given by Fellows and Liu (2008) as research involving active participation by researchers in the process under study. The aim of such action research is to identify, promote and evaluate problems and potential solutions. Cohen et al. (2003) stated that action research is proper in any context when specific knowledge is needed for a specific problem in a specific situation, or when a new approach is to be applied to an existing system. In this study, specific knowledge derived from a pre-occupancy evaluation platform, was used to support the specific situation of designer-client communication. It was also the aim to overcome the specific problems encountered during the designer-client communication process. In addition, the researcher was involved in the experimental studies as a facilitator, so action research provided an ideal research technique for this study.

1.3.2.5 Questionnaire Survey

The questionnaire survey requires systematic collection of data from population’s samples, in who have been exposed to or experienced an event or process (Denzin and Lincoln, 2003). A questionnaire survey was used for this research during the validation process based on the experimental studies, which attempted to collect descriptive data as qualitative results for the experimental studies.

1.4 Thesis Structure

The rest of the thesis is organized into 6 chapters. As always in a study of this nature, this thesis stands on the body of work of previous researchers and practitioners. The literature review is an important part of this thesis and is presented in two independent but related chapters. Chapter 2 is a review of problems encountered during designer-client communication in the briefing and design stage. Chapter 3 reviews the related technologies and techniques which can address those problems.

Chapter 4 first provides an overview of the Pre-occupancy Evaluation Platform (PEP) proposed in this thesis, including architecture, components as well as the process for implementation PEP in real project. Then it details the three PEP modules namely, the building information module, the user information module and the pre-occupancy evaluation module. The details include the functions of each module, the relevant theories and the interfaces developed for implementation.

Chapter 5 describes the validation experiments. It introduces the application of PEP to a real campus project, to test the effectiveness of the method in supporting designer-client communication in real situations. The findings and conclusions of the case study are also presented.

Chapter 6 starts by drawing conclusions from the study as derived from the research methods used in this study, followed by the clarification of the contribution to knowledge made by the research. The limitations of the research and suggestions for further research are then discussed.

Chapter 2 Designer-Client Communication in the Early Design Stage

2.1 Introduction

This chapter gives an overview of the briefing and design process from the perspectives of basic concepts and problems encountered during designer-client communication.

2.2 Design Process

2.2.1 Development of Design Process

Before the Renaissance, buildings were constructed but not planned, and a master mason developed a simple schema usually by following the traditional patterns he learned as an apprentice or a journeyman. As practice developed, the architects of the Renaissance began to formally plan the whole building before construction and to communicate this plan to the builders. Scale drawings and models became the primary means of representation. With the introduction of scale drawings and models, the architects became designers, who demonstrated professional skills through drawings rather than by supervision of the construction processes. Since the clients were less capable of understanding the abstract scale drawings, scale models have always been the preferred tools for communication as they represent the building three-dimensionally. In the 1450s, architectural design became a form of professional practice. The separation of design from construction led to architects becoming independent agents who were skilled in theory, drawing and making models (Kalay, 2004).

2.2.2 Various Design Processes

In this research study, the term “early design stage” mainly refers to the process of briefing and architectural space planning design. RIBA (2000) defined the outline plan of work in a building project as consisting of five stages: preparation, design, pre-construction, construction and usage (Figure 2.1). Specifically, this research addresses problems in stages B, C, and D of Figure 2.1.

RIBA Outline Plan of Work 7th Edition, 2000

Preparation		Design			Pre-Construction			Construction		Use
A	B	C	D	E	F	G	H	J	K	L
Appraisal	Strategic Briefing	Outline Proposals	Detailed Proposals	Final Proposals	Production Information	Tender Documents	Tender Action	Mobilization	Construction to Practical Completion	After Practical Completion

Figure 2.1 Outline plan of work in a building project

The architectural design literature uses various definitions for components of the architectural design process. Reekie (1972) stated that the design process is a “continuous B.A.S.I.C linear step”, in which B, A, S, I, C, respectively represent “briefing”, “analysis”, “synthesis”, “implementation” and “communication” (shown in Figure 2.2).

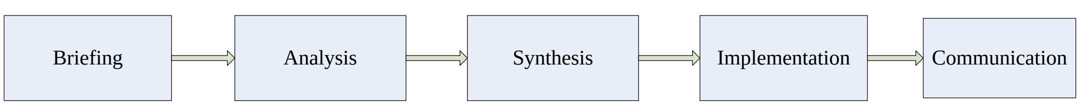


Figure 2.2 The linear design process (Source: Reekie, 1972)

Jones (1970) claimed that the design process is one of choosing “the best solution out of several divisions of design solutions” (Figure 2.3). Different options are generated during the design process before the final solution is selected.

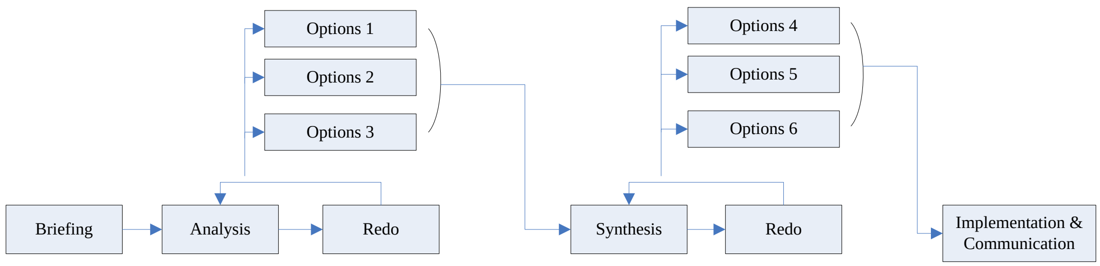


Figure 2.3 The optional design process (Source: Jones, 1970)

A "centralized" architectural design process was described by Lawson (1997), who thought that "steps" do not exist in design process, and that everything occurs at the same time. (Figure 2.4)

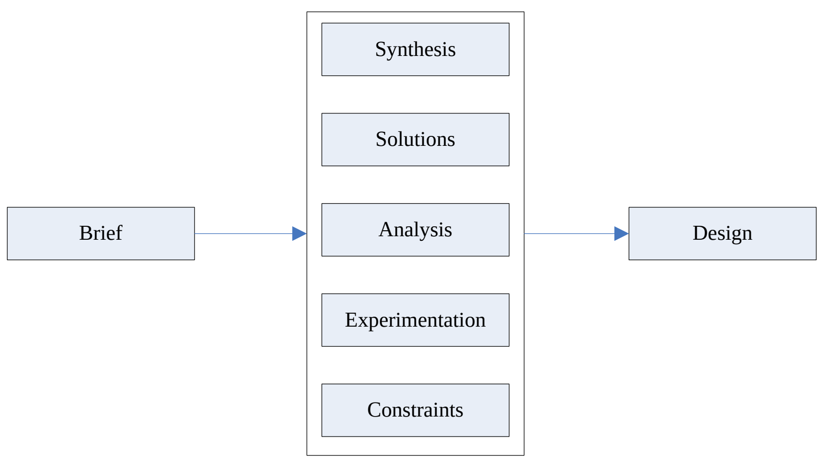


Figure 2.4 The "centralized" design process (Source: Lawson, 1997)

Snyder (1979) illustrated an architectural design process as "an endless repetitive cycle" (shown in Figure 2.5).

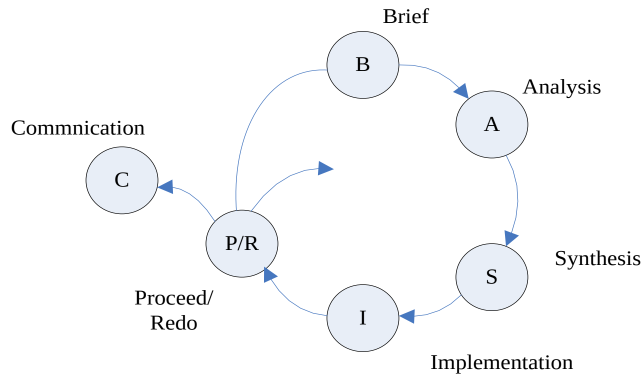


Figure 2.5 The "cycle" design process (Source: Snyder, 1979)

A "selective investigation" architectural design process was introduced by Kalay (1985), who suggested that each step in the design process is based on a selective investigation of various ideas and solution options (Figure 2.6).

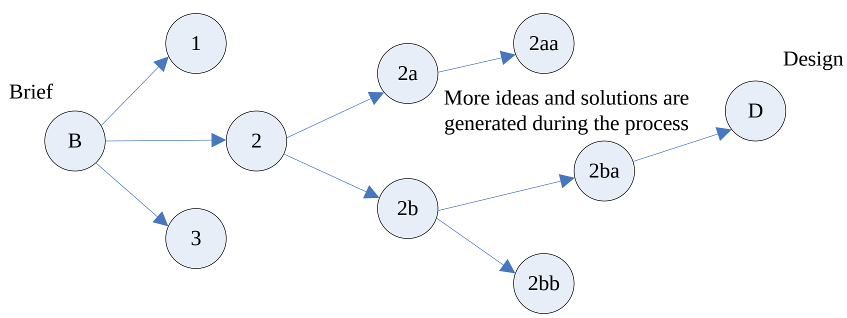


Figure 2.6 The "selective investigation" design process (Source: Kalay, 1985)

2.2.3 The Common Process of Design

Although design processes vary, the common ground is that each process usually starts with a briefing stage, and ends in the form of design drawings. In most cases, the design process is interactive involving the designers and clients in discussion of design requirements and solutions.

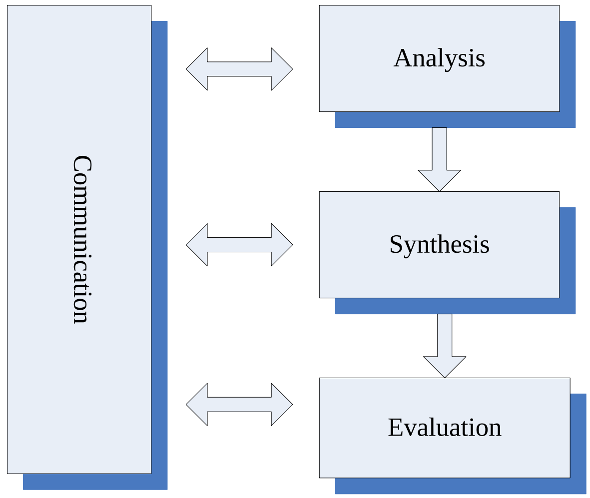


Figure 2.7 The major design process (Source: Kalay, 2004)

In the book *"The Structure of the Design Process"*, Archer (1968) defined a design process as four intertwined phases: (1) problem analysis, (2) solution synthesis, (3) evaluation and (4) communication (Figure 2.7). The further development of this research is based on this typical design process. It focuses on the communication part mainly. Kalay (2004) illustrated the details of these four steps as follows:

2.2.3.1 Problems Analysis

The problem analysis process is an analytical, rational process, which relies on information gathered from client interviews, precedents, surveys, building codes, economic and physical forecasting. Such a process is also known as a feasibility analysis within which the designers try to identify all elements of the problem including both goals and constraints. Goals usually rely on client requirements (function, number of employees, budget concerns etc); and constraints may include site conditions (weather, topography, views, and proximity to existing buildings), building codes, socioeconomic factors, cultural factors and so on. The possible side effects and after effects (e.g. increase of traffic toward a given site and the shading of adjacent buildings and open space) are usually determined by an environmental impact studies. Thus, the information obtained during problem analysis is the starting point for the subsequent steps.

2.2.3.2 Solution Synthesis

In the design process solution synthesis is a creative phase. The architect might generate various ideas and solutions to address the goals and constraints defined during problem analysis. Sometimes, solution synthesis is not a rational process. Although Louis Sullivan's famous proclamation "form follows function" has had its impact on modern architecture and industrial design in the 20th century, some designers have pointed out that no causal relationship has ever been found (at least not in architecture) between form and function (Kalay, 2004). However, knowledge of rules of function related composition, style, precedents, metaphors, and reflective sketching do benefit the generation of design solutions.

2.2.3.3 Evaluation

The design solutions generated during solution synthesis might not address all the requirements or constraints, and may even contain some discordance. It is necessary, therefore, to compare these solutions with the design goals and constraints in the evaluation process. Although this appears to be a rational process, not all the performance criteria can be rationally evaluated. Thus different qualitative and quantitative evaluation methods have been developed for different purposes (Kalay, 2004):

Evaluating quantifiable qualities:

To conduct an evaluation, there needs to be a design, a set of objectives (benchmarks) which specify the desired level of performance. A method then needs to be applied to compare the design object with the objectives. Some aspects of building performance can be measured, such as structural safety, architectural function needs (sizes, proportions, and adjacencies), cost, energy consumption, acoustics. Some computational tools have been developed to evaluate these building performance variables, for example, SAP 2000 for structural analysis, energyPlus, DOE-2, SustArc and PLACE3S for energy analysis.

Evaluating non-quantifiable qualities:

Some building-related performance characteristics are not amenable to quantitative evaluation. One example is the *relationship between the built environment and its inhabitants*. Research, in this area, studies how people respond to and behave in built environments under normal and emergency conditions, such as their behaviour in emergency exit situations.

Methods of post-occupancy evaluation (POE) can help analyze human responses in existing buildings to help improve the design of similar facilities. In the design stage, however, the intended built environment does not exist, and the following methods can be used facilitate the evaluation process of human factors.

- Reference to norms and regulations;
- Case studies and precedents;
- Direct-experience behaviour simulation;
- Indirect-experience behaviour modelling;

- Virtual user simulations.

Kalay (2004) also pointed out that the best way of evaluating the impact of the environment on its inhabitants is humans themselves. Full-scale mock-ups such as model homes, model kitchens and model bathrooms are used for this purpose. Yet due to the difficulties and relatively high expense of developing full-scale realistic models, virtual prototyping technology is used instead. This technology can be used to evaluate human responses to the built environment at lower cost. Aesthetic quality is another important factor among the non-quantifiable qualities. Many methods can be adopted to evaluate this factor, for example, application of the principles of rhythm, proportion, and symmetry, or the commonly adopted prescriptive and/or descriptive approach methods.

2.2.3.4 Communication

The purpose of communication during the briefing and design processes is to inform the participants of evolving goals and solutions, and to support the solution generation and evaluation processes.

The role of the designer "in many project teams, is to be somewhat involved in programming (briefing), heavily involved in design, involved in a limited way with documentation, and not very involved with construction" (Shoshkes, 1990). Meanwhile, the clients are mainly involved in the briefing process and partially engaged in the design and construction process. In addition to the architects and clients, the participants involved during the briefing and design processes may also include consultants from other disciplines, such as structural engineers, mechanical engineers, building code specialists, contractors, economists, lawyers.

The method of representation is the “vehicle” of communication which usually contains scale drawings, specifications, renderings, models and notes. Representation is an abstracted symbolic means of encoding and conveying information containing as many of the characteristics of the message as the sender cares to communicate. Standard methods of representation in architectural design include the following five types (Kalay, 2004):

Arbitrary codes: these are a highly abstract means of communication, based on a common notational language which can represent ideas. The most common form of arbitrary code used by professionals is the scale drawing;

Graphics: sketches, renderings, perspective drawings, and photographs are important modes of communication in architecture. Visualization has advantages over other modes of communication because it allows “visual cognition” by the receivers. Human beings attain greater understanding from visual stimuli than from any other form of communication;

Scale models: scale models not only provide information about the volumetric properties of the buildings, but also promote active participation in the communication process;

Mock-ups: namely full-scale models. These allow the observer to understand how the design will function after construction and how it will feel spatially;

Prototypes: these are mock-ups made from the actual materials to be used. Such representations enable participants to fully and directly communicate the visual, spatial, and material properties. All the characteristics of the finished building can be demonstrated.

However, there are some limitations to the application of these conventional methods of representation. For example, the lack of flexibility in adjusting the level of abstraction as needed at each stage of the design process; the inability to change and evolve as the design process progresses; limited potential for managing the vast amount of information needed to design a building and provide efficient access to that information; inability to provide adequate information for evaluating the design in progress and for predicting its performance; and the centralization of control over the design process in the hands of a few people (Kalay, 2004).

With the power of the computer, however, technologies such as virtual prototyping and building performance simulation have made it possible to change these traditional methods of representation and improve the effectiveness of communication. Among others, building information modelling is an emerging technology which can facilitate both the modelling process and the management of related building information. More details about building information modelling are introduced in Chapter 3.

2.3 Designer-Client Communication during Briefing and Design Stages

2.3.1 Interaction between Designers and Clients

Communication between different participants continues throughout the whole design process. Participants in a typical architectural design process mainly include architects, clients, and consultants from other disciplines. During the briefing and design solution development process, designer-client communication is intensive and essential. Except preparing and demonstrating design proposals, other common duties of architects during the briefing and design process, extracted from the *"Architect's job book"* (RIBA, 2000), include:

- Consulting the client about significant design issues;
- Informing clients of their duties;
- Investigating the feasibility of the requirements;
- Advising clients of land use limitations and effects on the building;
- Advising on the initial brief;
- Advising on development of the brief to suit the client's requirements.

The above are several of the many duties an architect may perform during the life cycle of a building project, in relation to design solution generation and its evaluation. The other duties concerning tendering, procurement, construction, economics and contract forms are also significant, but beyond the scope of this research.

Generally, communication between designer and client is based on client requirements and solutions provided by designers (shown in Figure 1.1). Therefore the client's duties during the briefing and design stages mainly include (but are not limited to) these two issues:

- Specifying and developing requirements;
- Reviewing the design solution and giving feedback.

The brief is a formal document which contains the written instructions and requirements of the client to a construction project. A project brief should define all the design requirements, and is the foundation on which the design will develop. The development of a design brief is a cyclical process. Based on the brief, designers propose outline design solutions from outline proposals before developing detailed proposals. There is constant interaction, between the brief and design proposals (RIBA 2000).

Because of the interactions between these two groups of people, the relationship between them is significant, affecting the decision making process throughout the architectural design stages. In the book *"The architect's handbook of professional practice"* Demkin (2001) states that:

"Strong client-architect relationships are rooted in understanding, commitment and effective communication and serve to reinforce client satisfaction."

Thus, during this communication, in addition to the commitment, issues such as understanding, communication efficiency as well as client satisfaction are crucial for building up good designer-client communication, so as to improve the outcome of the design process. Correspondingly, techniques or tools which improve the understanding of client requirements and design solutions, or enhance communication and client satisfaction can benefit the process and the outcome of the briefing and design process.

The following sections introduce the basic concepts in the briefing and early design process (which is mainly about space planning), so as to define *the problems related to designer-client communication*. Factors affecting the performance effectiveness of these two groups of participants are also specified.

2.3.2 Brief and Briefing

2.3.2.1 Definition of Briefing and Architectural Programming

The terms “briefing” and “brief” used in Hong Kong and the UK are synonymous with terms as “architectural programming” and “program” in the USA (Yu, 2006).

According to the definition given by CIB (1997), briefing is “the process by which a client informs others of his or her needs, aspirations and desires, either formally or informally, whilst a brief is a formal document which sets out a client’s requirements in detail”. Kelly and Duerk (2002) also define briefing as “the process of gathering, analyzing and synthesizing information needed in the building process to inform decision-making and decision implementation”. The purpose of briefing is to identify and clarify the client objectives and requirements. A brief, therefore, is a formal document containing the written instructions and client requirements in relation to a specific construction project (Yu, 2006).

After the first normal treatment of architectural programming published by Pena and Focke (1969) in *“Problem Seeking”*, broad definitions have been offered by American and Canadian researchers of the term “architectural programming” , which is a term used in the USA and Canada. Table 2.1 shows definitions summarized by Palmer (1981) in his book “The Architect’s Guide to Facility Programming”.

Table 2.1 Definitions of architectural programming/briefing (adapted from: Palmer, 1981)

Author	Definition of architectural programming/briefing
Edward J. Agostini	"The end product of the program is information-not design. It is a coherent, meaningful compilation of the facts needed to create facilities which will most effectively support the client's operations and organizational goals. It should permit wide design latitude and provide necessary criteria against which the architect can assess the validity and vitality of his design solution."
Michael Brill	"Architectural programming tries to describe the desired range of specific human requirements a building must satisfy in order to support and enhance the performance of human activities. It is a pre-design activity, but a critical part of the design process; it involves the investigation phase of a four-stage process that also includes design, implementation and evaluation."
Gerald Davis	"Programming for facilities is that part of decision-making process that links the management of a complex organization and the users of its buildings to the planning, design and operation of those facilities…The programming function works best when it contributes to an ongoing interactive dialogue between the client organization and the design team; that is, it expresses the client's mandate in a cumulative series of statements of requirements to which the design team responds with progressive development of its design solution."
Howard Davis	"The building program is the central organizing force of the building; and, since a building is the crystallization of the social organization it contains, the building program must be the simultaneous specification of the organization and of the spatial relationships which are needed to house it."
Herbert Mclaughlin	"In reality, programming is design… not only is programming design, but it is a peculiar form of design, allowing client and architect to break through many of the preconceptions and limitations which dominate the usual design process."
Walter Moleski	"Programming is simply that part of the design process which enables the architect to identify and define the problems which must be solved, the potential effects that the solutions will have on the people who will use or come in contact with the building and the constraints that will control the design process."
William. Pena	"The first two steps of the total design process are distinct and separate: (1) programming (analysis) and (2) schematic design (synthesis). Programming is problem seeking and design is problem solving."
Wolfgang F. E. Preiser	"Programming enables communication among the eventual occupants… and can be defined as the process that elicits and systematically translates the mission and objectives of an organization, group or individual person into activity-personnel-equipment relationships, thereby resulting in the functional program."
Henry Sanoff	"The program is a formal communication between designer and client in order that the client's needs and values are clearly stated and understood. It provides a method for decision making and a rationale for future decisions."
Edward T. White	"Programming is getting ready for design. Programming addresses the facts, conditions and judgments that influence and even determine form, while design addresses the making of the form."

Palmer (1981) also observed the “philosophical diversity” reflected in the definitions, such as “programming is design”, “programming is not design”, “programming is getting ready for design”, and “programming is an inappropriate tool for designing”. Palmer’s definition of architectural programming emphasized the information aspect, which is a process aiming to identify and define the design needs of a facility and convey the requirements of the client to the designer. In addition, Palmer stated that “the programming is clearly within the scope of design, whether it is viewed as a separate service or an indistinguishable part of the design process; whether the program is provided by the client, the designer or by a third party.” Some other researchers agree with Palmer’s statement. They believe that a brief is a live and dynamic document which develops interactively from an initial global brief in a series of stages, and that briefing is deemed an ongoing activity evolving during the design and construction processes (Barrett and Stanley, 1999; Alastair Blyth and John Worthington, 2001; Kamara et al., 2002; Othman and Pasquire, 2004; 2005).

There are other arguments, however, about the briefing stage in the life cycle of a building project. Some researchers agree that the brief is an entity in itself, which needs to be stopped after a critical period; and then briefing becomes a stage or stages in the design process (Hershberger, 1999; Hyams, 2001; RIBA, 2000; Yu et al., 2006).

In this research, briefing is deemed an interactive and dynamic process which continues throughout the design process.

2.3.2.2 Strategic Brief and Project Brief

According to RIBA (2000), the briefing starts from "client's requirements" and "statement of need", and is then divided into the two stages of "strategic briefing" and "project briefing". These two sub-processes are related to development of the design process.

A checklist given by RIBA (2000) lists the tasks that should be finished by the end of strategic briefing and project briefing. This strategic briefing checklist includes four categories of information:

- General
- Planning and building consideration
- Environmental
- Financial

The CIB strategic brief (CIB, 1997), sets out the broad scope, purpose and key parameters containing the overall budget and program. This type of brief is intended to provide an output specification which explains what is expected of the project in clear terms. In contrast, a project brief transfers the strategic brief into construction terms and puts initial sizes as well as quantities to the elements and an outline budget. Cherry (1999) stated that the difference between a schematic program and a design development program is merely a matter of the scale of information involved.

The project brief is a detailed development of the strategic brief, as shown in Table 2.2.

Table 2.2 A project brief checklist for a normal building project (adapted from: RIBA, 2000)

Factors	Detailed requirements
The aim of the design	Prioritized project objectives Accommodation requirements, including disabled access policy Space standards Environmental policy, including energy Environmental performance requirements; Image and quality Flexibility to accommodate future reorganization Allowance for future expansion or extension Life span for structure, elements, installations Special consideration (e.g. security)
The site, including details of accessibility and planning	Site constraints (physical and legal) Legislative constraints
The functions and activities of the client	Schedule of functions or processes Activities Spatial relationships Schedule of installations
Other issues	The structure of the client organization The size and configuration of the facilities Options for environmental delivery and control Servicing and options and specification implications, e.g. security, deliveries, access, workplace, etc Outline specifications of general and specific areas A budget for all elements The procurement process The project execution plan Key targets for quality, time and cost, including milestones for decisions Method for assessing and managing risks and validating design proposals

This checklist covers most of the required building information (design and construction), organization information (function and activities) and other information (cost, quality, time and so on). Clients need to specify their requirements in relation to almost every aspect of a building project. In addition, the participation of clients, designers and consultants from other disciplines is crucial to this process. The experience of the client and the communication between designer and client may affect the efficiency of the process and outcome of the briefing.

2.3.2.3 Problems Related to Designer-Client Communication in Briefing Stage

Briefing is a complex and dynamic process, within which client needs and requirements are identified. Based on the briefing literature some problems of the briefing process related to designer-client communication are summarized below.

Newman et al. (1981) conducted a national postal survey of UK briefing practices and identified the following problems:

- problems of inexperienced clients:

  Inexperienced clients may have the following problems, such as, changing their mind, not understanding their own requirements, having preconceived ideas or not properly understanding the drawings;
- problems with architect and client communication:

  Clients do not understand what the architect does or they appoint the architect too late. The architect does not fully investigate or understand the client's requirements and motives.
- problems with client organizations:

  There is a lack of personnel who can take the responsibility for the project and keep contact with end-users or tenants. Some conflicts may exist within the client organizations.

Other problems related to costs, regulations and bureaucracy as well as related to site and project timing was also found by Newman et al. In addition, Yu (2006) conducted a comprehensive review, described in her PhD thesis, summarizing the briefing problems encountered from a variety of perspectives (Table 2.3).

Table 2.3 Problems encountered during briefing (adapted from: Yu, 2006)

Problems encountered during briefing	Kelly, MacPherson and Male (1992)	Barrett and Stanley (1999)	Kamara and Anumba (2001)	Kelly and Duerk (2002)
Inexperienced client	✓	✓		
Client organization not set up to deal with project or consultants		✓		
Unstructured approach and lack of focus for project		✓		
Focus of feasibility studies is limited mainly due to financial consideration		✓		
Confusion over direction and aims of project within client organization		✓		
Lack of management interest		✓		
Inability of client to read drawings		✓		
Identification of client needs	✓		✓	
Interpretation of client needs in building terms				
Unstructured method to collect client’s requirements		✓		
Insufficient information on requirements		✓		
Definition by solution				✓
Lack of iteration in briefing				✓
Incorrect representation of client interest groups	✓			✓
Inadequate involvement of all relevant parties			✓	
Inadequate communication between participants in briefing			✓	
Irrelevant information collected about users		✓		
Difficulties of satisfying various needs of all users		✓		
Hidden agendas				✓
The wish-list syndrome				✓
Inadequate management of change in requirements		✓		
Insufficient time for briefing	✓		✓	

Table 2.3 indicates that a variety of problems have been encountered during briefing practice. Taking account of the scope of the Author’s research study , among all these problems, only those affecting client performance when communicating with designers are discussed, which mainly concern requirement specifications and design reviews. The

problems which need to be addressed in this research are grouped into three categories as follows:

Problems caused by clients with limited experience

Inexperienced clients often do not understand the structure of the building industry, nor do they have an appreciation of the technicalities of buildings. In addition, their expression of needs often changes with the development of possible design solutions. Some user representatives are unable to conceptualize and understand the implications of design decisions on how the building will function or to assess aesthetic impacts. This situation can only end when there is an understanding of what is possible in construction (Kelly et al., 1992). Inexperienced clients have insufficient knowledge to decide how to precede difficulties are encountered in reading drawings and in understanding construction jargon (Barrett and Stanley, 1999). Kelly and Duerk (2002) also found similar problems caused by the limited experience of clients.

Problems about client requirements management and participation

Kamara and Anumba (2001) investigated the problems encountered in briefing practice via case studies and industry surveys. The problems relating to clients were identified as follows:

- Inadequate consideration of the client's perspective;
- Inadequate communication among participants involved in briefing;
- Inadequate change management of requirements.

Yu et al. (2005) summarized the problems encountered in preparing a comprehensive brief in Hong Kong (in both public and private sectors), and found the following client related problems.

- Clients frequently change their requirements;
- Needs of end-users are not clearly stated;
- Lack of review and feedback to the client brief.

Insufficient time for briefing

It was found that when the briefing stage begins, the client group is anxious to proceed as quickly as possible. There is usually not enough time allocated to briefing. Hence, insufficient briefing time is a problem identified by many researchers (Kamara and Anumba, 2001; Kelly et al., 1992; Yu et al., 2005).

2.3.2.4 Improvement Areas of Brief and Briefing

Barrett and Stanley (1999) proposed five major solutions for improving the effectiveness of briefing and suggested that action in these areas can significantly improve the effectiveness and efficiency of the briefing process. The five solutions are:

- empowering the client;
- managing the project dynamics;
- achieving appropriate user involvement;
- using understandable visualization techniques;
- building appropriate teams.

Other researchers have emphasized feedback with the client briefing system and proposed the following improvement factors (Bassanino et al., 2001):

- communication;
- continuity of relationships;
- the ability to respond to changes;
- the ability to balance conflicting demands;
- mechanisms that implement feedback, and effective management.

In the context of Hong Kong, based on the survey by Kwok et al. (2002), the top five improvement areas for both public and private sectors are:

- a full understanding client needs;
- allowance of sufficient time to prepare the brief;
- participation of the end-user in the briefing;
- good communication skills;
- regular review and provision of feedback to clients in relation to their needs.

In this research the improvement methods in briefing were extracted from knowledge of the above issues. To be more specific, this research is intended to enhance the inexperienced client performance by increasing their understanding of the design solutions and facilitating the management of client requirements as well as feedback, so as to improve the efficiency and effectiveness of communication between designers and clients in the briefing stage. The problems in early architectural design stage are introduced in the following sections.

2.3.3 Space Planning

Buildings play the role of accommodating user organizations and equipment, and facilitating their activities. Buildings not only provide users with an indoor environment, technique services, and platforms for activities, but also protect users from intruders, and wind and rain etc. (Ekholm and Fridqvist, 2000). This defines a building's basic function, which is to accommodate user activities and provide appropriate indoor environments. In most cases, the design of a building needs to satisfy the basic functional requirements of users. Spatial requirements are the most frequently defined requirements in the brief. These spatial requirements are usually satisfied by the designs proposed by designers.

This section introduces the concept, processes, techniques and problems of space planning. The problems related to designer-client communication during this process are also summarized.

2.3.3.1 Definition of Space Planning

Space planning mainly deals with the allocations of activities into spaces resulting in satisfying various constraints. As defined in the book *"Space Planning Basic"* written by Karlen (2004):

"Space planning is not a simple process involving a single category of information; rather, it is a complex dovetailing of several processes involving many categories of information related to the organization and construction of buildings."

These "several processes" refer to "building code principles", "environment control techniques" and "development of desired spatial qualities".

Space planning generally starts with the analytical process of collecting adequate information to identify the design problem. A criteria matrix is then set up to specify the requirements of each space such as *adjacency, public access, daylight, view, privacy, etc*. In a conventional space planning process, all the requirements are considered and transferred to a bubble diagram, based on which a block plan is then created. Such a block plan will take geometrical factors appropriate to each space into account. When the block plan is completed, refinements are continually made to suit the constraints imposed by other factors such as building codes, lighting design and acoustical planning until a better solution is produced.

Space planning is usually considered during the conceptual design stage. Problems which need to be solved during space planning include how to allocate spaces, how to evaluate design solutions "with respect to the best use of space" by determining the "optimal number of floors" or "perimeter of the plan", "how should employees be located within an office so that group contiguity is maintained with a minimum number of workspace moves?", "how can unused space be consolidated effectively to minimize lease costs?", or issues of "time-phased layouts" induced by changing projects (Liggett, 2000).

2.3.3.2 Classification of Problems and Approaches of Space Planning

Referring to the review by Liggett (2000), the fundamental problem of space planning is to allocate activities into spaces. There are three different associated problems:

- Assignment of *n* activities into *n* spaces (one-to-one assignment problem), which does not take into account the area and shape of each space;

- Assignment of many activities in a multi-storey. Many to one or one-to-many assignment problem, also called the stacking problem, in which the area of each space is concerned, but the shape is simplified;
- The area and location of the space is considered according to the requirements of the activities (unequal area problems or block plan problem).

Liggett also categorized space planning into three major approaches:

Approach to optimize single criterion

This approach attempts to minimize the "cost associated with communication or flow of materials between activities", for example, the surface area of the space or length of the walls. Buffa et al. (1964) first formulated the floor plan layout problem as a quadratic assignment problem, in which the objective is to minimize the cost of product flow between departments. Two major procedures can solve this type of problem, namely the constructive and the improvement procedures.

The constructive procedure it aims to "come up with a solution from scratch using an *n*-stage decision process." Some simple selection rules or complex criteria can be used during the design stages;

The improvement procedure "starts with a single solution and attempts to incrementally improve it." The basic method is "pair-wise" exchange, in which the consequences of possible exchanges between pairs of activities are evaluated and an exchange made if it improves the value of the criterion (Liggett, 2000).

Table 2.4 Methods to optimize single objective problems (adapted from: Liggett, 2000)

Author(s)	Method or techniques	Purpose
Elshafei (1977)	Evaluating all possible moves of a single activity	Reduce the evaluation of activities exchanges for saving the cost of computation time
Hunan et al. (1976)	Focuses on the closest activities	
Vollmann et al. (1968)	Considered the exchange the two activities which contribute most to the current solution at each stage	
Sharpe and Marksjo (1986), Jajodia et al. (1992)	Simulated annealing method	Optimize the layout design solutions
Tate and Smith (1995), Jo and Gero (1998)	Genetic algorithms method	
Liggett (1980), Jo and Gero (1998)	Hybrid approaches combine both constructive and improvement methods	

Approaches based on graph theory

The use of graph theory to solve layout design problems is found in the work of Grason (1971). Many subsequent approaches were based on Muthe's (1973) systematic layout planning methodology. A “space relationship diagram” becomes the “design skeleton” from which a layout design can be generated. In the space relationship diagram, the activities are represented by nodes, and the adjacency requirement areas are represented by links between the nodes However, there are some limitations in applying graph theory approaches:

- Some of the methods require the building perimeter to be rectangular;
- Direct adjacency requirements are taken into account, but not the communication costs of activities between non adjacent areas;

- Most graph theory based methods are suitable for design only when there is much design freedom available (Foulds, 1983).

Approach based on feasibility

The third approach adopts “feasibility” as the main criterion. General Space Planner (C.M. Eastman, 1973) and Design Problem Solver (Pfefferkorn, 1975) are the early examples of such approach. Another example is SEED (Flemming and Woodbury, 1995) which was developed for the purpose of generating schematic layouts of spaces which are rectangular under a variety of constraints, such as access, natural light and privacy.

SEED (Software Environment to Support Early Phases in Building Design) is a software system whose architecture includes modules to support analysis, visualization and evaluation of the early design. These modules are SEED-Pro, SEED-Layout, SEED-Config, SEED-Pro is used during the briefing/ architectural programming process, SEED-Layout supports the layout design/ space planning stage, and SEED-Config supports the generation and evaluation of schematic three dimensional building configurations at a greater level of detail.

While SEED-Layout takes multiple criteria into account, the developer admitted, “It appears difficult indeed to automate the complex functional and formal reasoning needed to evaluate these alternatives against each other and make an informed selection.” In other words, it reminds us that although this system has taken many factors or constraints into account and it aims to generate suitable layout designs, the final design still needs to be selected by architects or experts rather than the computers, especially in large scale buildings.

According to this review of space planning approaches and related techniques, some conclusions are as follows:

- The methods aiming at optimization of a single objective seldom take the area and shape of each space into account, and only take into account a single criterion such as cost associated with communication；
- When using a graphical method, such as the conventional SLP method, the adjacency relationships between varieties of activities are decided by rule of thumb. The representations of the relationships are circles and lines which cannot reflect material and people flows.
- Automating the complex functional and formal reasoning process to evaluate alternatives layouts other is very difficult and usually futile.
- Many requirements of the building projects are complex and difficult to be measured. There are even contradicts among these requirements sometimes. Therefore the automated optimization is almost impossible.

2.3.3.3 Suggestions for Facilitating Designer-client Communication during the Space Planning Process

Liggett (2000) has given suggestions for developing computer-aided space planning tools:

"A system which meets commercial needs of today should provide interface capabilities ranging from complete user interaction, where the user interactively specifies the location of each activity, to complete automation, where an algorithm generates an initial solution. Or as desired, a designer should be able to interactively locate some activities

and use an algorithm to locate or suggest locations for others. Rather than generating a single least-costly plan, the designer with the aid of automated algorithms can make tradeoffs between competing criteria and converge on a solution that responds to a broad spectrum of complex and often ill-defined issues."

To support designer-client communication during the space planning process, the method and supporting software platform needs to have the following features:

- to facilitate interactive communication between designers and clients. For example, the enablement of the end-user to interactively specify the location of each activity;
- the provision of suggestions to the designers as to which space planning alternatives are the most effective according to a postulated objective function, which can be varied.
- the provision of a platform to evaluate a space plan under different constraints such as area, adjacency relationships between activities, access, privacy , lighting requirements
- the simultaneous consideration of both subjective and objective factors. For example, efficiency and aesthetics factors.

The author's research is not concerned with finding an algorithm which facilitates the generation of an optimized space plan according to a certain single criteria, but with establishing a platform enabling clients to specify their activities, their requirements and to review design solutions in a more efficient way. The platform is expected to enhance client performance and collaboration with designers towards the generation of better solutions which maximize client satisfaction.

2.3.4 Basic Requirements Concerned During Briefing and Design Stage

2.3.4.1 Basic Factors Concerned by Clients

From the architectural point of view, the building's function, appearance, cost, building, proportions, building code constraints etc. are all important. The client, however, may primarily be concerned only with such factors as function, appearance and cost (Tessema, 2008).

Function

According to the book "Understanding Architecture", the Vitruvius three-part definition of architecture contains utility, firmness, and beauty (Roth, 2007). The first element is function, the building's utility. Buildings accommodate user organizations and their equipment, and enable their activities. In addition, buildings not only provide users with an indoor environment, technical services, and platforms for activities, but also provide shelter from the weather and a barrier to intruders (Ekholm and Fridqvist, 2000). The functions of a building can also encourage relationships and interactions between the inhabitants of rooms and other interior and exterior spaces, facilitate the flows of materials and promote a healthy indoor environment (light, weather, etc).

Therefore, the basic function of a building typically relates to its spatial attributes, and the accommodation of occupant activities (e.g. size, adjacency, circulation factors etc.) and the quality of its indoor environment (e.g. furniture, materials, lighting, indoor air pollution, etc.).

The conventional 2D CAD drawing representations do not readily convey building function information to clients. One solution is to use 3D models, which can enhance client understanding of the building elements and how the spaces enable building functionality with the assistance of annotations. Nevertheless it remains difficult for a client to fully appreciate the usage of space, the movement patterns and adjacency relationships.

Appearance

The appearance can include the visual attribute of size, shape, colour, texture, glossiness, transparency and opacity features of a building design. It also refers to the elements of a building, for example, the windows, façade, roof shape, size and patterns of openings, trim and details, and materials and colour. The appearance of a building can make a client feel good or satisfied and this is crucial to a client's agreement to proceed. A building looks its best when it is made of "attractive materials" or "attractive organization of forms in relationship to one another and with the environment". Thus the appearance of a building is mainly influenced by the two significant components of form and aesthetics. Form gives "a certain mass and volume" to a building which can be recognized by viewers. Aesthetics is "a form or texture added or subtracted to articulate the base form" (Tessema, 2008).

Those representations which convey building appearance information (e.g. graphics, scale models, 3D effect drawings etc.) assist designers to convey the appearance information to clients. An inexperienced client can also benefit from the improved quality of appearance information, assisting effective communication through improved familiarity with the building.

Cost

Cost is a crucial factor which needs to be considered for the lifecycle of a building project. There is often a trade-off between the investment and lifecycle costs. The traditional clients may be mainly interested in the investment costs, however, the lifecycle cost became an important issue concerned by clients increasingly. The cost of a building project may be primarily of concern to clients because it affects many building decisions, including size, configuration, material selection and other details. It is essential to decide whether the desired building can be built within the given budget.

2.3.4.2 Frequently Defined Requirements in Brief

As listed in Table 2.2, the brief contains a number of requirements related to various aspects. Kiviniemi (2005) analyzed the briefs of 5 projects and classified the client requirements into several categories, encompassing the spatial system, indoor conditions, safety, comfort and aesthetics, accessibility, environmental pressure, location, service life, adaptability and regulatory building codes. Kiviniemi also indicated that the *spatial system* is the most frequently defined category of requirements. One of the reasons why clients usually define the spatial requirements is that "the spaces are the core element of the end-user activities in the buildings" thus defining the requirements in relation to spaces is "a quite natural approach with a long tradition in the AEC industry" (Kiviniemi, 2005). The requirements described of a spatial system are listed in Figure 2.8.

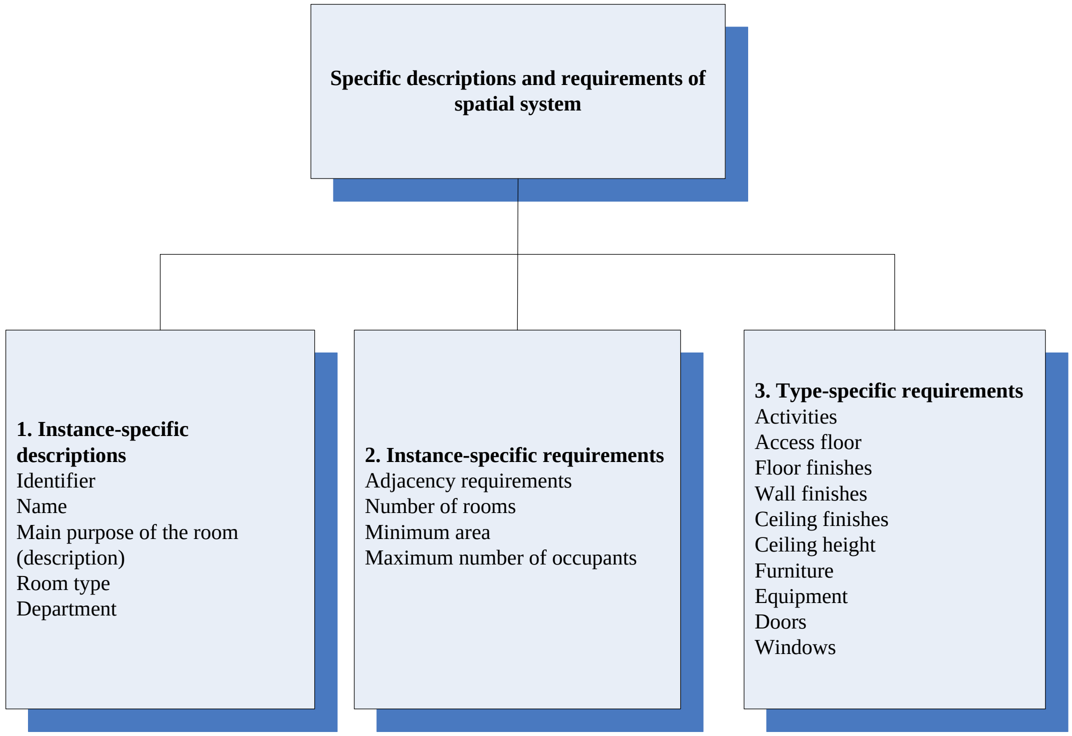


Figure 2.8 Space-specific descriptions and requirements (adapted from Kiviniemi, 2005)

This section illustrates the factors primarily considered by clients during their communication with designers as well as the most frequently defined requirements in the building brief. These factors and requirements provide the basis for the selection of evaluation indicators in the PEP pre-occupancy evaluation module.

In addition, since the aim of PEP is to enhance designer-client collaborative working concerning the usage of spaces, the main factors selected for evaluation were the spatial and functional factors of area, adjacency, location, circulation, flexibility etc. The appearance of the design will be taken into account within this study to some extent, but the issues of cost and other factors such as HVAC system are beyond the scope of this research study.

2.4 Summary

The above sections introduced the briefing and space planning process in the architectural design stages and summarized the problems encountered in designer-client communication (from the client perspective mainly). Improvements in the severity of the problems resulting from previous research, as described in the relevant literature, has been summarized.

According to the review, it appears that the effectiveness of briefing is reduced because inexperienced clients have insufficient knowledge on how to proceed. In addition, the common lack of requirements management systems and of reference feedback to these requirements during design also affects the utility of briefing.

During the design stage, space planning is a process which aims to satisfy client basic functional requirements. From the review of existing space planning approaches and related problems, it is suggested that a method which enhances designer-client communication would enable more user interaction, for example to help them interactively specify the location of activities, and to facilitate evaluation of the design solution based on both subjective and objective factors as area, adjacency, access, privacy, efficiency, quality of lighting, aesthetics etc.

Thus it is suggested that a platform which can support designer-client communication during the early design stage should include the following features: enhancement of inexperienced client understanding of the design solutions in terms of building elements and function; demonstration of the usage of the space and evaluation of related space attributes the better to facilitate clients in specifying their activities in the building;

guiding clients in the review of design solutions and help to designers with the management of client requirements and evaluation feedback to clients.

Chapter 3 Techniques to Facilitate Designer-Client Communication

3.1 Introduction

As stated above the purpose of this study is to discover how to better facilitate collaborative working between designers and clients with the various specific objectives already detailed. There are various technologies and techniques which can be applied to support this communication from different aspects, such as techniques for demonstrating the design solutions, improving the design efficiency, managing the building information and design requirements. According to the areas of improvement summarised in Chapter 2, three categorises of techniques are selected as the basis for the development of the pre-occupancy evaluation platform in this study, including building information modelling, user activity simulation and requirements management.

In this chapter, building information modelling (BIM) technology, which provides accurate building information to design demonstrations, is the first to be reviewed. User activity simulation technology employed for different purposes are then introduced. One of the user activity scheduling methods is selected as the basic activity scheduling method for use in PEP, and is illustrated in detail, therefore. Finally, different client requirements documentation methods or models are introduced, and a particular structural spatial requirements documentation method is selected for incorporation within PEP.

3.2 Building Information Modelling (BIM) in Building Design

3.2.1 Definition of BIM

Eastman et al. (2008) defined BIM as a "modelling technology and associated set of processes to produce, communicate, and analyze building models" and "BIM is one of the most promising developments in the architectural, engineering and construction (AEC) industries."

Specifically, BIM is the process of generating, managing the building data during the lifecycle of the building (Lee et al., 2006). It uses three-dimensional, real-time, dynamic building modelling software to increase productivity during the design and construction process (Holness, 2008). The BIM process produces the Building Information Model (also abbreviated as BIM), which includes building geometry, and annotations giving information on such as geographic information, spatial relationships, and quantities and properties of building components.

3.2.2 BIM Tools and BIM Technology

Eastman et al. (2008) have provided a general understanding of BIM tools and BIM technology in the "BIM Handbook", and also the definition of BIM tools and non-BIM tools as follows:

BIM tools derive from the older CAD systems. The general files produced by the conventional CAD systems mainly include vectors, associated line-types, and layer identifications. As the development of CAD systems developed and the introduction of

3D modelling, additional information as properties of building elements were added, in addition, advanced definition and complex surface tools were integrated.

The major difference between BIM tools and conventional design tools is that BIM tools focus on the model data rather than the drawings and 3D images. In other words, the BIM tool provides more information “on what it can support than what it contains”. BIM tools can produce building models containing parametric objects. The parametric objects have the following features (Eastman et al. , 2008):

- geometric definitions and associated data and rules;
- integrated non-redundant geometry and allowance for no inconsistencies;
- parametric rules for objects modify associated geometries automatically;
- the ability to define objects at different levels of aggregation;
- objects rules that can identify when a particular change violates such as object feasibility regarding size, manufacturability;
- objects have the ability to link to or receive, broadcast or export sets of attributes to other applications and models.

It is easy to be confused about the kind of software that should be categorized as a BIM tool. Some modelling tool features where BIM technology is not involved have been identified by Eastman et al. (2008) as follows:

- models that contain 3D data only and no object attributes: those can only be used for graphic visualization, with no intelligence at the object level, and no support for data integration and design analysis. Included are:

- models with no support for behaviour analysis: these models define objects but cannot adjust their positioning or proportions since they have no parametric intelligence;
- models that consist of multiple 2D CAD reference files which must be combined to define the building;
- models that allow changes to dimensions in one view which are not reflected in other views automatically.

There are a numbers of BIM tools on the market, such as Revit, Bentley systems, ArchiCAD, Digital project, Tekla Structures, DProfiler and other Autodesk-based applications. Among others Revit (Revit, 2011) has a well-designed and user-friendly interface as well as a set of object libraries for storing varieties of building elements and components, therefore it is chosen as the BIM tool for generating building models in this research.

3.2.3 BIM Tools in Design Stage

BIM technology places much emphasis on the architectural conceptual design stage (Eastman et al. , 2008). The solutions provided by BIM technology typically address issues such as resolution of siting issues, building orientation and massing, satisfying the building program, sustainability performance including energy saving.

BIM technology also supports the design and analysis process for the building system. Analysis includes many functional aspects such as structural integrity, temperature control, lighting, ventilation, acoustics, circulation, energy distribution and consumption and so on. In the early design process, analysis can include experimental analysis of structural performance, environmental controls, the construction method, use of new materials or systems, detailed analysis of user processes, and other aspects. The BIM tools supporting the early architectural design stage are categorised and summarized as follows:

- Tools for supporting conceptual design and preliminary analysis

There are several categories of software which can be used, such as sketch tools, space planning tools and building system simulation and analysis tools.

Some tools on the market are not of the BIM type, such as the Google SketchUp, form-Z, Rhino and Maxon, because the models produced by these tools typically do not typically carry object types or properties. However, most of the information generated by these tools can be transferred to BIM tools.

The space planning tools primarily help architects to expand client spatial requirements into the composition and organization of different functional spaces. Typically, these tools illustrate the programming process using a spreadsheet or a block diagram and then generate the layout based on the programming. Relevant software includes Visio Space Planner, Vectorworks, Space Planning Tools, Trelligence and the Facility composer. However, it seems most of these tools cannot support the generation of layouts within the constraints of a given building shell. These tools often put much emphasis on design efficiency from the designers' perspective.

- Tools for supporting building performance and function analysis

The analysis tools related to building models can be categorized by purpose. For instance, tools for structural analysis, energy analysis, mechanical equipment simulation, acoustic analysis, air flow/CFD simulation and analysis. These tools deal with physical problems and mainly conduct quantitative analyses.

Other tools are intended to check both quantitative and qualitative rules automatically for the purpose of building code checking (EDM Model Checker (Jotne, 2010)) or space program validation (Solibri (Solibri, 2011)). Eastman et al. (2009) defined these automated rule checking tools as software that do not modify a building design, but assess a design on the basis of its configuration, relationships or object attributes. These tools can be used to check a proposed design based is compatible with relevant rules, constraints or conditions, to obtain results such as “pass”, “fail”, “warning”, or “unknown” when the required data is incomplete or missing in some cases. In most cases automating rule checking is applied to building code and accessibility criteria. One significant reason for this is that, in the building delivery process code compliance plan checking is often a costly bottleneck, and automated code reviews have the potential to save time and cost. These rule compliance checking systems also have the potential to become widely used in the AEC industries.

In addition, analysis tools are intended to enhance organizational performance within planned or given facilities. Most of these models focus on the efficiency of facilities such as manufacturing facilities, airports, and hospitals. Two important relevant fields are crowd simulation and emergency evacuation simulation. These researches are generally driven by the recognition that such analyses are having an increasing impact on the design process. Thus, Eastman et al. (2008) stated that:

"Whether architects take up such analytical capabilities, clearly, the integration of building designs with models of organizational processes, human circulation behaviour and other related phenomena will become an important aspect of design analysis."

3.2.4 Benefits of BIM Tools to the Clients

BIM provides easy methods of guaranteeing consistency across all drawings and reports, automating model checking, the basis for conflict analysis/simulation/cost estimation and enhanced visualization during different stages (Figure 3.1). Thus designers benefit from this technology and clients also benefit from the application of BIM tools by saving time and money through more efficient collaborative working between participants.

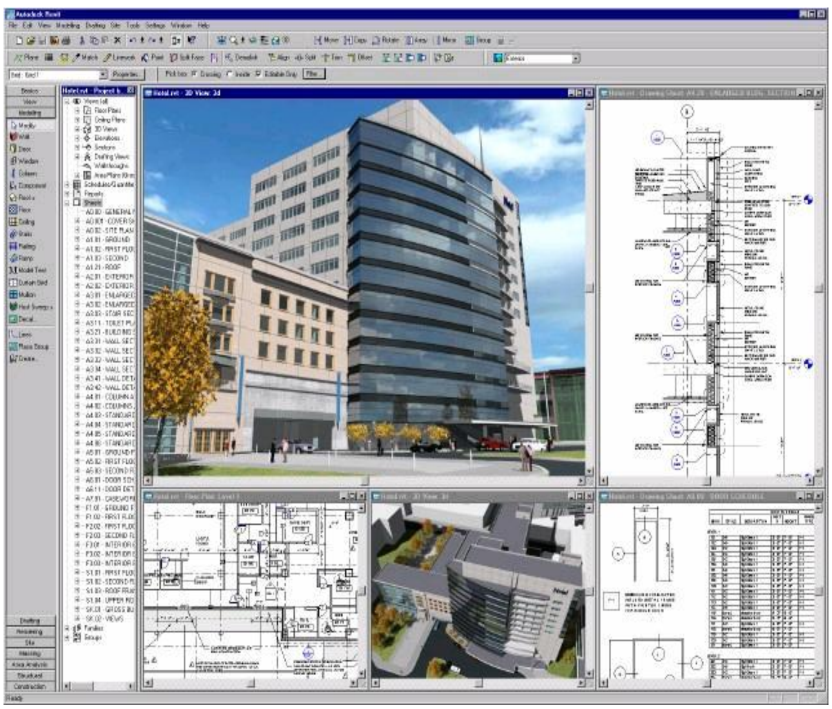


Figure 3.1 The drawings produced by Revit

The graphical information, non-graphical information and automatic features provided by BIM tools can help clients manage costs, plan schedules for design and construction, understand the complex building infrastructure and the built environment, analyze issues of sustainability, manage facilities and assess the design solutions (Jernigan, 2008; Krygiel and Nies, 2008). Thus in respect of design assessment BIM technology provides the following benefits for clients (Eastman et al., 2008):

- improvement of program compliance through BIM spatial analyses;
- more valuable input from project stakeholders through visual simulation;
- rapid reconfiguration and exploration of alternative design scenarios;
- simulation of facility operations.

Many BIM applications can be used in the design assessment process. Some tools have excellent visual simulation functions, which can generate accurate building models. In addition, the integration of human movement simulations can also increase user understanding of the design. For instance, the Navisworks (Khemlani, 2008) allows users to choose an avatar to walkthrough the model. It also provides a third person view which can help the users obtain a sense of scale (shown in Figure 3.2). However the experience of avatar navigation in Navisworks is relatively simple, and has nothing to do with user organization information.

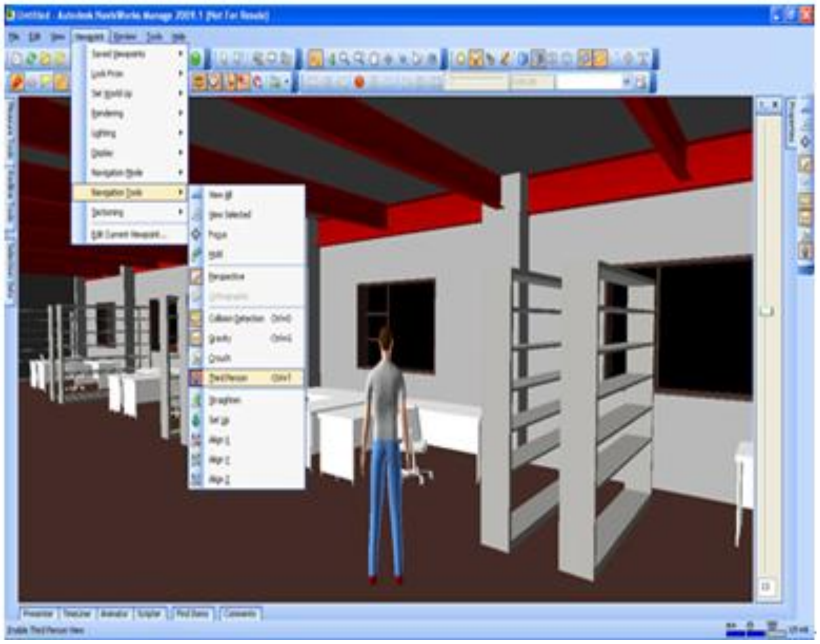


Figure 3.2 Avatar used in Navisworks (Khemlani, 2008)

Another way of facilitating communication between designers and clients focuses on the relationship between the client requirements and design solutions. Some BIM tools track and check user requirements during the design generation and development stage, such as Vectorworks Architect, Bentley Architecture, Allplan Architecture and Affinity (Khemlani, 2010). Vectorworks Architect allows architects to generate a space planning worksheet with area and adjacency information. It also helps designers to generate a bubble diagram, a stacking diagram and an adjacency matrix. The area of each room which exceeded or left over can be viewed graphically which is helpful to the designer. Bentley Architecture and Allplan Architecture help designers to import a spreadsheet containing a list of space requirements and use the associated area information to automatically create spaces of the correct size, which can be arranged to explore different spatial layout options. A useful aspect of Affinity is its project analysis and validation capability. It can analyze the schematic design according to the specified requirements, and highlight non compliance situations (Figure. 3.3).

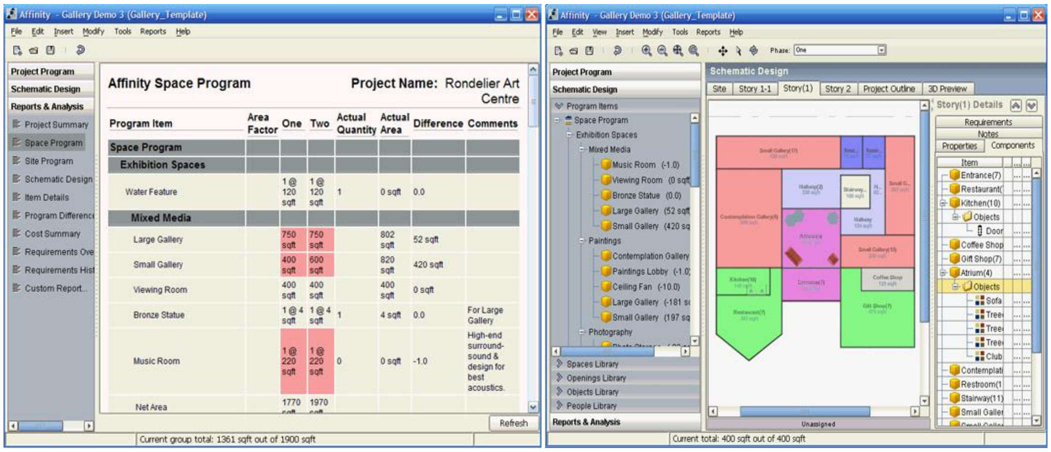


Figure 3.3 Space planning and brief checking function of Affinity (Khemlani, 2010)

Although some of the BIM tools can generate simple solution based on the requirements (e.g. space program) specified by clients, the communication between designer and clients is an interactive and dynamic process. This means the clients will continually generate requirements and give feedback as the development of the design, especially when they obtain further understanding of the design. In addition, the feedback from clients is significant to the further development of design. So it is necessary to help clients specify and manage their requirements, and collect feedback during the design evaluation process.

3.2.5 Benefits of Selecting BIM Tools as the Modelling Tools of PEP

Building information models can provide earlier and more accurate visualization of design solutions. These models can be used to visualize the design at any stage and are dimensionally consistent in every view. In addition, BIM tools can be used to check both quantitative and qualitative requirements, such as areas, materials quantities, and cost estimates. Another feature of the building information model is that it is an object-based parametric model, which contains not only geometry and topology attributes, but also incorporates various properties potentially relevant to other analysis application tools. For most objects, current BIM tools default to a minimal set of properties and provide the capability of adding an extendable set, if needed for applications as cost estimation or energy calculations. BIM technology was therefore selected as the basis of this research for the reasons cited above.

Regarding the aim of this research other issues are also need to be considered, with the exception of the building information model itself. First, the current BIM tools or applications usually focus on improving the designers' efficiency in design process, but have less concern with enhancing client performance regarding requirements specification and design review. In addition, it seems little work is intended to incorporate the simulation of end-user organization information into the 3D built environment based BIM tools for the purpose of increasing client understanding of how their organization will be accommodated in non-emergency circumstances. The user activity simulation technique, however, has been employed in wide disciplines for different purposes. Such techniques are introduced in the following section.

3.3 User Activity Simulation in Buildings

Many research studies have been conducted for different user activity purposes in the simulation field. Attempts are now made to evaluate building performance in the energy saving and building control areas. Others commentate on the behaviour of the building occupants, such as crowd simulation and emergency evacuation. This section first introduces the concept and techniques of building performance simulation, and then summarizes previous research into user activity simulations affected by different techniques and purposes.

3.3.1 Building Performance Simulation

Crawley (2003) defined building performance simulation as “a powerful tool which emulates the dynamic interaction of heat, light, mass (air and moisture) and sound within the building to predict its energy and environmental performance as it is exposed to climate, occupants, conditioning systems, and noise sources.”

In the early 1960s, the goal of simulating building performance was to study the energy transfer in buildings and methods for predicting the consumption of energy. Then computer software was developed, which could not only predict the energy and environmental performance but also create more complex and precise building models. There is now a growing emphasis on the carrying out of building performance simulations because of the modern emphasis on sustainable development. There are several types of building performance simulation application as follows:

- Energy use calculation

When selecting suitable HVAC systems, efforts have been made to calculate building peak heating and cooling loads (Corgnati et al., 2008; Crawley et al., 2001). Some software applications examples include DOE-2, EnergyPlus, Apache and ESP-r.

- Air Flow/Computational fluid dynamics (CFD)

CFD technology has been applied in the building industry to predict indoor airflows and external wind flows (Bartak and Beausoleil-Morrison, 2002; Djunaedy, 2005; Liu, 2004; Zhai, 2006). Flovent, Fluent and Microflo are typical applications software packages in this field.

- Lighting and acoustic analysis and simulation

Lighting and acoustic analysis simulations also support prediction of the quality of the indoor environment, as they are affected by the factors building configuration, orientation, positions of windows, and material finishes. Applications software as Radiance (Ward, 1994) is available for lighting analysis and visualisation, and Ease and Odeon for acoustic analysis.

Such simulation applications are increasingly applied in all stages of the design process, rather than just at later stages. Thus building performance can be predicted to facilitate designer-client communication and support pre-occupancy evaluation at early stages of the design.

3.3.2 User Activity Simulation Methods for Different Purposes

User or occupant activity simulation mainly evaluates the impact of a design on its occupants, such as on evacuation efficiency, circulation, building services control system, energy saving, and space usage. Relevant research covers pedestrian simulation, evacuation simulation, energy saving and building control simulation etc.

3.3.2.1 Pedestrian Simulation

Pedestrian behaviour simulation is part of traffic flow modelling research. The motivation behind this kind of research is that the interest in the relationship between design and planning decisions and the resultant pedestrian behaviour (Dijkstra et al., 2000; Dijkstra et al., 2006; Maat and Arentze, 2003). These tools simulate the behaviour of individual pedestrians and their interaction with other pedestrians and the environment (Kerridge, 2001). Several categories of models have been developed. They include the following.

- Cellular automaton models

A cellular automaton model is a discrete form of model utilised in many disciplines such as complexity science, computability theory, physics, mathematics, theoretical biology and microstructure modelling. It consists of a regular grid of cells, and each cell has one of a finite number of states (e.g."On" and "Off"). These states are subject to a uniform set of rules, which decide the behaviour of the system (Blue and Adler, 1999; Timmermans, 1999). The cellular automaton models can be used to simulate traffic scenarios, pedestrian dynamics and evacuation behaviour (Esser and Schreckenberg, 1997; Fang et al., 2003; Pelechano and Malkawi, 2008).

- Agent-based models

An agent-based model simulates the actions and interactions of both individual and collective autonomous agents to assess their effects on the whole system. The PEDFLOW model (Kerridge, 2001) uses a single process which has the capability of making decisions. It concerns the movements of pedestrians, either a single person or a group of people. The model STREETS applies agent-based techniques to study pedestrian behaviour in urban centres (Schelhorn et al, 1999).

- Social force model

Other techniques and models are also used in the pedestrian simulation field. The social force model is an example. It can simulate a pedestrian's internal motivation towards the making of certain movements according a theory known as social force theory (Helbing and Molnar, 1995).

3.3.2.2 Evacuation Simulation

The evacuation process is triggered when the occupants within a building notice an emergency situation (e.g. fire). The occupants experience mental processes and take actions before and/or during the movement to a safe place (Kobes et al., 2007). Generally the evacuation process simulation takes into account the environment and configuration of the given building and the configuration of the hazard, the management control actions taken during evacuation, and the social psychological and organizational characteristics affecting the responses of evacuees (Santos and Aguirre, 2004).

Evacuation simulation studies have considered all types of buildings which include residential buildings (Brennan and Thomas, 2001; Yung et al. 2001), football stadiums (Klüpfel and Meyer-König, 2005; Moldovan and Gilman, 2007). Other facilities or transportation systems were also taken into account of the evacuation simulation study area. In addition, models which employed varieties of techniques were developed for simulating human's behaviour during the evacuation process. One example of this type of model is EVACNET4 (Kisko et al., 1998). It employs a flow-based approach to model the nodes density in continuous flows, allowing the user to construct a simulated physical environment as a network of nodes. The physical elements, such as rooms, stairs, lobbies, and hallways are represented by nodes. Users define the number of people a particular node could contain In EVACNET4. The egress of evacuees is determined by the physical constraints including flow rates, usable area average, and configuration of nodes. The simulation results take account of a fixed set of assumed travel speeds, environmental features, and an arrangement of varying levels of service. However, no motion rules about social interaction or group processes are taken into account.

- Models concerning sociological factors

EXODUS (Owen et al., 1996) is one example of a model which considers sociological factors. As an agent-based model, the movement of individuals in EXODUS is established by a fixed set of motion rules. In other words, it incorporates sociological insights based on a set of social psychological attributes and characteristics for each agent. Among others, this set includes age, sex, breathing rate, running speed, whether dead or alive, familiarity with the building, agility, as well as patience. The model simulates the evacuation process for large numbers of people, and also the eventual cessation or delay of movement caused by extreme heat and effects of toxic gases. This model has different versions to simulate evacuation in diverse scenarios, including buildings (buildingEXODUS), ships (maritimeEXODUS), and planes (airEXODUS) (FSEG, 2011).

Other models using techniques such as the cellular automaton have also been implemented in the filed of evacuation simulation.

3.3.2.3 Energy Saving and Building Control

In the field of building performance simulation, behavioural research is mainly focused on control-oriented user behaviour, i.e. the interaction between the occupants of a building and environmental conditions controls, applied to such as windows, lights, and heating systems (Fritsch and Kohler, 1990; Hunt, 1979; Mahdavi and Mohammadi, 2008; Nicol, 2001; Zimmermann, 2006).

Stochastic processes were selected by some researchers as the basis of occupant activity modelling in the built environment, such as Markov chains (Page, 2007; Yamaguchi et al., 2003) or Poisson distributions (Wang, 2005). Other researchers designed different user profiles for modelling purposes. Abushakra et al. (2001) developed an advanced form of input, named “diversity profiles” for building simulation programs. The diversities of user profiles indicate and describe the presence of occupants and the corresponding lighting loads in different usage situation. Reinhart (2004) developed a model named Lightswitch-2002 to predict the interaction of occupants with lighting and blinds systems based on an adapted version of Newsham’s stochastic model (Newsham, 1995). However, most of the profiles in Lightswitch-2002 were fixed and were repeated for all workdays. SHOCC (Bourgeois, 2005) designed a platform to integrate advanced behavioural models to simulate energy usage for the whole building it was also based on the Lightswitch-2002 algorithm.

Tabak (2008) argued that the full realistic complexity of the human presence was not reproduced in previous research and he developed a system called User Simulation of Space Utilization (USSU) to mimic the real behaviour of office building occupants when scheduling activities. This system requires specific data on the activities of members of an organization. However, a large amount of user input data is needed, and there is no connection made with the 3D virtual environment. Based on Tabak's activity scheduling method, Zimmermann (2010) designed an agent-based method for modelling and simulating the individual behaviour of occupants for the purpose of energy consumption simulation.

3.3.3 User Activity Simulation Methods Used in PEP

The above review, shows that user activity simulation methods have mostly been used for simulations related to energy saving and emergency evacuations. However, user activity simulation has seldom been used to support the enhancing of client understanding of the architectural design and to facilitate the design review process.

Because one of the objectives of PEP is to demonstrate how end-users will be accommodated in a virtual built environment, user activity simulation methods need to be used for this purpose. To meet the problems which need to be addressed, a user activity simulation method should have the following features:

- the enablement of the individual user to specify his/her daily activities in the given building;
- the ability to simulate end-user working scenarios (such as route selection between activities and e movement patterns demonstration) based on the activity schedule specified by end-users.

Among other user activity simulation methods, the USSU developed by Tabak (2008) has provided a basis which facilitates the above requirements. Tabak's method has provided a framework to schedule individual user's activity according to different activities types. It also provided a method to predict the occurrence time of these activities. Although this activity scheduling method required a large amount of data to be input and had no connection with the virtual built environment, it is suitable as the basis activity scheduling method used in this research. The details of Tabak's activity scheduling method are introduced in next section.

3.3.3.1 Skeleton Activities and Scheduling Method

In the system USSU (Tabak, 2009), end-user activities are divided into two types: skeleton activities and intermediate activities. Two scheduling methods are applied separately.

Skeleton activities can be further divided into two types, namely planned and unplanned skeleton activities. The former type refers to activities which are scheduled in advance, and the latter to activities which are "conducted in the time that remains before, after and between all planned skeleton activities".

To describe an organization's skeleton activities, user roles have to be specified, as do organizational units, and the tasks associated with each role and each unit. In addition, each task has the following properties: time percentage, priority, average duration, minimum duration, whether a main task and task type. Task types are grouped for the purposes of scheduling interactive skeleton activities.

3.3.3.2 Intermediate Activities and Scheduling Method

Intermediate activities have a strong relationship with psychological and physical needs (e.g. get a drink) but depend less on a person's role. Intermediate activities can also be divided into two types: one type strongly depends on the time elapsed since the previous occurrence (e.g. get a drink); another type is spread over randomly the duration of the workday. Thus the number of occurrences of different types of intermediate activity during a workday depends on an average frequency and its variance. S-curve and probabilistic methods have been developed to predict the occurrence of these two types of intermediate activity.

- S-curve method

This method was used to predict the occurrence of the first type of intermediate activity mentioned above. It is assumed that satisfying the need of an activity yield a utility (Arentze and Timmermans, 2006). The utility of an activity increases with the time which has elapsed since the previous occurrence of that activity, and hence becomes more urgent (Tabak and de Vries, 2010). Tabak (2009) proposed a needs-based theoretical framework for predicting the occurrence time of intermediate activities based on the framework developed by Arentzea and Timmermans (2008). The equation for calculating the occurrence time of an intermediate activity t is (Tabak, 2009):

$$t = -\frac{In\left(\frac{V_{max}}{-\left(V_{min} + V_{context} + \varepsilon_{\alpha}\right.} - 1\right)}{\beta} + \alpha \tag{3.1}$$

The V_{max} ,V_{min} and $V_{context}$ are parameters representing the utility of an activity, which are determined by end-user behaviour. ε_{α} is a random utility. α and β decide the shape of the S curve (β is the slope of the S-curve, α is the horizontal displacement of the S-curve).

- Probabilistic method

The second type of intermediate activity is scheduled using a probabilistic method. The frequency with which a user performs these probabilistic intermediate activities during a working day is based on the mean and standard deviation values. The start times for the occurrences are randomly spread over the workday. A minimum time-interval between each occurrence is used to prevent two or more occurrences following too closely (e.g. 5 min). When calculating the time of the first occurrence of an intermediate activity, the whole working day is available as a timeslot for drawing the start time (Tabak and de Vries, 2010).

3.3.3.3 The USSU Output

The USSU output consists of a movement pattern in the form of an end-user activity schedule. The schedule includes start and end times of each user's skeleton activities, intermediate activities and the routes taken by him within the building. Based on such output, space usage scenarios can be predicted, such as duration and frequencies of using spaces/facilities as well as mean walking distance per user.

3.3.3.4 Discussion

Section 3.3 reviews various techniques adopted and studied for simulating user activity of different types in buildings. These techniques provided the foundation for the establishment of the activity scheduling method adopted during this study.

PEP is a virtual platform for supporting designer-client communication. During this process the client (including the end-user) is expected to obtain a better understanding of the proposed environment within the new facility as well as its practical functional performance in use. As stated by Kalay (2004) "the best apparatus for evaluating the impact of an environment on its inhabitants is, of course, the human users themselves". Thus more efficient and enhanced client understanding of the design solution will result if the platform allows end-users to specify their activities and interact with a virtual building model. Designers can also obtain more clearly defined design requirements as well as feedback from client.

To ensure the purpose of supporting designer-client communication is manifested, the user activity simulation method adopted in PEP needs to efficiently satisfy the user activity specification process, and also be capable of simulating the end-user activities, based on the building information models. Therefore an efficient user activity specification and scheduling method is established and adjustments will be made based on the previous work. The details of the user activity specification and scheduling method are introduced in Chapter 4.

3.4 Requirements Documentation and Management

As one of the design process objectives is to help clients (including potential end-users) to conduct a pre-occupancy evaluation in the virtual environment, this section introduces the concepts of post occupancy evaluation, pre-occupancy evaluation as well as requirement documentation methods (models).

3.4.1 Post and Pre-Occupancy Evaluation

The history of Post Occupancy Evaluation (POE) started with one-off case study evaluations in the late 1960s, and became a systematic and typical evaluation process in the 1970s and 1980s. Early POE focused on the residential environment and the design of housing for disenfranchised groups, which led to rapid home construction after Second World War. After that many urban renewal projects in North America as well as new town construction in Western Europe created large numbers of housing without comprehensive consideration of the behaviour, needs, expectations or lifecycles of the occupants inside these buildings (Preiser and Vischer, 2005). The social and architectural problems that continually arose resulted in the interest in systematic assessment of the physical environments in terms of how people were using them (Vischer, 2001).

The early definition of post-occupancy evaluation is the “examination of the effectiveness for human users of occupied designed environment”. The effectiveness may include the many ways that “physical and organizational factors enhance achievement of personal and institution goals” (Zimring and Reizenstein, 1980). Another definition of post-occupancy evaluation is "the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time" (Preiser, 1988), from the perspective of the people who use them. It aims to assess how well user needs can be matched by buildings, and identifies ways of improving building design, performance and fitness for purpose. The British Council for Offices (BCO) have stated that "a POE provides feedback on how successful the workplace is in supporting the occupying organization and individual end-user requirements" (Oseland, 2007).

The purpose of POE research differs from those technical evaluations made during the planning, programming, design, construction and occupancy phases of the building life cycle. It addresses the problems in terms of needs, activities, and goals of the people and organizations using a facility, including maintenance, building operations, and design-related questions. In contrast, measures applied in POEs may contain indices concerning performance of organizational and occupant, worker productivity and satisfaction, and building performance (e.g. lighting levels, acoustic, adequacy of space, spatial relationships, etc.) (Preiser and Vischer, 2005). Thus traditional post-occupancy evaluation provides feedback firstly on how well the evaluated building serves the functional purposes of the occupying organization, and secondly how well it meets individual requirements and meets the brief (Oseland, 2007).

The outcome of a post-occupancy evaluation can be expressed in terms of the "Three Es" framework endorsed by CABE and BCO (2005):

- efficiency of making economic use of real estate and driving down occupancy costs;
- effectiveness of using space to support the way that people work, improving output and quality;

- expression of messages both to the inhabitants of the building and to those who visit it, influencing the way they think about the organization.

On the other hand, Pre-Occupancy Evaluation (also abbreviated as POE) can be conducted in different circumstances. One type of pre-occupancy evaluation is based on the existing buildings. For instance, evaluation is conducted on certain existing building when one organization is planning to move into it. The indicators in such situation may contain “location”, “building”, “space” and “environment” (Molloy, 1989). This type of pre-occupancy evaluation can also be in relation to the building performance evaluation, such as evaluation of environmental parameters of existing buildings before occupancy (Grot et al., 1991). Another type of pre-occupancy evaluation is conducted during building design stage, which is usually based on the development of building performance simulation techniques for different purposes (as introduced in Section 3.3.1), such as energy estimation (Soebarto and Williamson, 1999) or human performance analysis (Palmon et al., 2006). The pre-occupancy evaluation in this study belongs to the second type, which aims to predict the results of a built environment and conduct a hypothetical post-evaluation exercise in terms of needs, activities, and goals of the people and organizations using a facility.

3.4.2 Requirements Documentation Method

Client requirements are usually expressed following the interviewing of clients, owners, and end-users. In many cases, client requirements are not initially clear, and the designers must convert these requirements into more accurate requirement descriptions and requirement attributes (Whelton and Ballard, 2003).

Kamara (2002) summarized the requirements capturing and documentation methods, which contain Quality Function Deployment (QFD), Client Requirements Processing Model (CRPM), Total Quality Management (TQM), and Failure Mode and Effects Analysis (FMEA). Kiviniemi (2005) argued that the QFD is not commonly used in building industry, because of the different process between building industry and manufacturing industry. Other reasons include that the QFD is less likely to deal with complex products and conflicting requirements (Prasad, 1996) and it potentially useful for defining strategic goals rather than details requirements (Ahmed et al., 2003). Kiviniemi (2005) also pointed out that the CRPM mainly focuses on the high-level requirements and it is difficult to discern the lower-level requirements from the higher-level requirements. In addition, the limited applicability of the weighting system is another problem of CRPM.

Research into requirements hierarchical classification has also been conducted. The International Centre for Facilities (ICF) has published several volumes documenting their standards for Whole Building Functionality and Serviceability (WBFS) since 1992 (ICF, 2000; ICF, 2009). The purpose of these standards is to help organizations to define functional requirements for their buildings. Thus the WBFS standards provide a checklist assisting the gathering of data and evaluating existing buildings, from portfolio management and tenant viewpoints, for example. Although the WBFS has provided a high-level evaluation checklist, there is no linkage with design tools. Another example is EcoPro, a software application developed by Technical Research Centre of Finland (VTT), intended to help building owners define their sustainability requirements. Kiviniemi (2005) designed a building requirement Industry Foundation Classes (IFC) specification called Product model extension for REquirements Management InterfaceS (PREMISS) based on the requirements hierarchies of WBFS and EcoPro. PREMISS attempts to manage requirements information during design process and provides the possibility of linking requirements to building project objects. A structure to cope with a cascading requirements hierarchy is also defined in PREMISS, which significantly simplifies the database structure in relation to space requirements.

Because of these PREMISS advantages, the requirements documentation method applied in PEP are partly based on the space requirements specification of PREMISS. However, in this research, a post-occupancy evaluation questionnaire is combined with the requirements specification to for enabling clients to better review the design solutions, since the collection of client feedback against these requirements is not catered for by PREMISS. Details are introduced in Chapter 4.

3.5 Summary

This chapter reviewed the literature on techniques and tools for addressing the problems stated in Chapter 2, which mainly contains building information modelling, user activity simulation in buildings, as well as the requirement documentation and management techniques. The three categories of techniques provide the foundation of the further development of the PEP, which is introduced in the following chapters.

Chapter 4 Design and Development of PEP

4.1 Introduction

The previous chapters provided the background to the basic concepts of the early architectural design stage and defined problems encountered during the designer-client communication process. In addition, suggested areas for improving designer-client communication were summarized from the literature. These areas needing improvement in the briefing stage include: (1) encouragement of appropriate user involvement; (2) application of understandable visualization techniques to enhance client understanding; and (3) establishing a mechanism which can collect feedback relevant to client requirements. On the other hand, suggestions for improvement during the space planning stage cover the following aspects: (1) the enablement of user interaction to allow end-users to interactively specify the location of each activity; (2) better support for architects in the evaluation of space planning alternatives and decisions as to which design solution is better, in relation to a given function objective; and (3) provision of a virtual environment for the evaluation of the design solution against different requirements, which embrace efficiency and aesthetics requirements at the same time (such as areas, relationships between activities, accessibility, privacy and, lighting).

Therefore, based on the literature, functions which need to be supplied via PEP consist of following:

- the use of virtual prototyping techniques to simulate the end-user activities in the given building model, so as to enhance the inexperienced client's understanding of not only building design but also how user activities will be accommodated;
- creation of a platform for increasing participants involvement, especially the end-users;
- facilitation of the specification by end-users of their activities (e.g. time and location) in the given design solutions;
- demonstration of the usage of the built environment to support the designers to improve the design;
- establishment of a requirements specification and feedback collection mechanism to manage the client requirements and feedback;
- the support of designers and clients in reviewing design solutions in terms of spatial factors, visual factors and other indoor environment factors;
- establishment of a structured process to guide the implementation of the PEP and achieve the above objectives on a real project;
- provision of the possibility of connecting the requirements and feedback information with current BIM software.

In this chapter, Section 4.1 to 4.3 introduces the rationale, architecture and components of the PEP. Section 4.4 to 4.6 then illustrates the detail of the three modules in PEP: (1) building information module, (2) user information module and (3) pre-occupancy evaluation module. The techniques applied in each module are also introduced. A guideline for guiding the application of PEP in real project is also illustrated in Section 4.7.

4.2 Rationale of PEP

The PEP is designed on the basis of the typical design process illustrated in Section 2.2.3. It focuses on the designer-client communication during the stages of briefing and development of early design solutions. In a typical architectural design process, clients first specify their organization information and requirements to generate a brief (usually under the guidance of designers). The designer then proposes preliminary solution(s) according to this brief. Modifications are continually made during this communication process based on the client's possible further requirements and subsequent feedback. Thus the conventional design process consists of three steps: 1. User information gathering; 2. Requirements specification; 3. Design synthesis (connected by dashed arrows in Figure 4.1).

The rationale of PEP is to integrate the organization information into a virtual environment. Thus this virtual environment not only contains the building model but also the user activity simulation. The PEP will enable evaluation and comparison against requirements of alternative solutions. Therefore based on the traditional design process, two more steps (4. User activity simulation and 5. Pre-occupancy evaluation) are added when the outline of the building design becomes available.

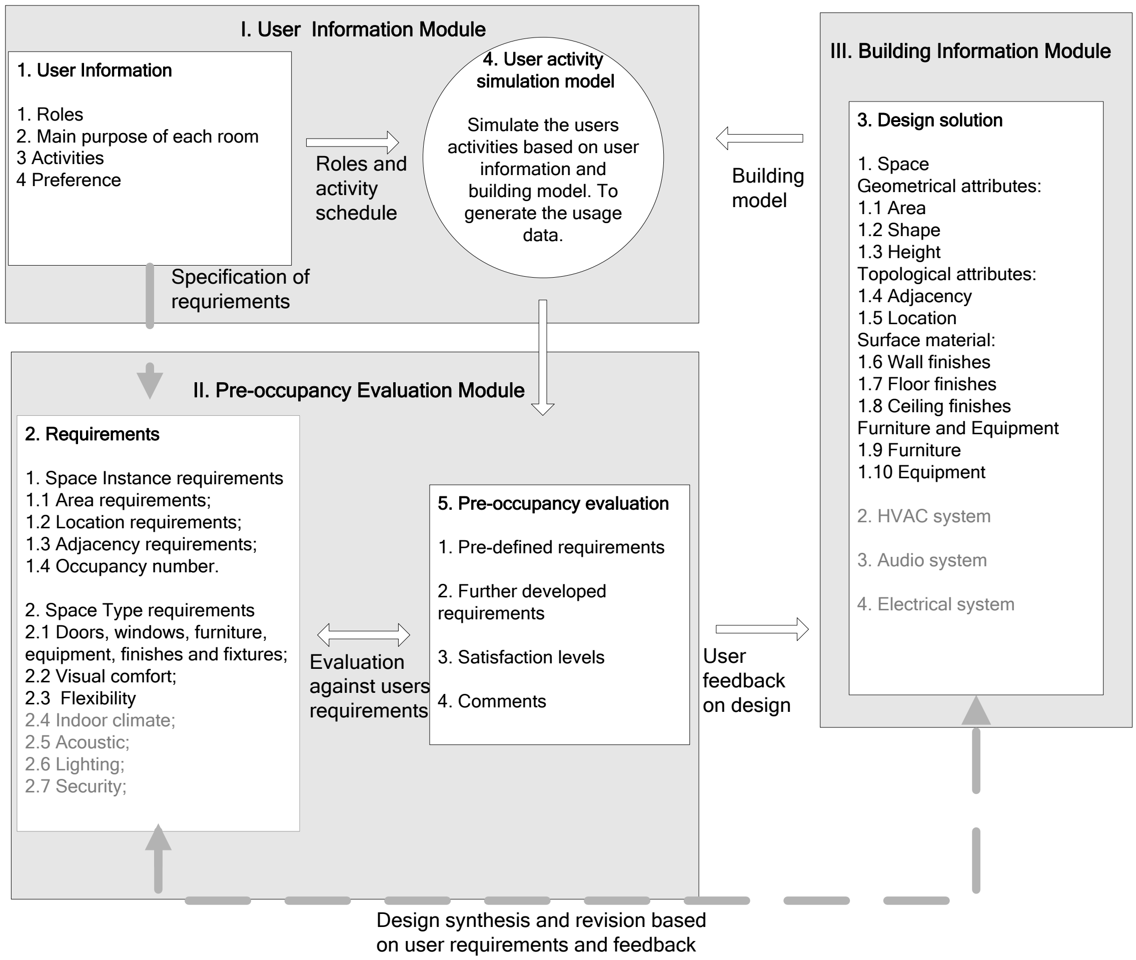


Figure 4.1 The flow chart of PEP

4.3 Components of PEP

Three PEP modules have been designed to support the designer-client communication process (Figure 4.2) which include:

Building information module: this module uses BIM tools to build up and update the building model based on the design given by the designer. It also provides the building information needed to illustrate building performance;

User information module: this module assembles information collected from the user organization, including user roles, activity schedules (activity type, occurrence time and location). The *user activity simulation model* is also generated in this module for demonstration of the organization's activities in a virtual environment;

Pre-occupancy evaluation module: this module enables a pre-occupancy evaluation to be made based on the virtual environment and the management of client requirements and feedback.

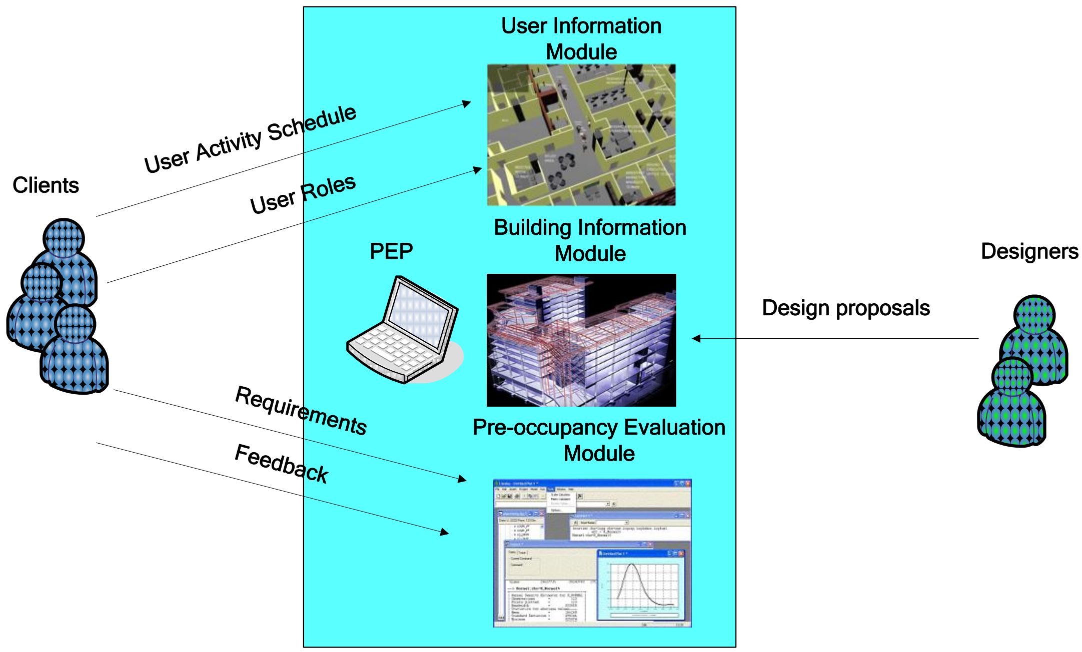


Figure 4.2 The architecture of the PEP

4.4 Building Information Module

This building information module creates the building information model based on the design solutions given by the designers. Although BIM tools (e.g. Revit Architecture) have been introduced to many design companies, 2D drawings are still widely used in the briefing and design stage. In the traditional designer-client communication process, 3D effect drawings are sometimes prepared to assist in clarifying 2D drawings. When applying the PEP in a real project, it is necessary to transform 2D drawings to the building information models via BIM tools. Other rendering tools (e.g. 3ds Max Design) are used for demonstrating the details of the material, interior decoration, terrain and other external environment (Figure 4.3).

In the PEP, graphical and non-graphical information generated using the BIM tools provide the basis of user activity simulation. The graphical information contains the geometrical attributes of the building elements; the non-graphical information includes other attributes, such as materials, function descriptions and so on. These two types of information provide the clients with a better understanding of the building design. In the application of PEP, during the development of the brief and design solutions, more details are added into the design, and the building information model is updated accordingly.

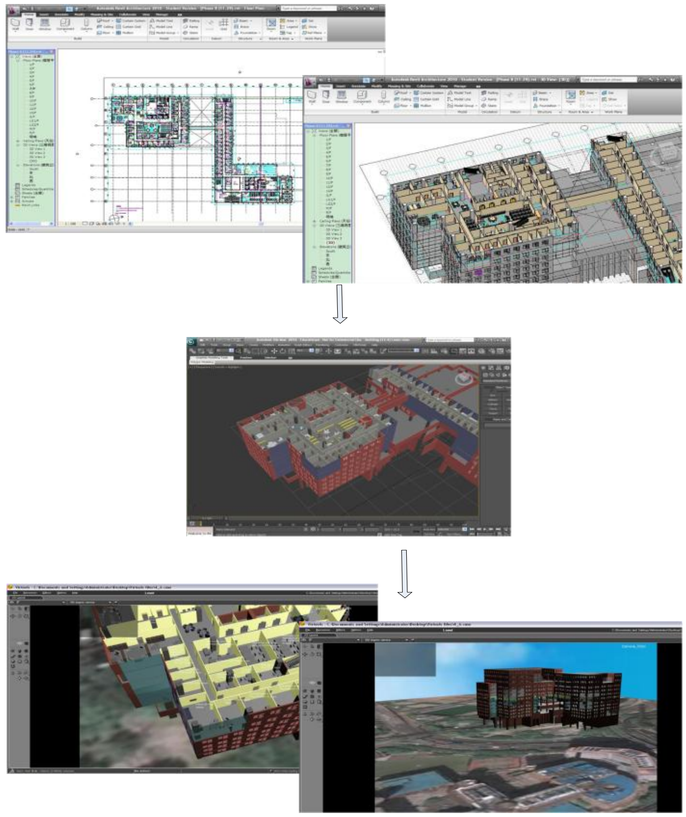


Figure 4.3 Modelling process in building information module

4.5 User Information Module

User information in this research refers to end-user organization information, which includes user personal information and activity schedules (activity type, occurrence time and location). This information is collected via the applications in this user information module. On the basis of the organization information, a *user activity simulation model* is generated to demonstrate the organization activities in the virtual built environment. The following sections introduce the user activity scheduling method, as applied in this module and also the features of the *user activity simulation model*.

4.5.1 User Activity Scheduling Method Applied in PEP

The user activity scheduling method used in the PEP is adapted from Tabak (2009)'s activity scheduling framework. Tabak's work focused on predicting the activity schedules of members of an organization in an existing built environment. In contrast, the scheduling method in PEP attempts to help end-users specify their activities and demonstrate how they will to be accommodated in the future built environment. Therefore, some adjustments have been made to Tabak's theory and framework.

The basic assumption is that activities specified by end-users in the virtual environment are consistent with the activities to be conducted in the future. In other words, the end-users are requested to describe their future working scenarios in advance.

As for Tabak's categorization, the types of user activities are divided into two types: skeleton activities and intermediate activities. However, in order to collect end-user activities information in a relatively short time, no distinction is made between planned, unplanned and interaction skeleton activities in this study. All of these skeleton activities are classified as planned activities referring to end-user working routines.

4.5.1.1 Scheduling of Skeleton Activities

Figure 4.4 shows the *user activity specification and scheduling interface* for end-users to specify activities in new buildings. The attributes of skeleton activities include start time, end time, and location of each activity based on their daily working routines or agenda on one specific working day. They can also specify the locations of each skeleton activity by inputting names of rooms directly or picking from the 2D layout by clicking a button representing each room/space.

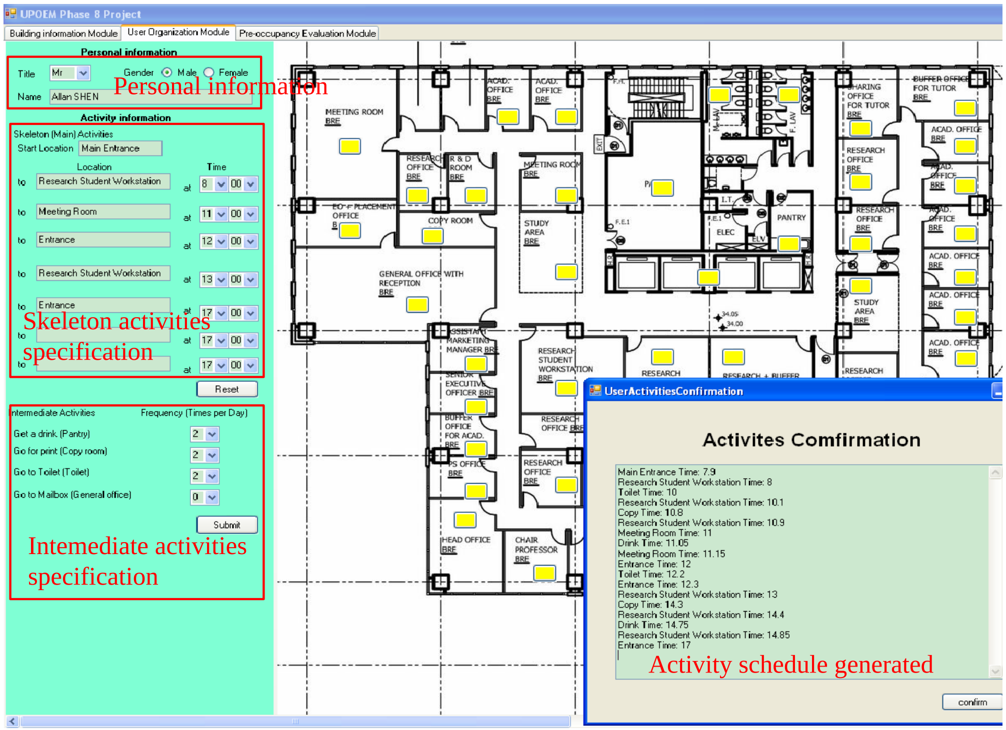


Figure 4.4 Interface for user activity specification and scheduling

4.5.1.2 Scheduling of Intermediate Activities

A simplified intermediate activity scheduling method is proposed, as the intermediate activity scheduling method in PEP is less concerned with predicting the occurrence time of each intermediate activity, than it is with demonstrating the usage of different functional rooms in a short time (e.g. 16 minutes represents 8 working hours in one day), The method has two features:

1. The occurrence time of all intermediate activities depends on the time elapsed since the previous occurrence;

2. A linear probability distribution method is used to simplify the S-curve method (Section 3.3.3.2).

This simplified method can save time in determining the shape of the S-curve, and is easier for users to describe their daily activities. Intermediate activities (such as, get a drink, go for print, go to toilet and go to mailbox) are described by daily frequency and their mean durations have assumed values (e.g. 10 minutes).

The algorithm for calculating the occurrence time of a given intermediate activity in a certain time span with a frequency N is as follows:

```
Step 1. RC = Random (0,1).
Step 2. IF (PC > RC)
            THEN // The intermediate activity will happen at this time.
                PT = CT; // Records the activity happening time to PT.
                    AC = AC + 1; // Increase the activity counter.
            ELSE // The activity will not happen, increase the time.
                CT++ ; // The interval of time increase is set to 0:05.
                GOTO Step 1;
Step 3. IF (AC = N)
    THEN // The activity has happened at the user indicated frequency.
                End Algorithm;
    ELSE
                CT++ ; // The interval of time increase is set to 0:05.
                GOTO Step 1;
```

The parameters used in the algorithm have the definitions below:

ST = The starting time of the simulation, predefined at 9:00 am.

ET= The ending time of the simulation, predefined at 17:00 pm.

CT= The current time.

PT= The time when the previous activity happened, which is equal to ST at the beginning.

RC = The probability that an activity will happen at random. Ranged 0 – 1.

N = Frequency of the activity. (Times of occurrence of the activity take place during the simulation, and are input by users.)

AC = Activity counter. Indicates how many activities have already taken place. Set to 0 at the beginning.

PC = The probability that an intermediate activity will happen in a given time. PC is calculated by the formula:

$$PC = (CT - PT)/((ET - PT)/(N - AC)) \tag{4.1}$$

According to formula 4.1, during a certain time slot, the probability of an intermediate activity PC will increase from 0 to 1.00 after the previous occurrence of such activity. This time slot is decided by remaining time of the working day as well as the occurrence times of the activities. In this way, the occurrence times of the intermediate activities will be distributed throughout a working day based on the predefined frequencies.

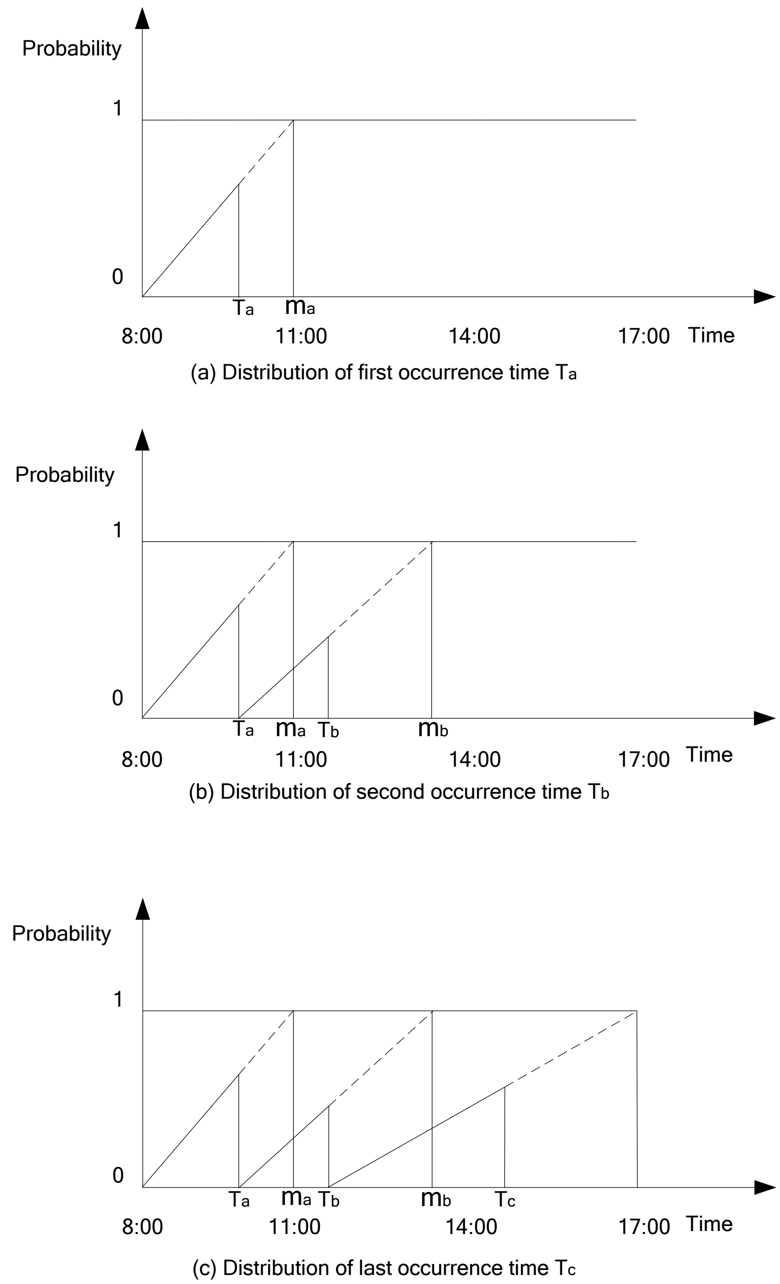


Figure 4.5 An example of the distribution of intermediate activities

Figure 4.5 shows an example illustrating the intermediate activity scheduling algorithm. In this example, an end-user works from 8:00am to 5:00pm. The frequency of one intermediate activity (e.g. have a drink) on a working day is pre-defined as three. In

Figure 4.5 (a), the occurrence probability of the intermediate activity P_a grows linearly from 0 to 1 as the time T increases from 8:00 to m_a. According to Formula 4.1, when

$$P_a = \frac{m_a - 8}{\frac{17-8}{3-0}} = 1$$

$$m_a = 11$$

Therefore, the first occurrence time T_a is distributed between 0 and m_a as probability

$$P_a = \frac{T-8}{3}$$

After this point, according to Formula 5.1, the probability of the next occurrence

$$P_b = \frac{T - T_a}{\frac{17 - T_a}{3-1}} = \frac{T - T_a}{\frac{17 - T_a}{2}}$$

When

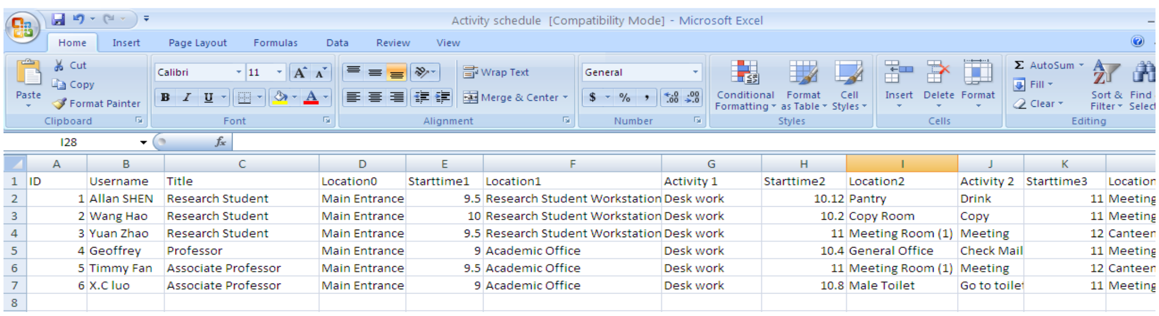
$$P_b = 1$$

$$T = \frac{17 + T_a}{2} = T_a + \frac{17 - T_a}{2} = m_b$$

So the second occurrence time T_b is distributed between T_a and m_b as probability P_b. The third occurrence time is calculated in the same way.

4.5.1.3 Generation of Whole Schedule

After determining the occurrence times, these intermediate activities are inserted into the intervals of the skeleton activities. The whole activity schedule including both skeleton and intermediate activities is then generated and saved into the database (Figure.4.6). For the purpose of reflecting the interaction activities and avoiding interruption between skeleton and intermediate activities, some adjustments are made. For example, interactive activities (e.g. a group meeting) are arranged to reflect the usage of a meeting room on certain days; or the intermediate activity is postponed when it conflicts with a skeleton activity which allows no interruption. These adjustments are conducted based on the activity schedules of members (Figure 4.6) in order to demonstrate different working scenarios in the future built environment. The finalized activity schedule is then imported into the activity simulation tool for generating the *user activity simulation model* in the virtual environment.



ID	Username	Title	Location0	Starttime1	Location1	Activity 1	Starttime2	Location2	Activity 2	Starttime3	Locatior
1	Allan SHEN	Research Student	Main Entrance	9.5	Research Student Workstation	Desk work	10.12	Pantry	Drink	11	Meeting
2	Wang Hao	Research Student	Main Entrance	10	Research Student Workstation	Desk work	10.2	Copy Room	Copy	11	Meeting
3	Yuan Zhao	Research Student	Main Entrance	9.5	Research Student Workstation	Desk work	11	Meeting Room (1)	Meeting	12	Canteen
4	Geoffrey	Professor	Main Entrance	9	Academic Office	Desk work	10.4	General Office	Check Mail	11	Meeting
5	Timmy Fan	Associate Professor	Main Entrance	9.5	Academic Office	Desk work	11	Meeting Room (1)	Meeting	12	Canteen
6	X.C luo	Associate Professor	Main Entrance	9	Academic Office	Desk work	10.8	Male Toilet	Go to toilet	11	Meeting

Figure 4.6 Saved user activity schedule information

4.5.1.4 Discussion

The aim of scheduling user activities is to describe the daily working scenarios of the organization for further virtualization and evaluation. The scheduling method applied in PEP is straightforward enabling end-users to describe their daily activities in terms of time and location. Although this simplifies the complex and erratic activities of actual individual user activities, the method represents the workflow pattern of an organization well enough to describe the usage of the buildings and demonstrate to clients whether the intended built environment will satisfy their requirements.

4.5.2 User Activity Simulation Model

4.5.2.1 Simulation Tools

A *user activity simulation model* is generated based on the user activity schedules and building information model via the virtual prototyping software 3DVIA Virtools. A virtual prototype can be defined as a system or subsystem simulation based on computer, which has a degree of functional realism when comparable to a physical prototype. Virtual prototyping is the process of applying a virtual prototype, instead of a physical prototype, for evaluating and testing specific characteristic of a design (Huang, 2009). This *user activity simulation model* aims to demonstrate the individual end-user and group user activities in a three-dimensional virtual environment, and provide a platform for clients to interact with the latest built environment design.

The company Virtools (founded in 1993) offers a development environment for creating 3D real-time applications and related services. It was acquired by Dassault Systèmes in 2005, and Virtools was renamed 3DVIA Virtools as part of Dassault Systèmes' 3DVIA brand in 2006. This platform is available for virtual reality applications, the video game market (prototyping and rapid development), and other highly interactive 3D virtual product experiences (Virtools, 2011).

3DVIA Virtools provides a platform for building virtual prototypes by creating or importing objects from other applications. It also provides varieties of integrated scripts (called "Building Blocks" in Virtools) for producing animations based on these prototypes. This software was selected for this research as the basic tool for creating a *user activity simulation model*, because of the above features.

4.5.2.2 User Activity Simulation Process

The user activity simulation process is as follows:

1. Importing the activity schedules into the 3DVIA Virtools

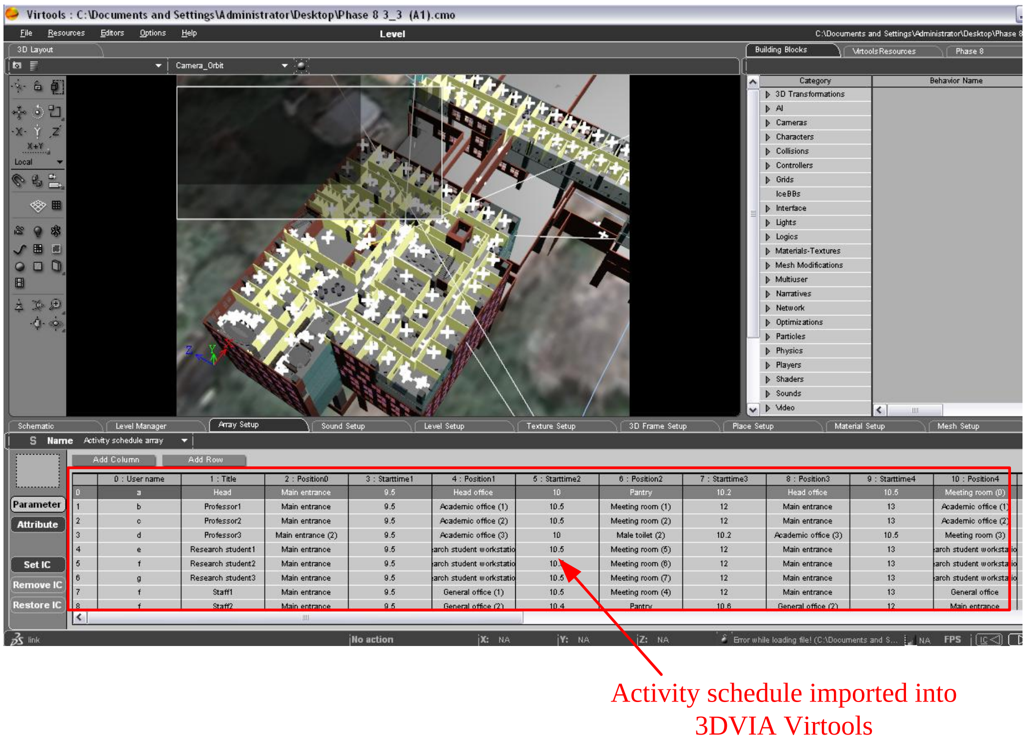


Figure 4.7 User activity schedule saved in 3DVIA Virtools

First, a script was written for loading the user activity schedules (in the form of an Excel file) into Virtools and saved in an array (Figure 4.7). This array contains the start time, end time and location of each user's daily activities.

2. Create avatars and assign schedules

The avatars and animations are created by 3ds Max, and exported into Virtools to form the *user activity simulation model*. Various animations can be produced and assigned to these avatars for demonstration purposes, for example, walking, printing, and deskwork (Figure 4.8).

Figure 4.8 Avatars moving according to schedules

The route taken during an individual end-user's daily life is divided into several smaller paths. Movement in one single path is triggered when the current time equals the start time of a certain activity. Figure 4.9 shows the script describing an individual user's activity on a working day.

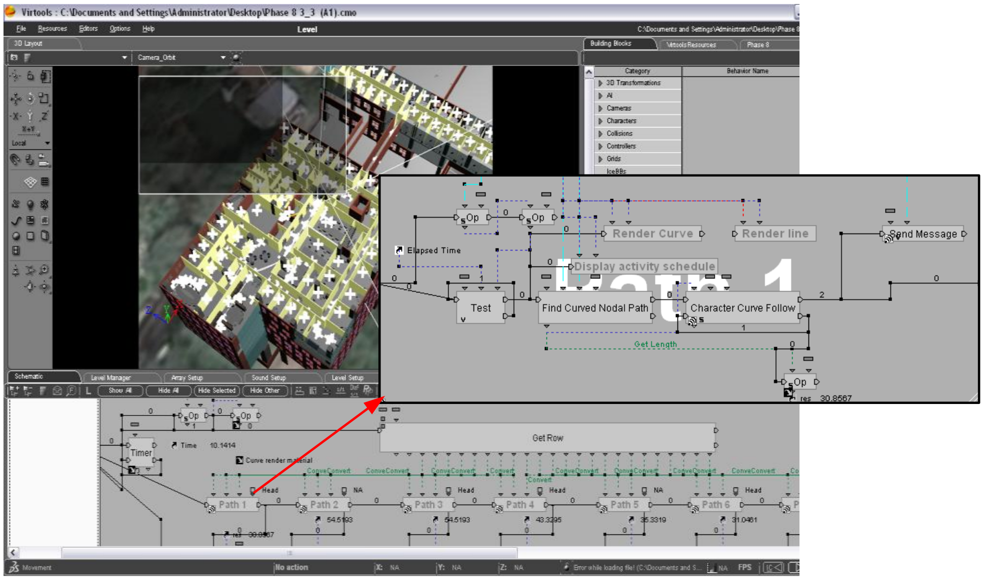


Figure 4.9 Scripts describing the daily activity of individual end-user

3. Integrating the movement patterns within the building model

A node network is established to connect different function spaces in the building (Figure 4.10). These nodes represent different locations in the building. The name of each node is the same as the name of each space. Thus the avatar movements can be illustrated by finding the target node in the network.

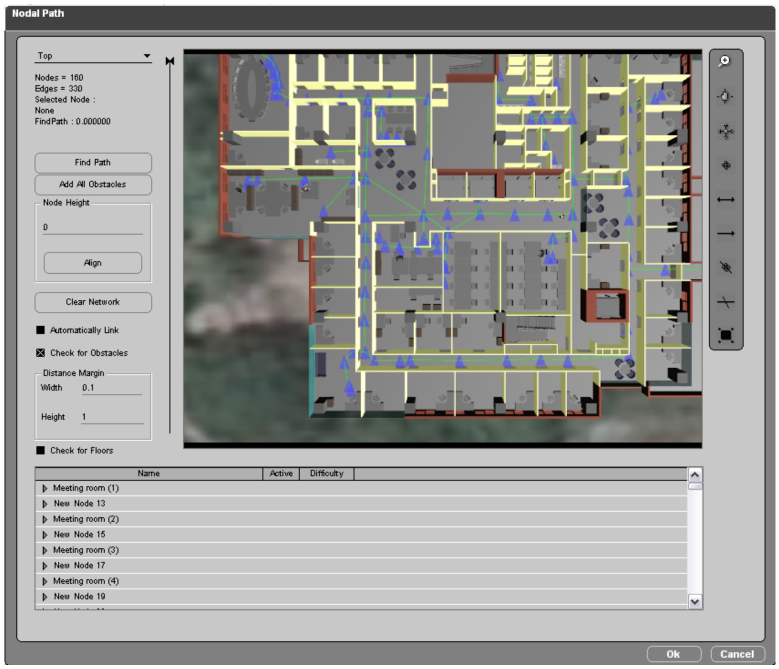


Figure 4.10 A node network representing locations in the building model

Consequently the algorithm for simulating individual end-user activities is as below:

- When the current time equals the start time of one activity;
- Find and follow the path between start node and end node;
- Trigger movements and other behaviour (e.g. sit down before a desk).

The assumption behind a user's movements is that they will follow the shortest path between two nodes in the node network if there is more than one path.

When the movement patterns of avatars are generated in the virtual environment, different interaction methods have been developed for clients to interact with the avatars as well as with built environment. Other non-graphical information, such as room name and building element name annotations are added for demonstration purposes. Sections 4.5.2.3 and 4.5.2.4 introduce the details of these features in the *user activity simulation model*.

4.5.2.3 Graphical Information to Facilitate the Demonstration Process

The avatars in the *user activity simulation model* represent different users in the actual organization. Usually the demonstration time will be shortened proportionately to adapt to the communication duration. During the demonstration, end-users follow the movement of the avatars to observe their daily activities in the new building according to their schedules. The users of the tool are able to choose different avatars and switch between them. Multiple observation angles are provided to support observation, including (1) overview (with zoom in and zoom out function), (2) third person and (3) first person views. Observers can switch to different angles to check the daily work environment (Figure 4.11). One of the advantages of this kind of navigation is that observers do not have to find their way in the new building by themselves. It is easy for clients to become quickly familiar with the built environment especially in the context of real designer-client communication.

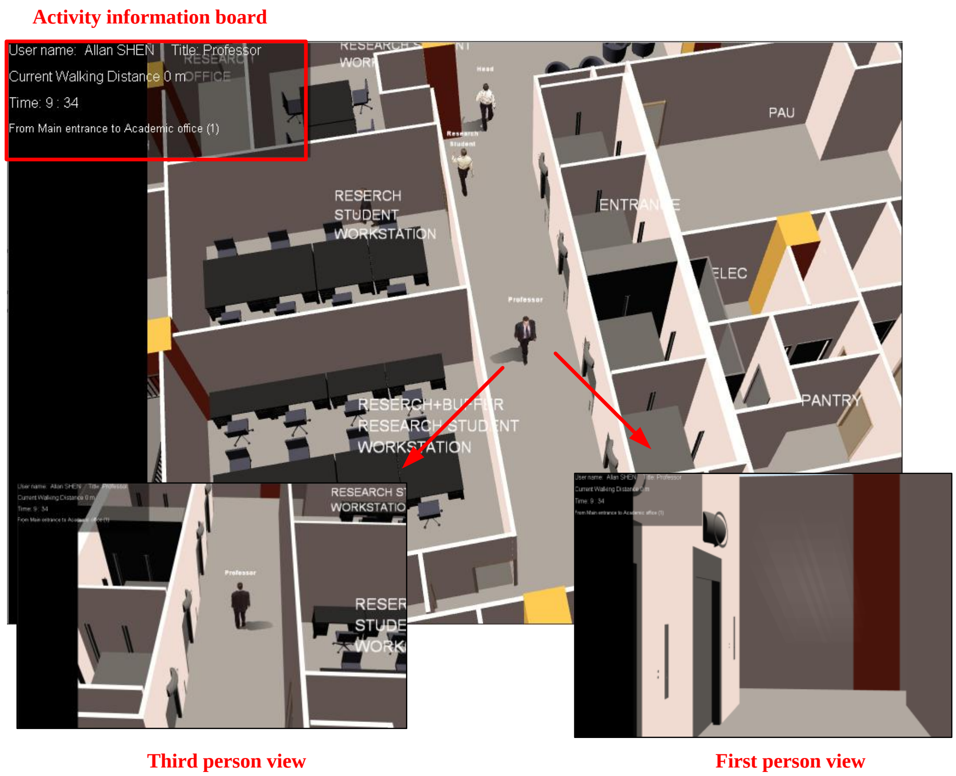


Figure 4.11 Snapshot of user activity demonstration

In addition to following the avatars, observers can switch to the normal observation modes as is commonly the case with other design software packages (e.g. Revit Architecture) to examine the design solutions, making use of walkthrough and flythrough models.

The activity simulation model can not only demonstrate individual user activity but also accept multiple user activity schedules and simulate the interactive scenarios as meetings and teaching. Figure 4.12 shows a scenario of five users attending a meeting. The participants at the meeting and its time and location are predefined by users' schedules. Through the avatar involvement, observers are expected to obtain a sense of scale in the room and a "feeling" for whether it is crowded or spacious. They also gain a feel for distance while following their avatars from one location to another. The focus of this model is facilitation of client understanding of the spatial properties of design solutions, such as sizes, adjacencies between different rooms and circulation. These are the factors most related to end-user movement and spatial comfort when living in a building.

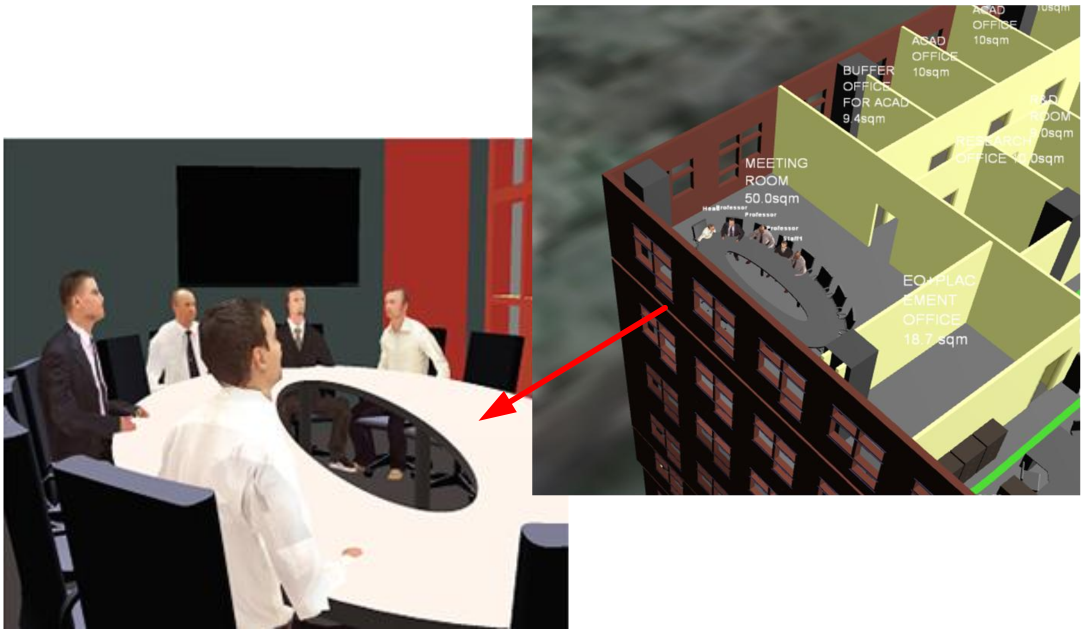


Figure 4.12 Demonstration of group user activity

In the process of design development, more details are added into the building model to enable clients to understand design details in addition to the layout. Others can include the interior decoration, material, lighting and the view outside the building. These details depend on the capabilities of the building simulation model.

4.5.2.4 Non-graphical Information to Facilitate the Demonstration Process

In addition to the walkthrough feature the activity simulation model provides statistical information. For example, Figure 4.11 illustrates the scenario of a normal working day in a university. A professor is walking from the main entrance to his office on arriving in the morning. Within the model, the activity information board on the left-up corner displays the personal information, such as “user name”, “title” and also “current time”, “current activity”, “walking distance”

During the design process, questions such as “will the layout design promote good communication between employees?” or “will traffic flow easily?” are always raised by designers, especially when traffic efficiency is emphasised in the design (e.g. airport and hospital projects). The clients are also concerned about the efficiency of travel around the building in such projects. Hence walking distance and travelling time are crucial indices of convenience and efficiency. The PEP provides the function of calculating and displaying walking distance during the demonstrations. Other data such as the total walking distance of all the users and the circulation time of each user can also be measured for different evaluation purposes.

End-user movement patterns are helpful to designers in evaluating layout as regards workflow and circulation analysis. The *user activity simulation model*, therefore, also provides a movement tracking function, to illustrate movement patterns and connections between rooms (Figure 4.13). These movement tracing curves can help clients understand the connection between different activities and specify adjacency preferences and requirements during the communication process. In addition, movement tracing curves of different colour are used to highlight the movement patterns of different types. For example, in a campus office building, the circulation of professors and research students are coloured differently, and therefore useful in supporting the circulation design and hence minimising interference between the different flows.

Figure 4.13 Tracking curve of user movement

4.5.3 Expected Benefit of the User Information Module

The *user activity specification and scheduling interface* facilitate the efficient specification of intended activities in the future built environment. The user activity scheduling method developed in the PEP enables end-users to specify the times and locations of skeleton activities. It can also predict the occurrence time of intermediate activities, so that end-user daily activities can be scheduled for further demonstration of the usage of the building.

The *user activity simulation model,* generated based on the activity schedules provides a virtual environment containing various types of graphical and non-graphical information. In addition, the *user activity simulation model* includes different observation techniques to enhance an observer’s visual experience of the built environment. The application of this model, therefore, is expected to narrow the understanding gap between designers and clients, and improve communication efficiency.

Further, two types of non-graphical information are provided by the *user activity simulation model*. One is the ability to annotate building elements with attribute and the other is to attach names to individual rooms and descriptions to the roles of end-users. This helps clients understand the detailed functions when observing the building models. Additional non-graphical information includes individual end-user personal information as well as activity related statistical data, which is shown on the "activity information board" (Figure 4.11). For example, the "current activity" navigates client observations as they follow avatar movement. Such information helps designers to evaluate the efficiency of occupant movements in the given layout, important for buildings such as hospitals and airports. Table 4.1 is an example of activity related data extracted from the *user activity simulation model*. Other information such as travelling time from one location to another, occupancy durations of rooms and total walking distances for all occupants can be also calculated to satisfy different assessment requirements.

Table 4.1 Activity related information provided by the user activity simulation model

Factors	Activity related information
User name	Allan SHEN
Title	Research Student
Current time	9:32 AM
Current activity	from Main entrance to Research student workstation
Current walking distance	17m

4.6 Pre-occupancy Evaluation Module

4.6.1 Introduction

The primary objective of the pre-occupancy evaluation module is to facilitate the clients to conduct the pre-occupancy evaluation based on the *user activity simulation model*. Evaluations focus on basic architectural design factors especially those relating to occupant activities, such as spatial factors and visual factors. This is because spatial factors (e.g. size, location and adjacency) and visual factors (e.g. appearance and views) are of prime concern to architects and clients during the communication processes (as discussed in Section 2.3.4.1). The extension of these evaluations to other aspects such as the site, building envelope and HVAC system are beyond the scope of this research, but are highlighted as desirable further research development.

In addition to selecting appropriate evaluation indicators, the pre-occupancy evaluation module also needs the following functions: (1) link the requirements documentation with the design solution; (2) remind the clients of the pre-defined requirements, and allow them to specify additional requirements; (3) collect feedback from clients against these requirements; (4) save these requirements and feed them back systematically, as “attributes” of each room for further design development. To achieve these objectives, a *requirements and feedback interface* was designed to help the client design review process. A corresponding requirements and feedback database is also set up for storing the information generated by the clients for change management and data enquiry.

4.6.2 Criteria Selected for Conducting Pre-occupancy Evaluation

In practice, the brief is a “yardstick” for assessing the further development of the design (RIBA, 2000). Sometimes the brief is changed even after approval, which might either lead to abandoning the completed design work, or have effects on the cost and statutory consents. Thus it is essential to start with an identifiable approved project brief and assess the design solutions against the brief.

The criteria selected for the evaluation process must typically, cover the different disciplines of architecture, structural engineering, mechanical, electrical, and plumbing (MEP), facilities etc. However, in light of the previous discussion, the requirements criteria selected for this pre-occupancy evaluation module focus mainly on spatial and visual factors.

Since clients need to evaluate the building models against these criteria the requirements specification needs the potential to connect with the building components and elements. Kiviniemi (2005) designed a building requirement Industry Foundation Classes (IFC) specification called Product model extension for REquirements Management InterfaceS (PREMISS) based on an integration of two large, widely used requirements hierarchies (WBFS and EcoPro), analysis of a brief in five building programs, and spatial requirements in the IFC existing specifications. This requirements specification manages requirements information during design process and provides the possibility of linking requirements to objects in the design. In addition, a solution for cascading requirements was also established by Kiviniemi with the aim of simplifying the requirements database.

PREMISS provides therefore, a basis for establishing client requirements and feedback database for supporting this pre-occupancy evaluation module.

The requirement specification of PREMISS covers 300 requirements in 14 main and 35 sub-categories. They form seven groups overall (1) Project requirements; (2) Site requirements; (3) Building requirements; (4) Storey requirements; (5) Space requirements; (6) Envelope requirements; and (7) Circulation requirements. Among others, in this study the space requirements category forms the basis for establishing the client *requirements and feedback specification* in the pre-occupancy evaluation module (Figure 4.14).

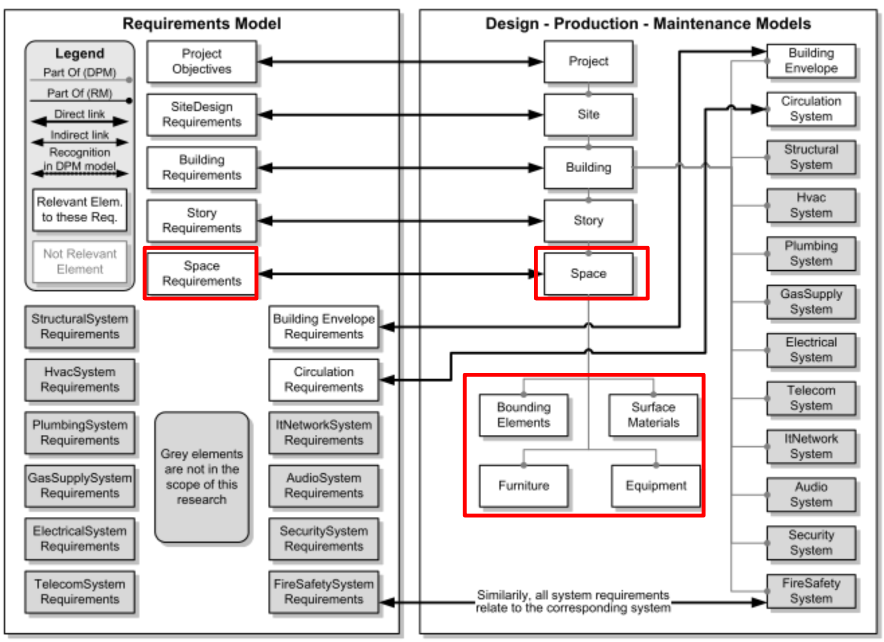


Figure 4.14 Space requirements in PREMISS (Source: Kiviniemi, 2005)

4.6.3 Specification of Client Requirements and Feedback Questionnaire

4.6.3.1 Introduction

This specification defines the evaluation objects and rules guiding the clients to review and evaluate the design solutions. The structure of this specification is a modified version of the spatial requirements in PREMISS. In Kiviniemi's work, the space requirements are of the following two main types:

- Requirements for space program instances (SPI) (Table 4.2). These requirements can be linked to a group of space instances in the design model.

Table 4.2 Space program instance requirements and descriptions (Source: Kiviniem, 2005)

Space program instance	Description
Standard required area	The floor area programmed for the space
Max required area	The maximum floor area programmed for the space
Min required area	The minimum floor area programmed for the space
Requested location	General description of the required location for the space
Employ type	General description of the employee type that will occupy the space
Max occupancy number	Maximum number of occupants for the designed usage of the space
Department	The department or other unit to which the space belongs
Adjacent spaces	List of space which should be located near to the space; or an alternative method to specify the related spaces as: "Has interaction requirements from"," Has interaction requirements to", and "avoid interruption from"
Number of space unites	Number of the space units belongs to this space type.

- Requirements for space program type (SPT) (Table 4.3). These requirements are the identical requirements shared by several space program instances. For example, the same type of academic offices in a university normally shares the same kind of requirements on fixtures, acoustic, visual contact and so on.

Table 4.3 Space program type requirements and descriptions (Source: Kiviniem, 2005)

Space program type	Description
Fixtures	Attributes set which define requirements for fixtures, furniture, equipment and finishes of a space type
Indoor climate	Attributes set which defines requirements for the indoor air quality, temperature, humidity and other condition requirements of a space type
Acoustic	Attributes set which define requirements for the background sound, reverberation time, sound insulation and traffic noise of a space type
Lighting	Attributes set which define requirements for daylight, lamp energy efficiency, lighting adjustability and other lighting requirements of a space type
Flexibility	Attributes set which define requirements for alternative furnishing, alternative use, division and combination of a space type
Security	Attributes set which define requirements for access zone and access control of a space type
Functionality and visual contacts	Attributes set which define requirements for interior design, functionality, external visual contacts and internal visual contacts of a space type

4.6.3.2 Space Requirements Used for the Pre-occupancy Evaluation

In the specification of the requirements and feedback questionnaire, the space requirements are also categorized into space instance requirements and space type requirements, which are equivalent to the SPI and SPT in Kiviniemi's work. However, because the focus of PEP is on the factors related to client activities and architectural design aspects, some adjustments have been made accordingly.

1. In PEP, the space instance requirements are linked to each individual physical space instance of the building model. The space type requirements are shared by several physical space instances. In PREMISS, the space program instances (SPI) are linked with several physical space instances, this may lead to some physical space instances sharing the same requirements as area, location and connection requirements, which may not be reasonable. For example, the academic offices (even the same function) in a university may have different requirements on certain requirement as location or adjacency.
2. The space flexibility and visual requirements have been changed from the space type requirement into space instance requirement. This is because the pre-occupancy evaluation is conducted by the individual occupant of a specific room, so the requirements and feedback for the same types of space may differ. For example, occupants in two labs may have different flexibility requirements or visual requirements because of the different functions of these two labs. In addition, the number of space units is also changed to space type requirements.
3. The indoor climates, acoustic and lighting have been removed from the space type requirements category. This is because the current *user activity simulation model* may not fully provide the relevant information. However this may be reconsidered following further study.
4. Circulation has been added into the space instance requirements. The circulation requirements and related questionnaire will guide the clients to evaluate whether the layout could match the daily workflow based on the *user activity simulation model*.

Table 4.4 The space instance and space type requirements used in PEP

Space instance requirements	Space type requirements
1.Area	1. Activity
2.Number of occupants	2. Wall finish
3.Location	3. Floor finish
4.Adjacency	4. Ceiling
5.Circulation	5. Windows
6.Flexibility	6. Doors
7.Visual	7. Furniture
	8. Equipment
	9. Number of space units

Table 4.4 is the list of space requirements and type requirements to be defined in PEP. The space instance requirements are used to evaluate the factors related to end-user daily activities, such as sizes of space, relationships between activities, movement patterns as well as visual factors.

The space type requirements include activities in the same types of spaces, and the various physical elements such as walls, furniture and equipment. In addition, the number of space units is also defined in the space type requirements.

The relationship between the space instance requirements and space type requirements is shown in Figure 4.15. The space instance requirements are connected to the building model by Room ID. Except for the requirements, there additional information needs to be specified by clients, such as room (space type), room ID, department, occupant name and title.

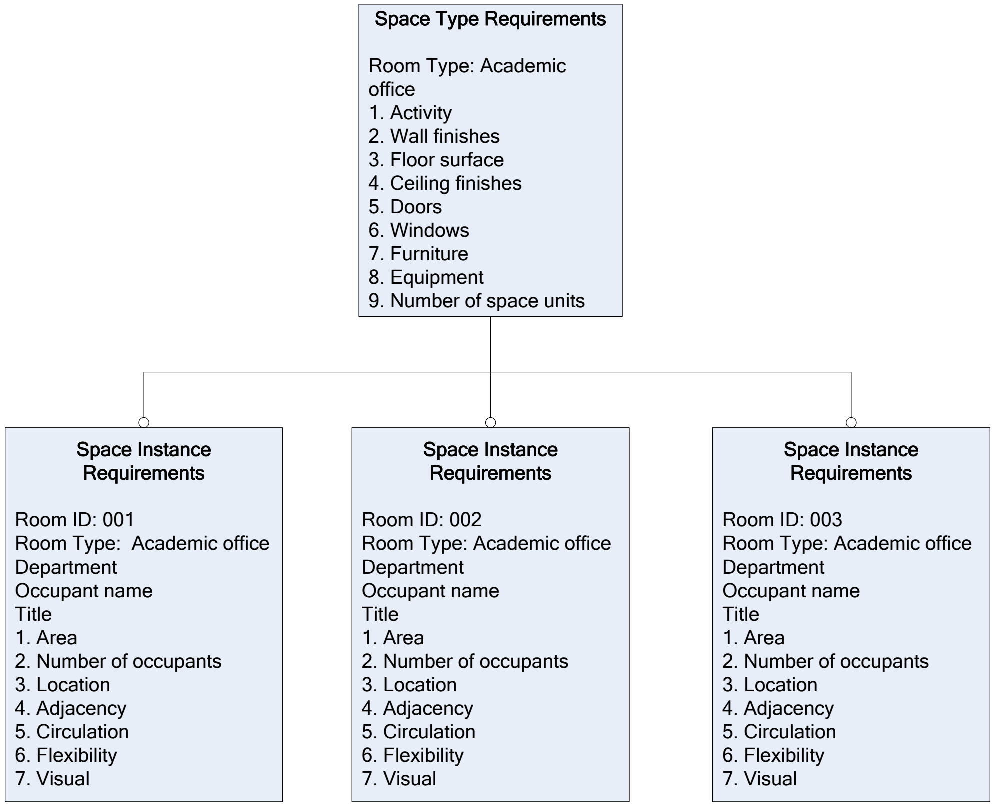


Figure 4.15 The relationship between space type and space instance requirements

4.6.3.3 The Design of Pre-occupancy Evaluation Questionnaire

To enable inexperienced clients to evaluate design solutions against requirements or to specify further requirements, a questionnaire is compiled along with the requirements.

This questionnaire is similar to a post-occupancy evaluation questionnaire survey, but is conducted in the virtual environment. The purpose of the traditional post-occupancy evaluation is to provide feedback on how successful the workplace is at supporting the occupying organization and meeting individual requirements and meeting the brief (if assessing a specific project) (Oseland, 2007). Adapted from the post-occupancy evaluation, the objectives of the pre-occupancy evaluation questionnaire are to:

- Guide the evaluation of the design solution against individual requirements so as to improve the organization's working environment;
- Collect feedback from the occupants as the suggestions for further design improvements.

1. Type of questions

The pre-occupancy evaluation questionnaire in PEP covers different aspects of the building design from workspace design, facilities and support, environmental conditions, work activities and so on. The range of questions is decided by the level of detail utilised by *the user activity simulation model*. In the PEP implementation process it is suggested the questions are compiled by the architects in charge of the project or based on building design and assessment books. Table 4.5 is an example of questions covering various built environment factors.

Table 4.5 An example of pre-occupancy evaluation questions

Type	Pre-occupancy evaluation questions
Workplace design	Dose this room have enough space to work without crowded feeling?
	Can this decoration provide a good brand representation and image?
Environmental conditions	How satisfied are you with the visual privacy of workstation?
	How satisfied are you with the natural light/daylight?
Work activities	Is it easy for you to collaboratively work with your colleagues?
	Is it convenient for you to access e public facilities?
Background	How satisfied are you with the current numbers of occupants?
	How satisfied are you with the current location?
Overall	How satisfied are you with the flexibility of this room?

2. Response scales of the questionnaire

Two typical response scales are used in the post occupancy evaluation questionnaires (Oseland, 2007):

- Multiple choices: a range of options are provided for selection;
- Open-ended scale: a comments box is provided for respondents entering text or data.

There are two types of multiple choice: (1) categorical options: e.g. choosing wall partitions from between “glass partitions”, “brick partitions” to “timber partitions”; and (2) rating scales: e.g. judging the quality of different choices “poor”, “fair” to “good”.

Both multiple choice and open-ended questions have been selected when compiling the pre-occupancy evaluation questions. For the multiple choice questions a labelled/categorical rating scale has been adopted, which consists of a series of progressive, symmetrical and labelled tick boxes, such as “very satisfied”, “satisfied”, “neutral”, “dissatisfied” and “very dissatisfied”. Five-point rating scales are used because it is easy for “respondents to distinguish between the extreme points and middle point of a scale” (Oseland, 2007). On compilation, the questionnaire also covered the requirements of each space instance.

4.6.3.4 Specification of Client Requirements and Feedback

The specification of client requirements and feedback contains two parts: first is the specification for space instance, and the second is for the space type. Table 4.6 illustrates client requirements and feedback specification for a space instance, which contains the following information:

- Pre-defined requirements: these requirements are extracted from the existing project brief. In the early design stages, there may be some basic requirements about the area and number of room units (in the form of a room sheet). During the design-client communication process, new or more specific requirements may be continually generated, thus the database in pre-occupancy evaluation module needs to record the generation and change of project requirements.
- Design solutions: although most of the design information is illustrated by the *user activity simulation model* (including the building model), some of the non-graphical information, such as the area of each room, is extracted from the building model and stored into this requirements and feedback database.

- Client feedback: questionnaires for collecting client feedback on the requirements for each space instance and space type are compiled. For example, "How satisfied are you with the current location" and "Does the layout match your daily workflow" are two typical questions integrated with location and circulation requirements. Clients can either respond at different levels or give comments directly.

Table 4.6 Specification of space instance requirements and feedback

Room ID:	005	**Department:**	BRE
Room name:	Academic office	**Occupant name:**	Allan SHEN
Room type:	Office	**Title:**	Research student

Factors	**Requirements**	**Design solution**	**Feedback from clients**
1. Area	**Minimum area:**	**Actual area:**	**How satisfied are you with the area of this room? (Can you work without crowded feeling?)**
	15 m^2	12 m^2	Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:
2. Number of occupants	**Preferred number:**	**Actual number:**	**How satisfied are you with the current occupant number?**
	1	2	Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:
3. Location	1. Enough daylight for long time desk work; 2. Suitable location in current organization.	Refer to building model	**How satisfied are you with the current location?** Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:

* The movement pattern curve and walking distance (time) are generated by the user activity simulation model.

Table 4.6 (Continued)

4.Adjacency	**Connection preference**	**Has interaction requests from :**	Research office	Refer to *movement pattern curve and walking distance (time) in activity simulation model	**Is it convenient for you to collaboratively work with your colleagues?**
		Avoid interaction from:	Entrance		Very poor/Poor/Neutral/Neural/Good/Very good Comments:
	Using of public facilities	**Has interaction requests from:**	Copy room		**Is it convenient for you to access to the public facilities?**
					Very poor/Poor/Neutral/Neural/Good/Very good Comments:
5. Circulation		1. Should match users' workflow 2. Should not be disturbed by other users' circulation		Refer to *movement pattern curve and walking distance /time	**To what extend does the layout match your daily workflow?**
					Very poor/Poor/Neutral/Neural/Good/Very good Comments:
6. Flexibility of space		1. Alternative finishing 2. Alternative use 3. Division and combination		Refer to building model	**How satisfied are you with the flexibility of this room?**
					Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:
7. Visual requirements		1. Avoid direct external visual contacts 2. Avoid internal visual contacts		Refer to user activity simulation model and building model	**How satisfied are you with the visual requirements?**
					Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:

* The movement pattern curve and walking distance (time) are generated by the user activity simulation model.

Based on the above specification, clients can specify their requirements and give feedback. However, sometimes inexperienced clients do not know how to specify requirements (Luo, 2010), and sample requirements are therefore provided in the specification. These sample requirements can remind clients of typical requirements defined in a brief, and help them develop further requirements regarding their own projects.

The specification of the space type requirement and feedback is similar to the specification of space instance. The difference is that the specification of space type focuses on building elements aspects (Table 4.7).

Table 4.7 Specification of space type requirements and feedback

Space type:			
Factors	**Space type requirements**	**Design solution**	**Feedback from clients**
1.Activity			**How satisfied are you with the type of activity in this room?**
			Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied
			Comments:
2.Wall finish	**Type**	Refer to the building model	**How satisfied are you with the type of wall finish?**
			Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied
			Comments:
3.Floor finish	**Type**		**How satisfied are you with the type of floor finish?**
			Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied
			Comments:
4.Ceiling	**Type**		**How satisfied are you with the type of ceiling?**
			Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied
			Comments:
5.Window	**Type**		**How satisfied are you with the type and number of windows?**
	Number		Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied
			Comments:

Table 4.7 (Continued)

6.Doors	**Type**	Refer to the building model	**How satisfied are you with the type and number of doors?**
	Number		Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:
7.Furniture	**Type**		**How satisfied are you with the type and number of furniture?**
	Number		Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:
8.Equipment	**Type**		**How satisfied are you with the type and number of equipment?**
	Number		Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:
9.Number of space units			**How satisfied are you with the number of this type of room?**
			Very dissatisfied/Dissatisfied/Neutral/Satisfied/Very Satisfied Comments:

4.6.4 Requirements and Feedback Interface

After the end-users have observed their “daily life” via the *user activity simulation model*, they are requested to evaluate the room they “used” and other rooms on which they would like to give comments in the virtual environment. Based on the specifications introduced in Section 4.6.3.4, a *requirements and feedback interface* has been designed to help clients conduct the pre-occupancy evaluation.

This interface is written in C#. During real project implementation, the 2D drawings are imported, and “buttons” are set to represent different rooms on the 2D drawings. The clients select these room buttons to trigger a requirements and feedback form to conduct the pre-occupancy evaluation in each space instance (Figure 4.16). A requirements and feedback form for each space type can be also opened (shown in Figure 4.17).

To save these requirements and feedback from clients, a database was set up (Figure 4.18) to store the following information: (1) pre-defined requirements from the brief; (2) design information; (3) further requirements developed by clients during communication; and (4) client feedback on the design solution.

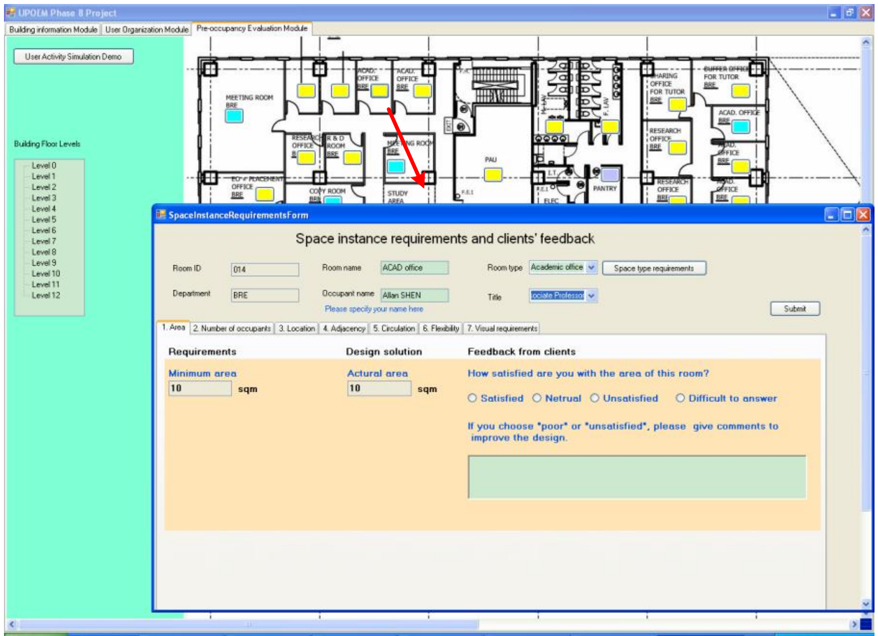


Figure 4.16 Space instance requirements and feedback form

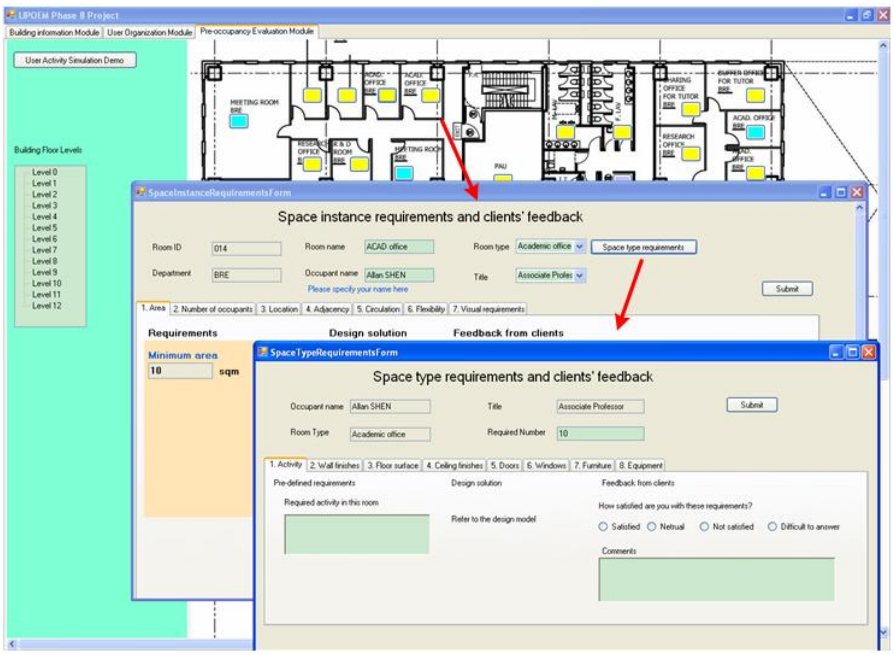
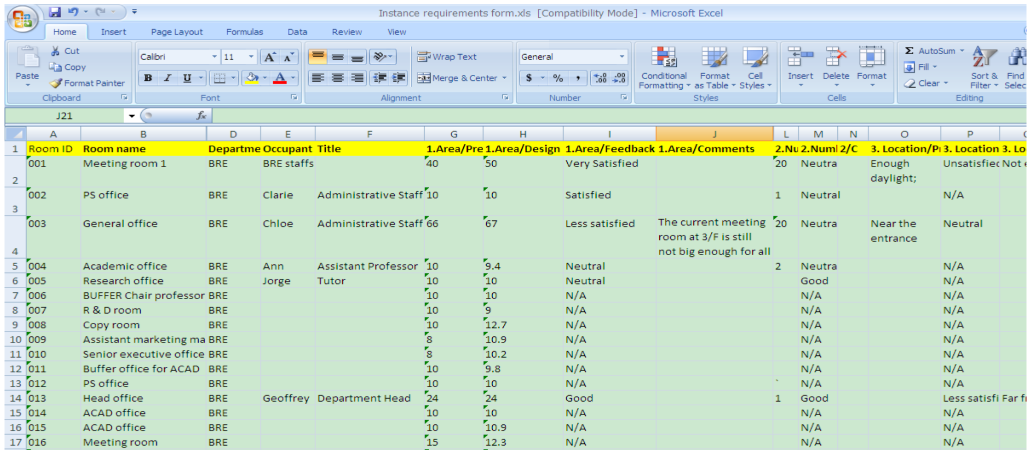


Figure 4.17 Space type requirements and feedback form



Room ID	Room name	Departme	Occupant	Title	1.Area/Pre	1.Area/Design	1.Area/Feedback	1.Area/Comments	2.Nu	2.Numl	2/C	3. Location/P	3. Location	3. Lo
001	Meeting room 1	BRE	BRE staffs		40	50	Very Satisfied		20	Neutra		Enough daylight;	Unsatisfiec	Not
002	PS office	BRE	Clarie	Administrative Staff	10	10	Satisfied		1	Neutral			N/A	
003	General office	BRE	Chloe	Administrative Staff	66	67	Less satisfied	The current meeting room at 3/F is still not big enough for all	20	Neutra		Near the entrance	Neutral	
004	Academic office	BRE	Ann	Assistant Professor	10	9.4	Neutral		2	Neutra			N/A	
005	Research office	BRE	Jorge	Tutor	10	10	Neutral			Good			N/A	
006	BUFFER Chair professor	BRE			10	10	N/A			N/A			N/A	
007	R & D room	BRE			10	9	N/A			N/A			N/A	
008	Copy room	BRE			10	12.7	N/A			N/A			N/A	
009	Assistant marketing ma	BRE			8	10.9	N/A			N/A			N/A	
010	Senior executive office	BRE			8	10.2	N/A			N/A			N/A	
011	Buffer office for ACAD	BRE			10	9.8	N/A			N/A			N/A	
012	PS office	BRE			10	10	N/A			N/A			N/A	
013	Head office	BRE	Geoffrey	Department Head	24	24	Good		1	Good			Less satisfi	Far f
014	ACAD office	BRE			10	10	N/A			N/A			N/A	
015	ACAD office	BRE			10	10.9	N/A			N/A			N/A	
016	Meeting room	BRE			15	12.3	N/A			N/A			N/A	

Figure 4.18 An example of the client requirements and feedback database

Because the *requirements and feedback interface* can retrieve information from the database, and also save input by clients, the clients can easily check the pre-defined requirements and give feedback during designer-client communication. The categorization of space instance and space type allows clients to comment on the same types of space instance by a single input. This saves much time and improves the evaluation efficiency. In addition, the specific requirements and comments from clients are saved in the database and sorted by room ID (in the form of Excel files), enabling designers to easily access the files and find relevant records.

4.6.5 Implementation of Pre-occupancy Evaluation

4.6.5.1 Pre-occupancy Evaluation in Virtual Environment

The pre-occupancy evaluation in PEP is based on the *user activity simulation model* and facilitated by the *requirements and feedback interface*. Table 4.8 and Table 4.9 list the details of evaluation methods for clients to compare design solution with requirements, from different aspects.

The *user activity simulation model* and the *requirements and feedback interface* are used jointly to support the evaluation process during the design stage.

Table 4.8 Pre-occupancy evaluation method based on space instance requirements

Space instance requirements	Evaluation method
1.Area	Clients obtain the information of area from the *user activity simulation model* (annotation) or the area information in the *requirements and feedback interface*. The pre-occupancy evaluation (POE) questionnaire is intended to collect users' feeling of the spaciousness as well as the feedback on whether they are satisfied with the area or not.
2.Occupants	The POE questionnaire is intended to collect client satisfaction with the arrangement of the occupant type and number of the current design solution.
3.Location	Clients obtain the information of location from the *user activity simulation model* or the location information in the client *requirements and feedback interface*. The POE questionnaire is intended to collect users' satisfaction with the current location.
4.Adjacency	Clients obtain the information of adjacency from the *user activity simulation model* (movement tracing curve). The POE questionnaire is intended to collect client satisfaction with the current adjacency.
5.Circulation	Clients obtain the information of workflow from the *user activity simulation model* (movement tracing curve). The POE questionnaire is intended to collect client satisfaction with the circulation.
6.Flexibility	Clients observe the building model in the *user activity simulation model*. The POE questionnaire is intended to collect client satisfaction with the flexibility of each functional room.
7.Visual	Clients obtain the information of visual private from the *user activity simulation model* (first person angle or observation angle). The POE questionnaire is intended to collect client satisfaction with the flexibility of each functional room.

Table 4.9 Pre-occupancy evaluation method based on space type requirements

Space type requirements	Evaluation method
1.Activity 2.Wall finishes 3.Floor surface 4.Ceiling finishes 5.Doors 6.Windows 7.Furniture 8.Equipment 9.Number of space units	Clients obtain the information of these building elements from the *user activity simulation model* and the *requirements and feedback interface*. The POE questionnaire collects client satisfaction levels with the type and number of the design solution.

4.6.5.2 Collection of Client Feedback for Improving Design Solutions

In the traditional designer-client communication process, 2D drawings and 3D effect drawings are used to convey client requirements and designer intentions. Designers usually record client feedback in the form of notes, sketches and other documents. The information exchange process between designers and clients lasts until a satisfactory design solution is generated.

The pre-occupancy evaluation in PEP is also a dynamic and interactive process which aims to improve the design solution (Figure 4.19). In this process, the virtual environment is first established based on some pre-defined requirements (for example, the space program given by clients containing the basic requirements on spatial requirements as required area, number of rooms and adjacency requirements).

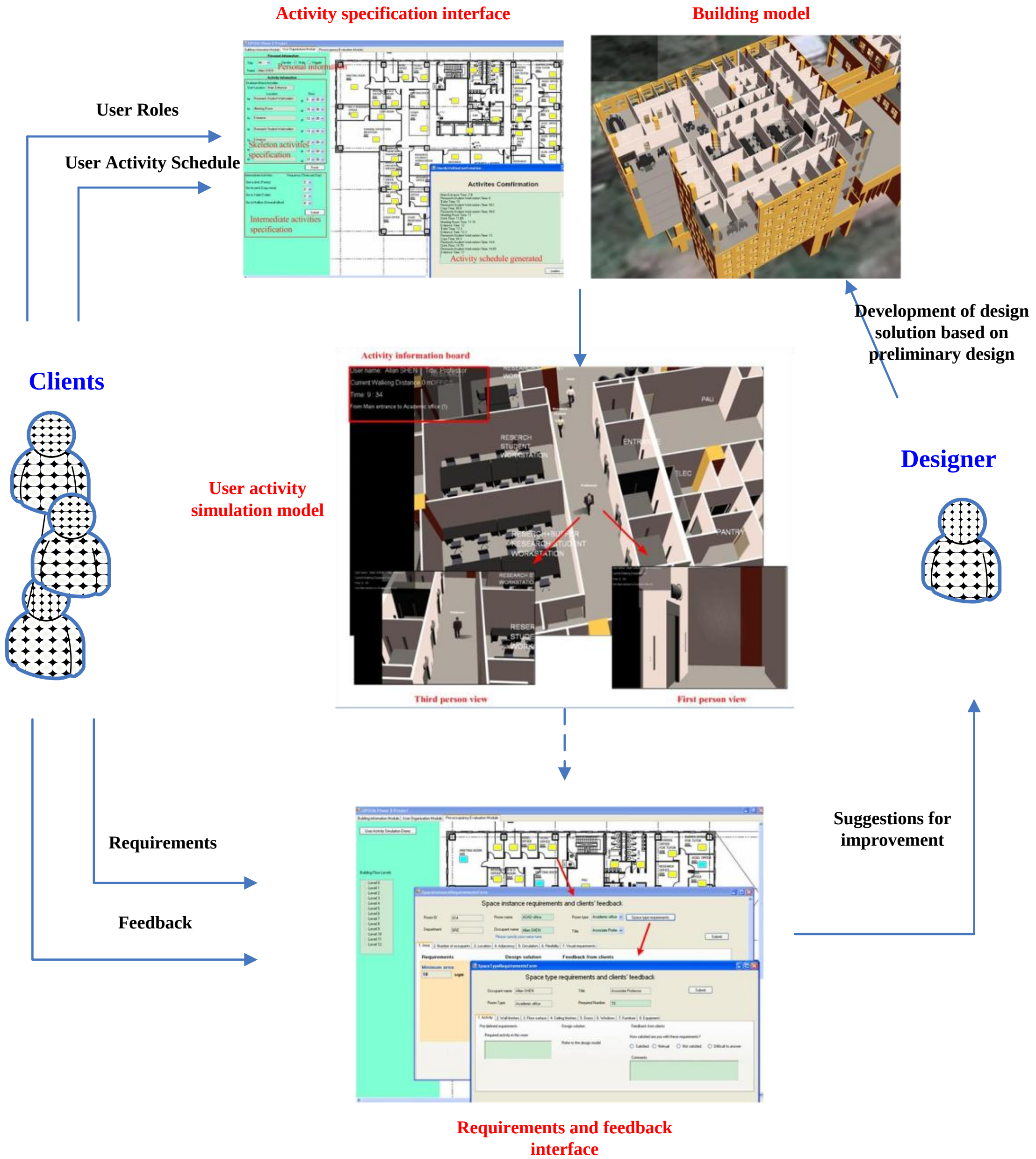


Figure 4.19 The implementation of pre-occupancy evaluation

The *user activity simulation model* is then generated. After observing the simulated end-user activities clients are expected to have an understanding of the built environment and how the daily activities would be accommodated. The feedback generated from clients is stored in the database for designers to conduct related modification. During development of the design solutions, the *user activity simulation model* and the *requirements and feedback database* are continually updated. This allows the clients to understand the impact of the design development on their daily activities. At the same time, changes of requirements and feedback can be monitored during the designer-client communication.

4.6.6 Expected Benefits of the Pre-occupancy Evaluation Module

1. Improve the effectiveness and efficiency of designer-client communication

Because the *requirements and feedback interface* facilitates requirements specification and further feedback on the design in a systematic manner, it is expected that designer-client communication will be more efficient and effective. The validation of the impact of the application of the PEP in real project is introduced in Chapter 5.

2. Connection with BIM tools

As introduced in Section 4.6.4, the database connected with the requirements and feedback interface, contains all the information generated by clients. This database also has the potential to be linked with the BIM tools database containing building information, such as room areas and building element materials. At the same time, the requirements and feedback regarding each space unit can be added as part of the attributes of the building elements. This database therefore provides the possibility of synchronizing client requirement information and feedback with the building information model (Figure 4.20). This enables designers to review design solutions and make revisions more effectively.

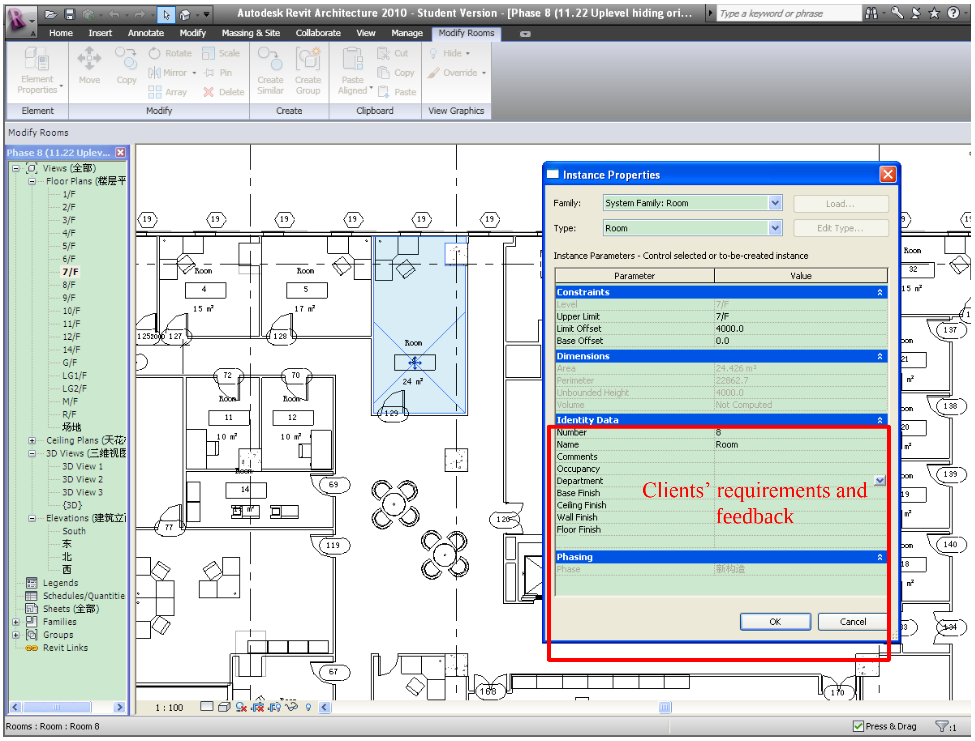


Figure 4.20 Link the database with room attributes in Revit Architecture

4.7 Process of Applying PEP in Real Projects

In practice, PEP is expected to be applied in supporting architectural design consultation meetings, in which designers (architects) and clients are the main participants. The clients can include the stakeholders who have set up the architectural design requirements as well as the end-users. The latter are invited to review the design solutions and give comment. It is expected that client satisfaction could be improved by formalised collaboration with the designers. The scope of projects suitable for the application of PEP includes such as office buildings, the scope of which, currently, incorporates such as commercial or teaching buildings.

4.7.1 Timing of Applying PEP

PEP is usually applied after the preliminary design proposal has been generated by the designer. The clients then need to work with the designers in evaluating the design solutions. The frequency of such interactions normally depends on the scope of the project and duration of the design period. Sometimes this continues until the design solution is finalized.

It is suggested that the PEP should be applied as early as possible, so that the client has a better understanding of the design proposal, and the designers obtain clear feedback from the client. As the design solution develops more information (building elements) will be incorporated and the intended state of the built environment continually updated. The clients can also give comments on design solutions as they develop.

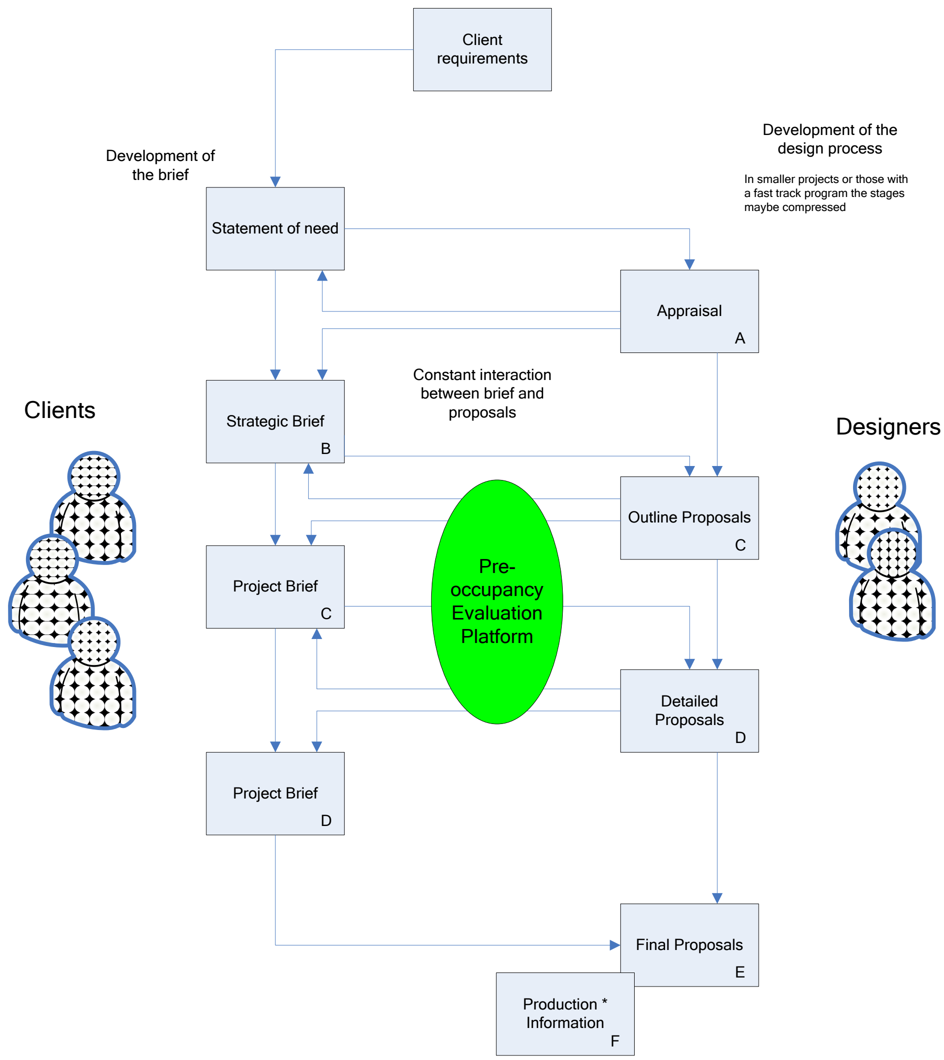


Figure 4.21 The timing of the application of PEP in the design stage

(adapted from: RIBA, 2000)

4.7.2 An Application Guideline

As illustrated in Figure 4.19, there are four main steps in conducting a pre-occupancy evaluation using PEP:

Step 1: Preparing the building information model

Based on the preliminary drawings given by designers, the building information model is built by BIM tools in this step (If there is no applicable building information model provided by designers). When clients give feedback on the design solutions, the building models need to be updated for further evaluation.

Step 2: Specification of user activities

By using the tools in user organization information module, end-users specify their activities and use of functional spaces in a specific day. This process sometimes should be under the support from facility management department. Then the end-users activities are scheduled according to their daily working routines. Thus the outcome of this step is the provision of end-user activity schedules.

Step 3: Simulation of the user activities

Based on the building models and user activity schedules generated in the first two steps, the activity simulation model is generated via the virtual prototyping tools. Various functions are provided in the virtual environment enabling clients to gain a better understanding of their future working environment.

Step 4: Pre-occupancy evaluation

Based on the virtual built environment, client feedback and further requirements are collected in this step via the *requirements and feedback interface*. The evaluation criteria are based on the building project requirements. A database has also been designed to record and manage feedback on the client's requirements.

After Step 4 the whole process starts again from Step 1 until a satisfactory solution is generated (see Figure 4.22). In this iterative process, Step 2 (specification of user activities) needs to be conducted only once. The application of PEP is shown in Figure 4.23. This guideline illustrates the input and output of each step as well as the relationship between them.

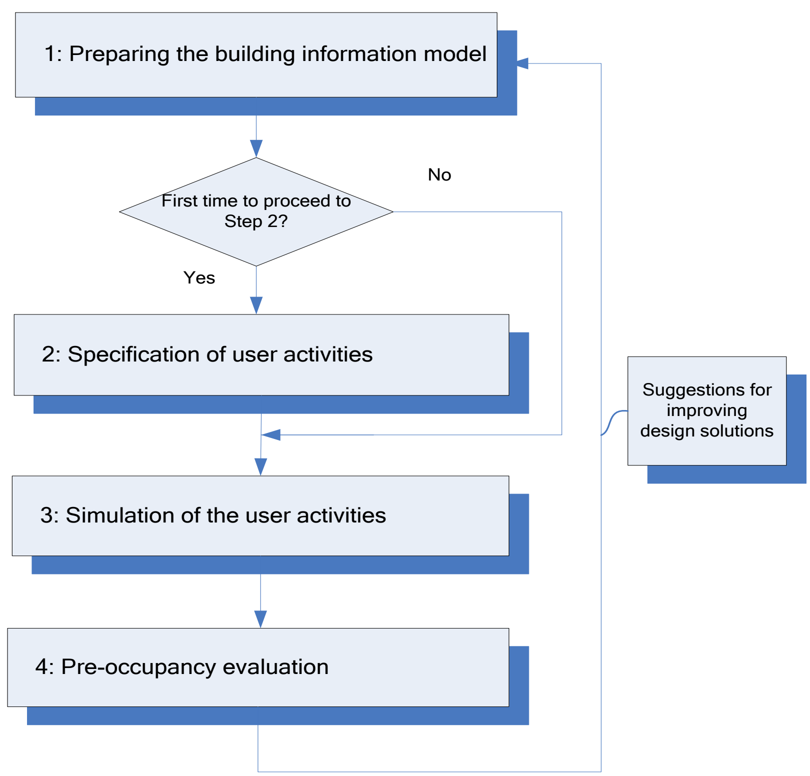


Figure 4.22 Four steps in the application of PEP

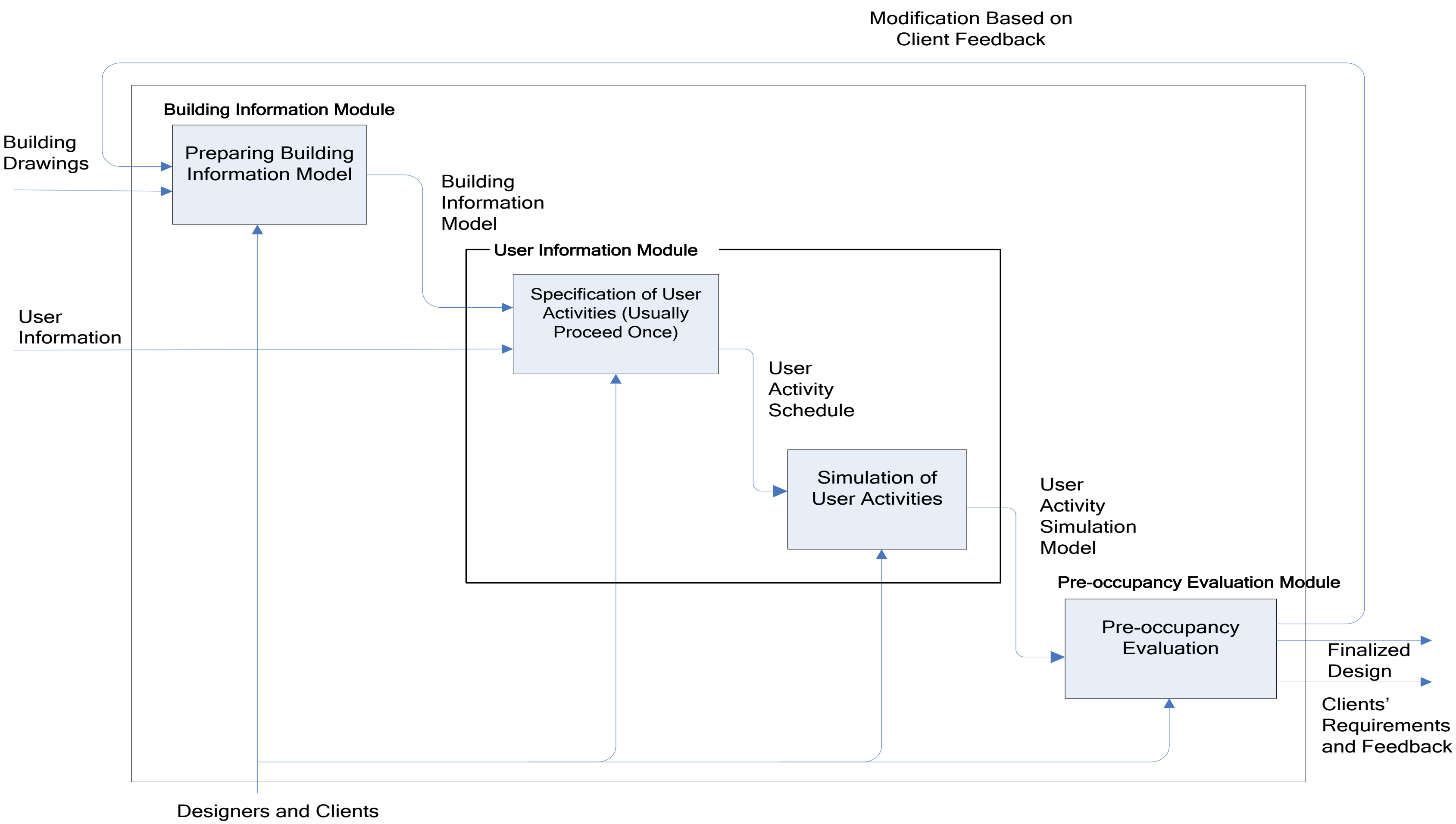


Figure 4.23 Guideline for applying PEP in projects

4.8 Summary

This chapter first introduced the rationale, architecture, and components of PEP, and also specified the requirements needed to be satisfied during the development process.

Then the details of the three modules contained in PEP were given, including the process of creating the building models used in PEP, the theory and method for scheduling the end-user activities, the method to simulate these activities in virtual environment, and how to conduct pre-occupancy evaluation supported by the virtual environment as well as the related user interface. The benefits of applying user information module and the pre-occupancy evaluation module are also summarized.

Also introduced in this chapter are the application timing, suitable project types and framework used when applying the PEP in real projects.

Chapter 5 Validation of PEP

5.1 Introduction

The focus of this validation is to investigate to what extent the PEP can improve client performance. Before the validation, the major criteria for measuring performance should be defined. A similar type of computer technology application for improving group performance is the group decision support system (GDSS).

DeSanctis and Galluple (1987) defined GDSS as "a computer technology that combines computing, communication, and decision support technologies to facilitate the formulation and solution of unstructured problems by a group of people". Researchers have also elaborated the aim of GDSS as "to improve the process of group decision making by removing common communication barriers, providing techniques for structuring decision analysis, and systematically directing the pattern, timing or content of discussion" (Fan, 2009).

Similarly, the PEP of this research applies computer simulation technology to build a virtual environment and employs a user interface to support designer-client communication. The factors suitable for measuring the effectiveness of a GDSS in enhancing participant performance were also adopted for this validation process.

Following the approach of Drazin and Van de Ven (1985), Benbasat and Lim (1993), Dennis and Kinney (1998), and Dennis and Wixom (2002), Fan (2009) defined the major factors to be effectiveness, efficiency and participant satisfaction when assessing the performance of GDSS. More specifically, researchers have suggested using the quality and number of ideas generated by the participants, the time for completing the task as well as participant satisfaction with the process and outcome as ways of measuring performance in relation to the three factors mentioned above (Dennis and Wixom, 2002).

Thus to validate the effectiveness of PEP in improving client performance, the number and content of the comments fed back by clients has been analyzed. In addition, participant satisfaction and the duration of the processes of communication have been considered.

5.2 Overview of Experimental Studies

The validation process is based on the real campus project in the Hong Kong Polytechnic University (Figure 5.1), of a teaching building called “Phase 8”. During this research, this project was at its briefing and design stage.

Phase 8 is located to the northwest of the Hong Kong Polytechnic University campus.

“Upon completion, the development will provide approximately 25,600 m^2 *net floor area for implementation of the new “3+3+4” academic system and other academic development. It will provide general teaching facilities including lecture theatres and classrooms; teaching and research laboratories; conference facilities; office accommodation; and amenities facilities including cafeteria, studio lounge and activities rooms” (Phase 8, 2011).*

Figure 5.1 An effect drawing of the Phase 8 project

The Department of Building and Real Estate (BRE) will be housed on the 7th floor of Phase 8. Therefore some future end-users from the BRE department were invited to attend workshops. Within these workshops, they discussed the floor plan (7th floor) with the architects in charge of this project from the Campus Development Office (CDO) of the university.

The PEP was employed in these workshops and compared with the traditional designer-client communication method supported by 3D models. The objectives of the workshops were to evaluate the effect of PEP in improving the effectiveness and efficiency of designer-client communication as well as client satisfaction and to compare findings with those of the traditional method.

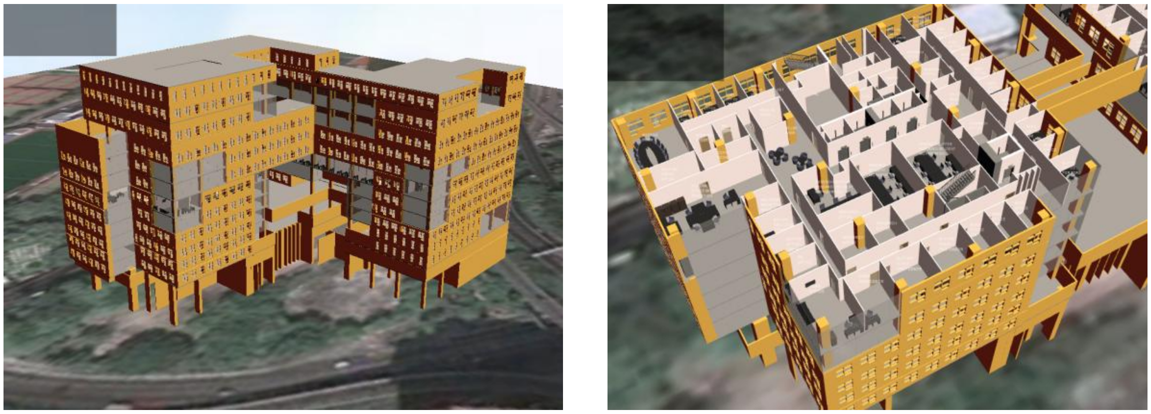


Figure 5.2 Application of PEP in Phase 8 project

The two methods of comparative experiment and questionnaire survey were used in this validation. The comparative experiment was intended to compare client efficiency and effectiveness performance. The questionnaire survey was used to collect the client feedback while using the PEP.

For the comparative experiment, two experimental studies (*Experimental study I and II)* were designed. The framework of validation is shown in Figure 5.3.

Experimental study I was a pilot study, within which small workshops were arranged, focussing on the questionnaire survey in relation to the effectiveness of the *user activity simulation model* in improving client understanding of design solutions. The *Requirements and feedback interface* was also tested, and suggestions were summarized for achieving more reliable results in *Experimental study II*.

The purpose of *Experimental study II* was to compare the quantity and content of traditional client feedback communication with that of PEP. A Questionnaire survey was also administered to collect the client feedback following use of the PEP in *Experimental study II*.

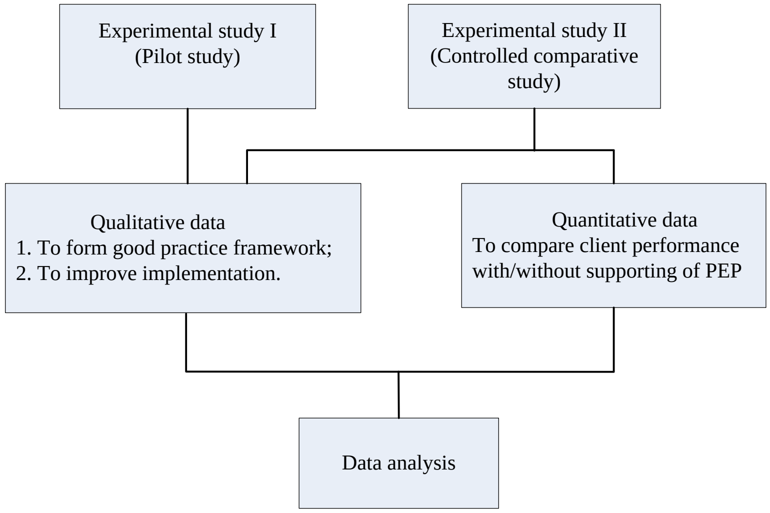


Figure 5.3 Framework of validation

5.3 Experimental Study I

5.3.1 Design of Experimental Study I

Three groups of end-users (10 for each group) from the Department of Building and Real Estate were invited to discuss the design with architects. Each group of end-users was involved in one workshop relating to the roles played by professors, research staff and research students (different roles have different types of working routines). Each time, a facilitator explained how to apply PEP and facilitated the entire workshop process. The procedure adopted at each workshop is as follows:

Preparation: before the demonstration, end-users had been asked to input organizational information and information related to daily activity schedules for a specific day via the user information module. The activity schedules for different users were then generated, based on the algorithm discussed in Section 4.5.1. Thus the *user activity simulation model* demonstrated the working scenarios for these end-users for the day specified.

Demonstration: the designer demonstrated the 7th floor plan in two steps:

- The conventional *3D model* was used to demonstrate the floor plan and enable participants to study the model via the normal modes of zoom in, zoom out, rotate and move;
- The *user activity simulation model* was used to demonstrate how the users would conduct their activities during the specified working day.

Interaction with the activity simulation model: after using the conventional 3D building model, participants were taught by the facilitator how to control the interface of

PEP and how to interact with the activity simulation model. This training was to ensure effective use of the observation functions provided by the activity simulation model so as to better understand the design.

After training, each participant observed the building model by following the avatar representing her or his role in the organization. Thus the participants 'experience' the built environment as if they had already moved into the building. The activity information board at the top-left of the screen reminds them of the nature of their current activity and how far they have walked so far. The simulation duration of one 8 hour working day is proportionally shortened to about 16 minutes. During the simulation runs, participants can switch between observation angles and zoom in and zoom out using a keyboard or mouse.

Giving feedback on the design: in this step, the participants specify their requirements and provide feedback on the design via the *requirements and feedback interface*.

5.3.2 Questionnaire Survey of Participant Feedback

At the end of each workshop, a questionnaire survey was conducted to compare the different impacts on participant experience of use of the conventional 3D building model and activity simulation model. The questionnaire results are summarized in Table 5.1 for thirty participants.

Table 5.1 Summary of the questionnaire survey of participant feedback

Statements asked in questionnaire		Standard deviation	Average rating
Overall understanding	Q1: The simulation of user activity can give me better understanding of the arrangement of the layout.	0.58	4.00
	Q2: The simulation of user activity can give me better understanding of my working environment.	0.58	4.00
	Q3: The simulation of user activity can give me better understanding of the function of the each functional space.	0.90	3.85
	Q4: The activity information board (the user name, title, walking distance, activities and time) can give me better understanding of how our organization accommodated in the given building.	0.69	3.85
Size and adjacency	Q5: The avatars can give me stronger sense of scale (size of room, width of the corridor).	0.63	3.69
	Q6: The avatars' movement can give me stronger sense of the distance.	0.65	3.62
	Q7: The movement pattern curve can give me stronger sense of the connections between different activities and help me understand the allocation of different rooms.	0.86	3.92
	Q8: The simulation of user activity can give me better understanding of the circulation pattern in the layout.	0.51	3.62
Appearance and view	Q9: The multiple observation method provided by the activity simulation model can help me understand the appearance of the external building and the interior decoration more clearly.	0.97	3.54
	Q10: The multiple observation method provided by the activity simulation model can help me have the view outside my office more clearly.	0.88	3.54
Involvement	Q11: I would be more interested and willingness to collaborate with the designers to improve the design (e.g. design consultation meeting) while using activity simulation model.	0.76	4.08
	Q12: I would be more confident to express my requirements and feedback on the design while using activity simulation model.	0.76	3.92

1: Strongly Disagree; 2 Disagree; 3: Neutral; 4: Agree; 5: Strongly Agree

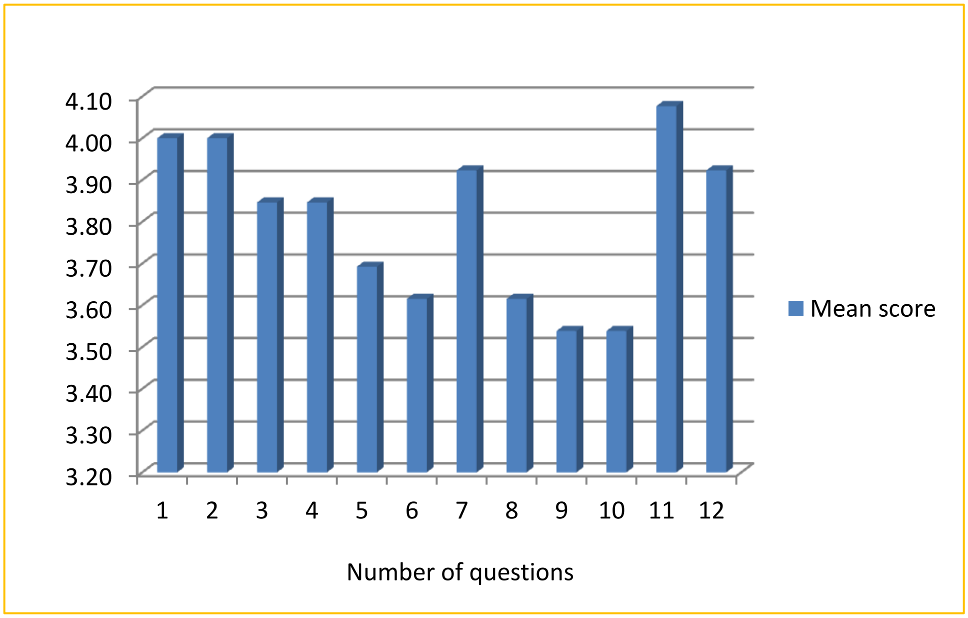


Figure 5.4 The score of each statement in the questionnaire survey

(Experimental Study I)

5.3.3 Findings of Experimental Study I

The result of the questionnaire survey in *Experimental study I* (Figure 5.4) have shown that most participants agreed that the activity simulation model helps them have a better overall understanding of their working environment, which includes the layout arrangement, function of each room and how they are accommodated in the given building. With respect to spatial properties, participants achieve a better sense of scale and distance, as well as better understanding of the connections between different rooms and circulation patterns. An increase in participant willingness and confidence to collaboratively work with designers was also agreed by most of the respondents.

However, the scores for questions 9 and 10 (appearance and view) are relatively low. The reason may be that participants can achieve the same level of understanding when observing traditional 3D models when assessing the appearance of a building. As to the exterior view the participants may have had difficulty in using the observation tools smoothly, such as switch to the first person view to observe the view outside. Therefore, it appears that the simulation of user activities has enhanced user understanding of the functional factors to a larger extent than the visual factors.

Another finding is that when interacting with activity simulation models, participants need to learn how to observe the model via keyboard and mouse. Due to the variations in learning speed and computer proficiency, participant performances differ. The participants who are more skilful at controlling via keyboard and mouse use more modes when studying the activity simulation model. By contrast, the less skilful participants interact less with the models. They may follow only the movements of avatars without further interaction (e.g. zoom in, zoom out, rotate or direct control of the avatar).

Thus among other things, one of the suggestions for *Experimental study II* is to provide sufficient time for training and practice to enable inexperienced users to interact with the activity simulation model. If end-users are not able to control the model smoothly, their understanding of the built environment will be affected, especially under the time constraint exerted by a workshop.

5.4 Experimental Study II

The purpose of *Experimental study II* is to compare the quantity and content of the feedback generated by clients when communication is supported by PEP and when the conventional process, supported by 3D models applies. A questionnaire survey was also administered to collect client feedback when using the PEP.

There are many representation methods applied in conventional communication, such as 2D drawings, sketches, and 3D effect drawings. The reason for choosing a 3D building model rather than 2D or 3D effect drawings is that the *user activity simulation model* in PEP combines use of a 3D building model with user activity simulation. If it is compared with the 2D drawings, the different impact on client understanding or number of client feedback may be caused by the distinction between 3D models and 2D drawings. For the purpose to analyze the effect of user activity simulation, the 3D models are selected to support the conventional designer-client communication.

The 3D building models used in this study were created by BIM tools such as Revit Architecture (Revit, 2011). To help clients interact with 3D models, the Autodesk Design Review Software (Autodesk, 2011) was used to view and mark up design models.

5.4.1 Hypothesis for Experimental Study II

As discussed in Section 4.5.3 and Section 4.6.6, the *user activity simulation model* has the potential to enhance user virtual experience, and the *requirements and feedback interface* can facilitate the design review process. The clients, therefore, are expected to have a better understanding of the design and to generate more feedback (assuming design solutions do have deficiencies).

Therefore, the primary hypothesis to be tested in Experimental study II is:

Clients supported by PEP during communication with designers, will generate more suggestions for improving design solutions than in the case when conventional communication methods apply.

The definition of "suggestions for improving the design" is specified as: (1) Unsatisfied requirements discovered during design-client communication; and (2) Further requirements specified during designer-client communication.

5.4.2 Design of Experiment Study II

Participants

Two groups of end-users were invited (Groups A and B) to discuss the layout design of the 7th floor for the new "Phase 8" project introduced above. There were 10 end-users in each group, representing the main functions of the Department on this floor. In addition, one designer and one facilitator were involved. Table 5.2 shows the roles and numbers of participants, who were randomly selected and shortlisted against two criteria: (1) have little or no architectural design experience; and (2) have not previously seen the drawings used in the experiment.

Table 5.2 Participants in each group

Title	Number
Academic staff	4
Administrative staff	3
Research students	3
Architectural designer	1
Facilitator	1
Total	12

Each group of end-user attended one workshop (Figure 5.5). Within each workshop, participants were requested to review two drawings successively with the designer (*Task 1* and *Task 2*). These drawings were two different 7th floor plan versions, which contained mainly architectural information. *Task 1* relates to the first version of the floor plan and *Task 2* to the 6th version following several revisions based on campus development office comments. Compared with the finalized version, both of these two drawings have deficiencies and unsatisfactory features from the architectural aspect.

Figure 5.5 Two workshops: Group A and Group B

Framework of experimental study II

In the first workshop, Group A evaluated the first version in the conventional way and then the 6th version using PEP. In the second workshop, Group B reviewed the first version using PEP first, and then the 6th version conventionally. The duration of the design review process in each case was limited to 20 minutes, including both time for reading drawing/model as well as giving comments.

The reason for this cross-comparison method (Table 5.3) was to avoid any one group reading a drawing more than once. In addition, although it is assumed that two groups of participants were "similar" in that they were selected randomly and were inexperienced clients, there might be specific factors affecting the quantities of feedback generated. For instance, if one group carried out only a PEP review and the second group only a conventional 3-D model review, it is possible one group would be more critical by nature than the other group, affecting the reliability of the comparison. Therefore each group was required to use both review methods in one workshop.

Table 5.3 Framework of the experimental study II

	Workshop 1 (Group A)	Workshop 2 (Group B)
Task 1 (1st version floor plan)	Conventional method	PEP
Task 2 (6th version floor plan)	PEP	Conventional method

Variables and measures

The comparison between the two methods is based on the feedback generated on each task. The independent variables are the supporting methods employed. For example, as shown in Table 5.3, the first plan version was evaluated separately by Group A using the conventional method and by Group B using PEP. Thus the independent variable is the difference in method. The dependent variable is the quantity of feedback (suggestions for improving the design) generated by each group of participants on the same task.

5.4.3 Procedures of Implementing PEP and Conventional Method

5.4.3.1 PEP Application Procedure

The procedure is similar to that for Experimental study I, which also contains four steps.

Pre-workshop preparation: End-users are invited to specify their activities in one working day. They may be asked to describe a "busy" working day in their organization, so more scenarios can be simulated in the model. The *user activity simulation model* is then generated, which can simulate the 10 user daily activities. The activity scenarios (presented in forms of animation) include daily working desk activities, meetings, use of copying machine, use of pantry, as well as movements between different rooms.

Demonstration: The architect or facilitator briefly introduced the design solutions in terms of spatial function, to give the participants a general understanding of the intention of the design.

Interaction with the activity simulation model: Participants had been trained to observe their own daily activity via the *user activity simulation model*. They then interacted with the *user activity simulation model* under the guidance of the facilitator (similar to Section 5.3.1). 2D drawings were also provided as an alternative representation for the participants.

Giving feedback on the design: After observing the activity model, each participant was invited to evaluate the design and give comments via the *requirements and feedback interface* of the pre-occupancy evaluation module. A video camera was used to record verbal comments generated during the workshop.

5.4.3.2 Procedure for Conventional Communication Method Using 3D Model

Demonstration: The architect or facilitator briefly introduced the design solutions in terms of spatial function, to give the end-users a general understanding of the design intention.

Review of the 3D building model: Before the design evaluation process, the participants had been trained to use the 3D building model via Design Review. A 2D drawing was also provided as an alternative representation for the participants.

Giving feedback on the design: After observing the building model, end-users were invited to express their feedback on the design. They either wrote comments on blank paper or spoke out. A video camera was used at all times to record verbal comments generated during the workshop.

5.4.4 Result of Experimental Study II

5.4.4.1 Record of the Participants' Feedback

The record of feedback generated by participants during these two workshops is shown in the tables below. Table 5.4 shows the feedback of the two groups in relation to *Task 1*, the first plan version: one group used PEP and the other reviewed in the conventional manner.

Table 5.4 Result of Task 1

Factors	Group A (PEP)			Group B (3D Model)		
	Unsatisfied requirements	Further requirements	Sub total	Unsatisfied requirements	Further requirements	Sub total
Area	0	3	3	0	0	0
Occupants	0	0	0	0	0	0
Location	3	0	3	1	0	1
Adjacency	4	0	4	1	0	1
Circulation	0	0	0	0	0	0
Flexibility	0	2	2	0	0	0
Visual	1	0	1	0	0	0
Activity/function	0	0	0	0	0	0
Wall finish	2	0	2	0	0	0
Number of space units	2	3	5	1	0	0
Windows/doors	0	0	0	0	0	0
Total	12	8	**20**	3	0	**3**

Table 5.5 Result of Task 2

Factors	Group A (3D Model)			Group B (PEP)		
	Unsatisfied requirements	Further requirements	Sub total	Unsatisfied requirements	Further requirements	Sub total
Area	0	0	0	2	0	2
Occupants	0	0	0	0	0	0
Location	0	0	0	2	0	2
Adjacency	0	0	0	4	0	4
Circulation	1	0	1	1	0	1
Flexibility	0	0	0	0	0	0
Visual	0	0	0	0	0	0
Activity/function	0	0	0	0	0	0
Wall finish	1	0	1	0	0	0
Number of space units	0	0	0	1	0	1
Windows/doors	0	0	0	1	0	1
Total	2	0	**2**	11	0	**11**

Table 5.6 Summary of the results in the two tasks

		Group A (10)		Group B(10)	
Task 1	Unsatisfied requirements	PEP	12	3D Model	3
	Further requirements		8		0
	Total		20		3
	Mean		2		0.30
	Standard deviation		1.63		0.67
	Mann-Whitney (mean rank)		13.55		7.45
	Significance	p=0.019<0.05[a]			
Task 2	Unsatisfied requirements	3D Model	2	PEP	11
	Further requirements		0		0
	Total		2		11
	Mean		0.20		1.10
	Standard deviation		0.42		1.10
	Mann-Whitney (mean rank)		7.40		13.60
	Significance	p=0.019<0.05[a]			

a Significant at the 0.05 level.

5.4.4.2 Findings of the Comparative Experiment

Finding from the record of client feedback generated during the workshop:

1. The total number of feedback comments generated when PEP is used is larger than for the conventional review method. Table 5.6 shows that during the design review process of *Task 1*, Group A when using PEP generated 20 suggestions for improvement; by contrast, Group B generated only 3 suggestions. In the design review process of *Task 2*, Group A who this time reviewed conventionally generated only 2 suggestions, whereas Group B, making use of PEP, generated 11

suggestions. Because the number of feedback suggestions generated was not normally distributed and the two groups of suggestions are independent, the nonparametric Mann-Whitney (M2) mean rank tests were used to test for significance of the differences. The result shows that in both workshops, the numbers of feedback comments generated by PEP using groups is statistically larger than for non PEP using groups.

2. To analyze the content of participant feedback, it can be found that, in both Task 1 and Task 2, the group supported by PEP generated greater amounts of feedback in the relation to area, location, adjacency and number of space units. Detailed explanation is as follows:

   Area: The questionnaire survey in Study II showed that avatars can provide the sense of scale to a room, such that participants can feel crowded or otherwise. The pre-occupancy evaluation questionnaire asked "Can you work without crowded feeling in this room?" guided the participants to evaluate spaciousness issues. Table 5.4 and Table 5.5 show that, for both Task 1 and Task 2, participants supported by PEP were able to identify more cases of unsatisfactory space provision in the design.

   Location and adjacency: The Study II survey indicated that the simulation of occupant movements and the tracing curves give participants a stronger sense of distance and connection between different rooms. The pre-occupancy evaluation questionnaire asked "Is it convenient for you to collaboratively work with your colleagues?" and "How satisfied are you with the current location?" also prompted participants to specify their requirements and give feedback on issues of location and adjacency. Table 5.4 and Table 5.5 also show that, when participants used PEP they identified greater numbers of the stated requirements to be unsatisfactorily provided for in relation to both Task 1 and Task 2;

Other factors: In addition to area, location and adjacency mentioned above, larger quantities of feedback were also generated in respect of other factors. Referring to the result of the comparative experiment (Task 1), it was found that PEP causes participants to identify more cases of unsatisfactory requirements on space unit provision and suggestions for further requirements. For example, after observing their daily activities some participants found that with only one pantry on one side of the floor, occupants from the other side of the floor had to walk a long way for a drink. In addition, the PEP groups generated more feedback about such factors as flexibility, wall finishes, number of windows, circulation pattern as well as visual issues. Differences in these factors, however, are less than the previous factors.

Findings of the facilitator

Since there was one facilitator for each workshop, their observations on participant performance and reactions are summarized below:

1. Integration of the working scenario helps participants, efficiently, to become familiar with the building model. Although the use of 3D models (e.g. as generated by Revit or 3ds MAX) gives participants a better understanding of the building elements and the layout than the use of 2D drawings, there are still some difficulties in understanding how the building will function. For example, clients

may need a certain period of time to become familiar with the location of different functional rooms and the relationships between them even in the 3D virtual environment. It is also not easy, in a short time, to combine building elements and spaces together so as to mentally visualise how the building will function when in use. Thus the simulation and demonstration of end-user daily activities, which enhance this understanding, make a significant contribution to narrowing the gap.

2. The pre-occupancy evaluation questionnaire is important in guiding participants when reviewing design solutions. Because these clients are “inexperienced” compared with professional designers, sometimes they do not know “what is wrong with this drawing”. In fact, they do not know “what they really want” or how to express their requirements. Therefore specification of categories of requirements and implementation of the pre-occupancy evaluation questionnaire are crucial in guiding the review process. It is found that using the questionnaire to systematically collect participant feedback leads to the gathering of more feedback than to simply ask “How do you feel about this design”.

5.4.5 Survey of Participant Feedback

5.4.5.1 Questionnaire Survey

A questionnaire survey of 17 questions was answered by the 20 participants in Groups A and B. This questionnaire included an additional question type based on the questionnaire in Experimental Study I. There were five categories of question (1) overall understanding, (2) size and adjacency, (3) appearance and view, (4) Involvement of participants and (5) process of requirements specification and design review.

Table 5.7 Summary of survey result

Statements asked in questionnaire		Standard Deviation	Average rating
Overall understanding	Q1: The simulation of user activity can give me better understanding of the arrangement of the layout.	0.60	4.16
	Q2: The simulation of user activity can give me better understanding of my working environment.	0.60	3.84
	Q3: The simulation of user activity can give me better understanding of the function of the each functional space.	0.71	3.79
	Q4: The activity information board (the user name, title, walking distance, activities and time) can give me better understanding of how our organization accommodated in the given building.	0.80	3.74
Size and adjacency	Q5: The avatars can give me stronger sense of scale (size of room, width of the corridor).	0.56	3.74
	Q6: The avatars' movement can give me stronger sense of the distance.	0.50	3.84
	Q7: The movement pattern curve can give me stronger sense of the connections between different activities and help me understand the allocation of different rooms.	0.75	4.00
	Q8: The simulation of user activity can give me better understanding of the circulation pattern in the layout.	0.74	3.89
Appearance and view	Q9: Using multiple observation method provided by the activity simulation model, I can understand the appearance of the external building and the interior decoration more clearly.	0.66	3.89
	Q10: By using multiple observation methods provided by the activity simulation model I can get the view outside my office more clearly.	0.61	3.53

Table 5.7 (Continued)

Involvement of participants	Q11: I would be more interested and willing to collaborate with the designers to improve the design (e.g. design consultation meeting) while using activity simulation model.	0.52	4.05
	Q12: I would be more confident to express my requirements and feedback on the design while using activity simulation model.	0.62	4.05
Process of requirements specification and design review	Q13: It is easier for me to discover the unsatisfied requirements of the design by observing activity simulation model.	0.52	4.05
	Q14: The requirements and feedback interface categorized the requirements into a structured hierarchy, so this can facilitate me to specify the requirements on the design.	0.50	3.84
	Q15: The requirements and feedback interface reminded me the pre-defined requirements, so this can guide me to evaluate the design solutions and specify further requirements.	0.42	3.79
	Q16: The requirements and feedback interface systematically recorded my feedback, so this can facilitate me to express my comments on the design.	0.46	3.89
	Q17: It is easier for me to express my opinions by typing rather than speaking out in public. It can avoid pressure from others' comments or shyness when speaking.	0.50	3.84

Note: 5= strongly agree; 4= agree; 3= neutral; 2= disagree; 1= strongly disagree.

5.4.5.2 Findings of the Survey

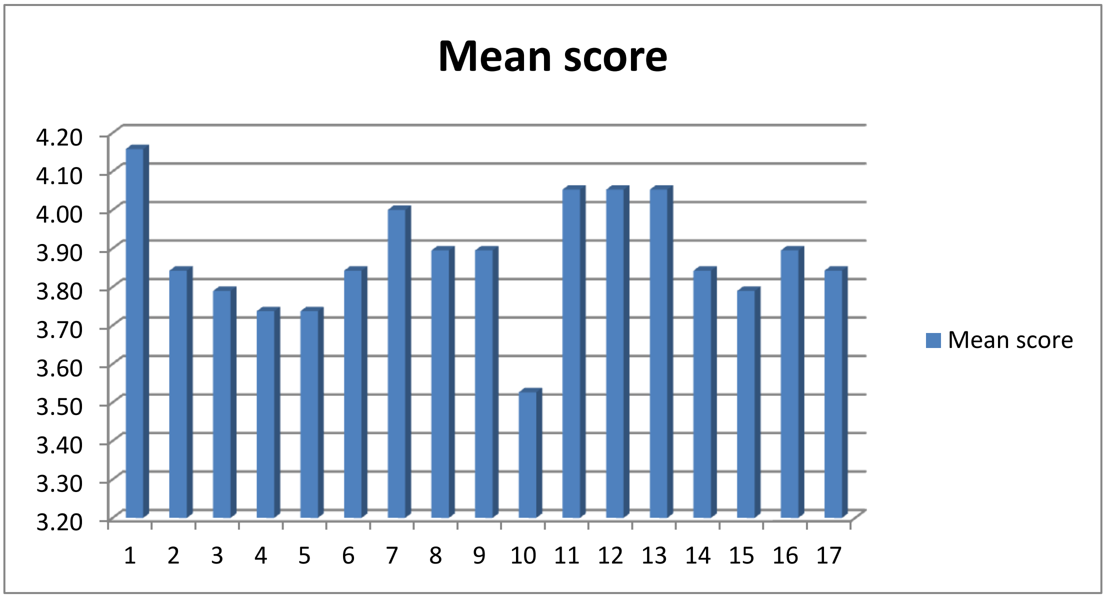


Figure 5.6 The score of each statement in the questionnaire survey

(Experimental Study II)

From Figure 5.6, it is found that most of the statements were agreed with by participants. Five of the 17 questions scored no less than 4.0. Except for Question 10, all other 16 questions scored above 3.7. Question 1 “The simulation of user activity can give me better understanding of the arrangement of the layout” obtained the highest score, of 4.16. The question type “involvement of participants” obtained higher scores than the other four types of question.

The result for question type “overall understanding” indicated that the *user activity simulation model* gives participants a better understanding of their working environment, layout arrangement, and uses of the spaces in the future built environment. The result for question type “size and adjacency” showed that the *user activity simulation model* improves participant understanding of the areas and floor plan spatial relationships The "involvement of participants" questions reflected participant interest and willingness to work collaboratively to improve the design with the aid of the *user activity simulation model*. The questions about "process of requirements specification and design review" were designed to test the value of the *requirements and feedback interface*. The result suggests that this interface has the potential to help participants to specify requirements and review the design in an effective and systematic way. This interface can also help participants who are reluctant to speak in public.

However, Question10, "By using multiple observation methods provided by the activity simulation model, I can get the view outside my office more clearly" scored the lowest at 3.5. This result is similar to that for the same question in the survey of *Experimental study I*. This illustrates the same problem of participants finding it difficult to switch to the proper mode for observing (e.g. switching to the first person view). Although in Study II, the facilitator provided 5 minutes of focussed training before the 15 minutes exposure to the *user activity simulation model*, the Q10 result shows that longer training is needed. Another reason is that in this case study, the view outside is not realistic enough.

5.4.6 Conclusions of Experimental study II

Based on the findings of the comparative experiment and questionnaire survey, some conclusions are drawn below:

1. The PEP provides a method which improves the effectiveness of designer-client communication. Following the comparative experiment, it is found that the PEP helps

participants to generate more suggestions likely to lead to improvement of design solutions.

In brief, the PEP can improve the effectiveness of designer-client communication by increasing the amount of feedback from clients. To be more specific, the increased feedback mainly relates to spatial property factors, such as area, location, adjacency and numbers of space units. The amount of feedback on other factors increases to a lesser extent, though this may be due to the features of the case selected for this study. Nevertheless, the hypothesis raised in Section 5.4.1 has been proved.

2. The results of the questionnaire survey in Study II indicates that use of PEP improved client understanding of the design drawings and increased satisfaction during the design review stage.

The questionnaire focussed on: (1) overall understanding, (2) size and adjacency, (3) appearance and view, (4) involvement of participants and (5) the requirements specification process and design review. The feedback from clients showed that most agreed that there is improvement in the above respects with most scoring no less than 3.7. However, the lack of enough time for participant training in using different observation methods has led to the result that the response score for the factor “the improvement on appearance and view” is relatively low. The limitations of and further improvements required in the implementation of PEP are summarized in the following section.

5.5 Summary

Chapter 5 introduced the process of validating PEP in a real campus project. First the objective of this validation and the factors used to measure the client performance were specified. Then the comparative experimental study and questionnaire survey were applied as the main methods to conduct the validation. *Experimental Study I* was carried out as a pilot study for analyzing the impact of PEP on improving client's understanding of the design. *Experimental Study II* further tested how PEP will affect the client's feedback on design solution in the aspects of quantity and content. The findings and limitations of this validation were also illustrated.

Chapter 6 Conclusions

6.1 Introduction

This chapter presents the conclusions of this research study. The research objectives are first reviewed, supplemented by a summary of main findings from literature review, development of the Pre-occupancy Evaluation Platform (PEP), as well as the validation process. A summary of the contributions made to knowledge then is given. Limitations of the research results and recommendations for further research are also presented.

6.2 Review of Research Objectives

The aim of this research, stated in Chapter 1, was to investigate to what extent a Pre-occupancy Evaluation Platform (PEP) can improve the effectiveness and efficiency of designer-client communication in the early design stage. To achieve this aim, there were four objectives: (1) to review early architectural design processes presented in the literature to a) examine problems affecting effectiveness of designer-client communication b) identify areas where improvements could be made and c) illustrate suitable technologies and techniques which can be used to address these problems; (2) to design and develop a Pre-occupancy Evaluation Platform (PEP) which would a) integrate such techniques as building information modelling, user activity simulation and requirements management, and b) facilitate designer-client communication in terms of design reviews and requirement specification; (3) to test the effectiveness of PEP on real projects and validate its effectiveness in enhancing client performance during design review and requirement specification processes.

Regarding objective 1, Chapter 2 reviewed the problem domain of this research, which focused on the problems emerged between designer and client during two significant stages, briefing and early architectural design.

In the briefing stage, problems emerged during the designer-client communication can include the following three categorise: (1) problem caused by the limited experience of the clients; (2) problems related to the client requirements management and participation; and (3) insufficient time for briefing. Therefore the primary improvements area of client performance in briefing stage focused on (1) increasing their understanding of the design solutions, and (2) facilitating the process of requirements specification and design review.

The literature review in Chapter 2 also found that problems emerged at the early design stage (focused on space planning). Section 2.3 introduced the concepts and process of space planning, varieties of techniques of generating and optimizing space planning solutions in practice, and limitations of these approaches. Based on the literature, the features of a better platform for supporting the designer-client communication in space planning stage are listed in Section 2.3.3.3.

The second part of the literature review (Chapter 3) focused on the techniques used to establish the proposed PEP. BIM tool, because of the various advantages, is selected as the basic tool for generating the building models in the PEP. In addition, a user activity simulation method was adopted to demonstrate building usage scenarios. Types of user activity simulation techniques were then introduced and categorized by different purposes. The basic theory of the user activity scheduling method employed in this research, as described in Section 3.3.3 was also introduced. Finally, the requirements management models and specifications about building projects were reviewed. One requirement specification was selected as the basis of the pre-occupancy evaluation module in the proposed PEP.

To achieve objectives 2, a Pre-occupancy Evaluation Platform was designed and developed. Chapter 4 introduced the rationale, architecture, components of this PEP as well as the guideline showing how to implement it in a real project (office building mainly). The details of modules in PEP are also illustrated in Chapter 4. The building information module and user information module are intended to build up the virtual environment based on information from the client organization and designers' solutions. Details of the user activity scheduling method are illustrated in Section 4.5.1. The functions of *user activity simulation model* are demonstrated in Section 4.5.2. On the basis of this virtual environment, designer-client communication is further facilitated by the pre-occupancy evaluation module in Section 4.6. In the pre-occupancy evaluation module, the requirements and feedback specification integrates the requirements of the building and a set of pre-occupancy evaluation questionnaire to help clients review the design solutions. A *requirements and feedback interface* was also designed to improve the efficiency of this process.

To achieve objective 3, the PEP was validated in a real campus project (Chapter 5). Factors such as number of suggestions for improving design solutions, client understanding of design solutions, and level of satisfaction during the implementation of the PEP were selected as the indicators for measuring the results of experimental studies. Thus both qualitative and quantitative analyses were conducted in this process. Research methods including questionnaire survey, action research and experimental study were also employed.

6.3 Summary of Major Findings of this Research

1. There is a lack of a comprehensive method to guide the application of user activity simulation in supporting designer-client communication in the early architectural design stage. Although many building analysis tools take human activities into account (some are based on BIM technology) such as crowd behaviour simulation, emergency evacuation simulation, and building control-oriented user behaviour study, work on user activity simulation techniques in support of designer-client communication relatively lacking. A systematic method to guide this process is therefore necessary.
2. The simulation of user activities in normal circumstances based on building information models can increase inexperienced client's understanding of design solutions during the early architectural design stage. In the validation of PEP, it was found from the questionnaire survey that, the *user activity simulation model* gives participants a better understanding of their working environment, layout arrangements, function of the spaces and activity in future environment. The simulations also improve participant understanding of such spatial factors as area, adjacency, location and circulation in the floor plan and increase participant interest in working collaboratively with designers.
3. The specification of client requirements and feedback in PEP can improve the inexperienced client's performance in conducting the pre-occupancy evaluation. During the validation process, as observed by facilitators, it was found that the pre-

occupancy evaluation questionnaire is an important guide to participants in reviewing design solutions. Experimental study II (Section 5.4.4.2), found that the number of inexperienced client's suggestions for improving design solutions increases with the support of the PEP. The Experimental study II questionnaire suggests that the *requirements and feedback interface* helps participants to specify requirements and to review the design systematically and effectively. In addition, the feedback on requirements specification can be incorporated in current BIM tools as part of the attributes of each space instance and type.

4. By applying the PEP, post occupancy evaluation can be switched to the design stage saving design change costs and increasing client satisfaction. The application of techniques as building information modelling, user activity simulation and requirements specification provides a basis for conducting post occupancy evaluation in the virtual built environment.

6.4 Contributions to Knowledge

1. This research has lead to new knowledge on establishing a Pre-occupancy Evaluation Platform (PEP) for improving effectiveness and efficiency of designer-client collaborative working during the early design stage. This platform integrates building information modelling techniques, user activity scheduling and simulation techniques as well as requirements management methods, all jointly enhancing designer-client communication. The platform also enables the post-occupancy evaluation to be shifted into the design stage, saving costs and increasing client satisfaction.
2. This research has provided new insights into building up a *user activity simulation model* which contains both information about the building design and user

organization in a project. A user activity scheduling method and related interface have been developed to help end-users efficiently specify working scenarios. The *user activity simulation model* makes it possible to narrow the gaps in understanding between inexperienced clients and designers, and improve communication efficiency during the briefing and design processes. This can also lead to a higher degree of client satisfaction.

3. This research also provides new knowledge on establishing and implementing a specification for client requirements and feedback, with reference to the requirement specification and traditional post-occupancy evaluation. This specification supports clients in conducting a systematic pre-occupancy evaluation based on the virtual built environment during the design stage. The *requirements and feedback interface* and related database support inexperienced clients in efficiently reviewing design solutions and give rise to a greater number of suggestions for design improvements when meeting designers. Designers also benefit from the systematic documentation of client requirements and feedback during the design development stage.

6.5 Limitations of the research

1. Although the *user activity simulation model* can increase client understanding of the design, at current stage, this model may not accurately predict end-user working scenarios due to the complexity of human behaviour.
2. The modelling process of the *user activity simulation model* (including building model) is time-consuming. It can only provide basic architectural information currently.

3. The connection between different modules within PEP, as well as the link with external BIM tools is not fully automatic. Some processes, such as importing building information into the *requirements and feedback interface* are manually completed.
4. During the validation process of PEP in real project, insufficient time was arranged for training inexperienced users to interact with the *user activity simulation model*, which led to the result that participants may not be able to control the model smoothly. Some of the participants may know the author before, although the author attempted to avoid bias in comparative experimental study (e.g. using specific questions to shortlist participants), the impact of personal relationship on experiment result is inevitable. In addition, the PEP was validated using only a limited number of projects and specific types of users.

6.6 Recommendations for Future Studies

1. Further research should give more attention to simulate the interactions between end-users and between end-users and the environment so as to demonstrate the built environment and working scenarios more realistically.
2. More building performance information could be integrated into the *user activity simulation model*. For example, information relating to building performance simulation, including lighting, acoustics, and thermal performances could be added to more comprehensively reflect actual building performance and usage scenarios, thereby extending the scope and usefulness of the pre-occupancy evaluation.
3. More functions such as automatic model checking can be further developed within the *user activity simulation model*. The *requirements and feedback interface* can be

further integrated into the virtual environment. In this case, the feedback generated from the clients can also be recorded as attributes of the building model directly.

4. Further implementation over a larger range of projects and user groups is desirable.

Appendix 1: Record of Outcome of the Workshops in Experimental Study II

Table 1 Feedback from Group A (Task 1, PEP)

User ID	Name	Unsatisfied requirements	Further requirements
1.	Ann	1.It is not easy to access my office (Adjacency) 2. Glass partition is better than interior wall (Wall)	1. Provide flexibility for further development of the organization (Flexibility)
2.	Chloe	1. Male and Female toilet are too closed. (Location) 2. Only one pantry for the whole floor is not enough. Please consider the 2nd one near the academic staff. Please also consider a bigger area for water bottle storage. (Unit/Area)	1. I want to know the actual area of our existing office for making comparison. Now Our existing room is so crowd, and we want to have a new room with bigger size. (Area) 2. We also need a store room besides the general office for placing cabinets, especially some teaching material need to be kept confidentially. Our existing store room is too small. (Space unit) 3. The current meeting room at 3/F is still not big enough for all staff. It is suggested to design a big meeting room, and it could be separated in 2-3 small meeting rooms by using the movable doors/walls. (Area)
3.	Christine(Staff)	1. One more pantry is suggested. (Space unit)	1. For marketing purpose, it is suggested to have a small store room. As practice, it takes space to store marketing leaflets and booklets, premiums and tools (e.g. exhibition stuff) etc. (Space unit)
4.	Fan Hongqing	1. Far away from common facilities such as washroom, meeting room, general office, pantry etc.; (Adjacency) 2. Students go in and out of classroom (Adjacency) 3. It is not easy for me to access my	

		office, not easy for me to go to washroom, not easy for me to go to meeting room (Adjacency)	
5.	Grace(Staff)		1. We should have a larger meeting room which can occupy all of our academic staff. (Area) 2. The current General Office has a small store room which is keeping up-to-date information. It's more convenience to have one more store room next to our office. (Space unit)
6.	Jorge	1. The rooms along the corridor which have no windows can change the interior walls into glass walls (Wall finish)	1. The common facilities should use removable partition walls to adjust according to the needs.(Flexibility)
7.	Geoffrey Shen	1. Head office location is not good; (location) 2.Pantry location is not good; (location) 3. The corridor is too long (Visual)	
8.	XC Luo		
9.	Maggie Tang		
10.	Wang Hao		
Total number		12	8

Appendix 1: Record of Outcome of the Workshops in Experimental Study II

Table 2 Feedback from Group B (Task 1, Conventional method)

User ID	Name	Unsatisfied requirements	Further requirements
1.	Li Heng		
2.	Tan		
3.	Xia Bo		
4.	Timmy Fan	1. There is one pantry in this floor (space unit)	
5.	Thomas Lin	1. The meeting room should not be in the corner of the floor; (Location) 2. The meeting room is too far away from the entrance and pantry; (Adjacency)	
6.	Yuan Zhao		
7	Maggie Tang		
8.	Irene Tang		
9.	Christine Ng		
10	Carmen Lam		
	Total number	3	0

Appendix 1: Record of Outcome of the Workshops in Experimental Study II

Table 3 Feedback from Group A (Task 2, Conventional method)

User name	Unsatisfied requirements	Further requirements
1.Ann	1. Circulation pattern is not good. (specify on the drawing) (Circulation)	
2.Chloe		
3.Christine		
4.Fan Hongqing		
5.Grace		
6.Jorge		
7.Geoffrey Shen	1. Change wall partitions into class (Wall type)	
8. XC Luo		
9. Maggie Tang		
10. Wang Hao		
Total number	2	0

Appendix 1: Record of Outcome of the Workshops in Experimental Study II

Table 4 Feedback from Group B (Task 2, PEP)

User name	Unsatisfied requirements	Further requirements
1.Li Heng	1. The location of my office is far from my lab. (Adjacency)	
2.Tan	1. My office is far from the public facilities, such as meeting room and copy room. (Adjacency)	
3.Xia Bo	1. Meeting room (2) is too small to accommodate a normal departmental meeting. (Area)	
4.Timmy Fan	1. There is only one pantry. (Space of unit)	
5.Thomas	1. The meeting room should not be in the corner of the floor; (Location) 2. The meeting room is too far away from the entrance and pantry; (Adjacency) 3. General office is too far away from some offices, this is the most used office in the dept which would better be in the middle of the layout. (Adjacency) 4. The research workstation should not be in front of the lift. (Location)	
6. Yuan Zhao	1. There is no window in the research student workstation to outside, no fresh air. (Window)	
7. Maggie Tang	1. The location of the door of the research workstation is not convenient for access. (Accessibility)	
8. Irene Tang (Staff)		
9. Christine Ng		
10. Carmen Lam	1. Not sufficient space between bookshelves (Area)	
Total number	11	0

Appendix 2: Sample of the Questionnaire for Collecting Participants Feedback

Personal information

Name:__________________

1. Do you have any experience in architectural design?

Yes (_____Years)   No

2. Have you ever seen the drawings of Phase 8 before?

Yes   No

3. Have you ever joined any kind of designer-client consultation meeting before?

Yes   No

The following questions aim to compare your experience of using the user activity simulation and pre-occupancy evaluation method with the conventional method during the designer-client communication.

Using of activity simulation model

//Overall understanding

Q1: The simulation of user activity can give me better understanding of the arrangement of the layout.

Strongly disagree;   Disagree;   Neutral;   Agree;   Strongly agree;

Q2: The simulation of user activity can give me better understanding of my working environment.

Strongly disagree;   Disagree;   Neutral;   Agree;   Strongly agree;

Q3: The simulation of user activity can give me better understanding of the function of the each functional space.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q4: The user information data (the user name, title, walking distance, activities and time) can give me better understanding of how our organization accommodated in the given building.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

//Size and adjacency

Q5: The avatars can give me stronger sense of scale (size of room, width of the corridor).

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q6: The avatars' movement can give me stronger sense of the distance.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q7: The movement pattern curve can give me stronger sense of the connections between different activities and help me understand the allocation of different rooms.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q8: The simulation of user activity can give me better understanding of the circulation pattern in the layout.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

// Appearance and view

Q9: Using multiple observation method provided by the activity simulation model, I can understand the appearance of the external building and the interior decoration more clearly.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q10: Using multiple observation method provided by the activity simulation model I can get the view outside my office more clearly.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

// Involvement:

Q11: I would be more interested and willing to collaborate with the designers to improve the design (e.g. design consultation meeting) while using activity simulation model.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q12: I would be more confident to express my requirements and feedback on the design while using activity simulation model.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Requirements specification and design review

Q13: It is easier for me to discover the unsatisfied requirements of the design by observing activity simulation model.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

//Process of requirements specification and design review:

Q14: The requirements and feedback interface categorized the requirements into a structured hierarchy, so this can facilitate me to specify the requirements on the design.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q15: The requirements and feedback interface reminded me the pre-defined requirements, so this can guide me to evaluate the design solutions and specify further requirements.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q16: The requirements and feedback interface systematically recorded my feedback, so this can facilitate me to express my comments on the design.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Q17: It is easier for me to express my opinions by typing rather than speaking out in public. It can avoid pressure from others' comments or shyness when speaking.

Strongly disagree; Disagree; Neutral; Agree; Strongly agree;

Suggestions for improving the User Pre-Occupancy Evaluate Method:

1.____

2.____

3.____

Thank you for completing this questionnaire!

- THE END -

Appendix 3: Instruction for the User Activity Simulation Model

1. In the initial statue you can use the Camera_Orbit to observe the scene:

Up, Down, Left, Right (arrow) to control direction of the view;

‘Z’ to zoom out, ‘X’ to zoom in, ‘H’ to show or hide the upper building.

2. To trigger the activity simulation:

Press ‘T’ to start the activity simulation demo;

3. Switch observe angel:

‘Space’ sequentially. So you can switch to three different views:

Camera_Orbit:

Up, Down, Left, Right (arrow) to control direction of the view;

‘Z’ to zoom out, ‘X’ to zoom in, ‘H’ to show or hide the upper building;

Camera_Follow;

(3) Camera_First person

4. Free observation:

Press ‘Q’;

Hold left mouse and move to rotate; Hold right mouse and move to transfer;

Scroll to zoom in and zoom out.

5. Switch to different users/show information board/show and hide trace curve:

Appendix 3: Instruction for the User Activity Simulation Model

Press User Number

6. Restart and Pause the demo:

‘Right click’ mouse and choose ‘restart’ to start from beginning;

7. Control a “free user” to walkthrough:

You can choose a ‘free man’ to walkthrough if you do not like to follow the avatar.

Press ‘5’ to switch to number 5 avatar;

Press ‘F’ to trigger his free walk function;

Use mouse to click any place on the screen, this avatar would find the nearest path to get there.

Appendix 4: Sample of Interview Form of the End-user Activity Specification

In the following form, you are invited to fill in the daily activities you conduct on a working day. For the aim to demonstrate as many functional rooms as possible, you are expected to specify a 'busiest' day in your daily life, such as "attending meeting, meeting supervisor, looking up books in care resource centre.

Name: ______________________

Title/Position: _______________________

Example:

Activity	Start time	Location	Activity type
1. Research work	8:00	Office	Desk work
2.Meeting	10:00	Meeting room	Meeting
3.Lunch	13:00	Outside	Lunch
4.Research work	14:00	Office	Desk work
5.Leave	18:00	Main entrance	

Appendix 4: Sample of Interview Form of the End-user Activity Specification

Skeleton activities:

Activity	Start time	Location	Activity type
1			
2			
3			

Intermediate activities:

	Frequency	Location
Drink		
Toilet		
Break		
Printer		
Mailbox		

Note: this form is an alternative method to specify end-user activities.

Thank you for completing this form!

- THE END -

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