BIM-BASED USER PRE-OCCUPANCY EVALUATION METHOD FOR SUPPORTING THE DESIGNER-CLIENT COMMUNICATION IN DESIGN STAGE

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Abstract
This paper introduces a BIM based user pre-occupancy evaluation method (UPOEM), which is applied in architectural design stage for the aim to improve the efficiency and effectiveness of the communication between designers and clients.
There are constants interactions between the clients' requirements and designers' solutions during the early design stage. However, there are some problems emerged during the designer-client communication process which may affect the effectiveness of designer-client communication, such as, inexperienced clients have difficulty in understanding 2D drawings, and the lack of an efficient method to guide the clients to review the design against their requirements.
The building information model (BIM) and BIM tools have provided a better platform to demonstrate both of the graphical and non-graphical information of the design. However the BIM tools paid less attention on facilitating clients to understand how their activities are accommodated in the building model, or helping them to express their requirements and feedback on the design. Therefore, this proposed method simulates the end users' activities in the future built environment based on building information models, so as to improve the clients' understanding on the design; a clients requirements and feedback interface is also designed to help clients express requirements and review the design. A framework of applying the UPOEM in conventional designers-users communication meetings is proposed in this paper.

Keywords: BIM, User activity simulation, Pre-Occupancy Evaluation

INTRODUCTION

Although design process varies, the common ground is a design process always started from a briefing stage, and ended in forms of design drawings. RIBA (2000) defined the outline of work of architect in the life cycle of a building project in the book "Architect's Job Book" (Figure 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 1: *Outline Plan of Work in a Building Project*

The communication between designers and clients in the briefing and design stage is usually based on the requirements of clients and the solutions of the designers (shown in Fig 2). A project brief should define all the design requirements, and is the foundation on which the design will develop. Generally, the design process is cyclical, and there is constant interaction between the brief and design proposals (RIBA 2000).

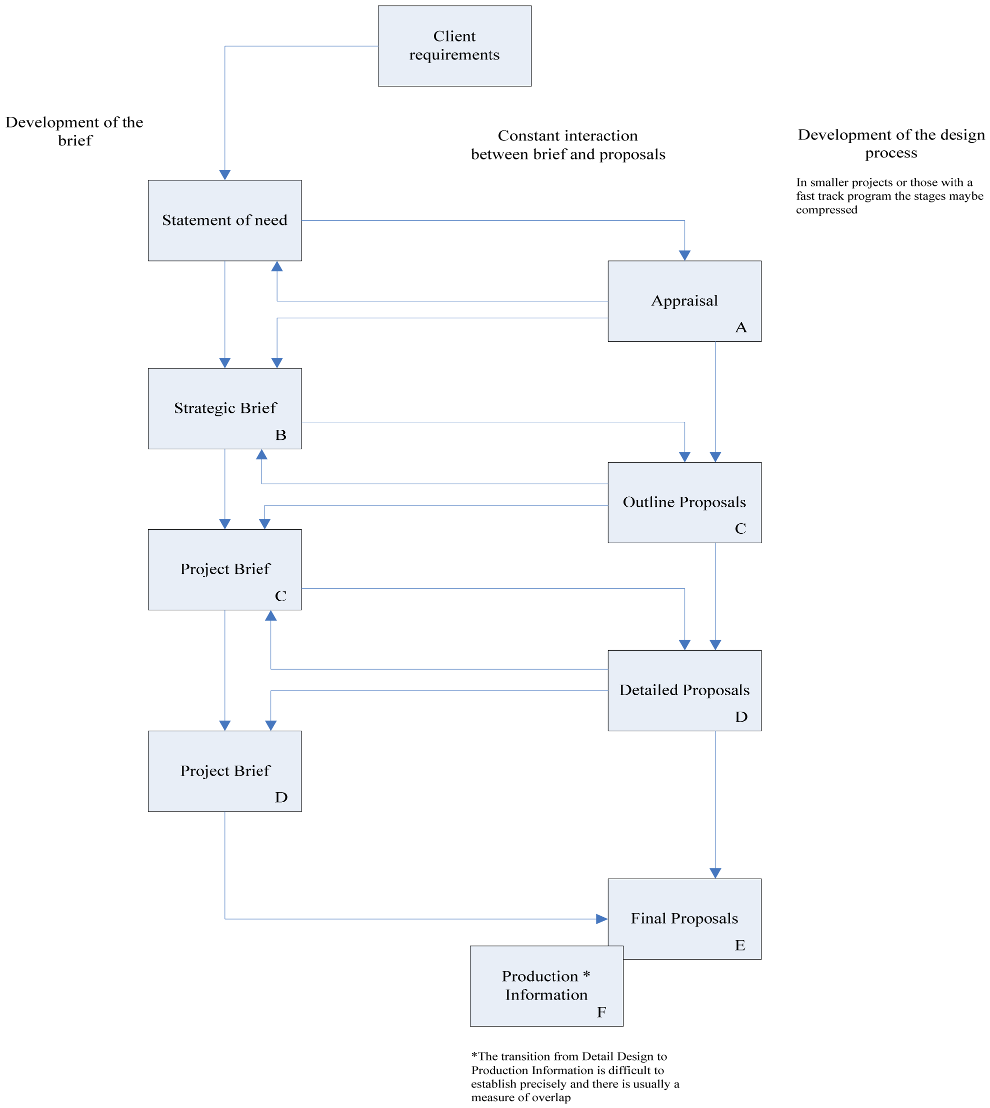


Figure 2: The process of brief and design development (Source: RIBA 2000)

A considerable gap between the designer and client is, unlike architects, users are usually not trained and their comprehension in three-dimensional space is limited. Problem usually stems from a fact that users cannot imagine how the design will be emerged after construction phase (Lertlakkhanakul, Choi, & Kim, 2008). The inability of users to read drawings also affects them to specify the client brief (Barrett, 1999).

In addition, another problem which would also affect the efficiency of designer-client communication is about the requirements management during the designer-client communication process. Kiviniemi (2005) found that there is a lack of mechanism for designers to record, manage and track changes of the clients' requirements during the design stage, which will lead to the result that the end design solution is significantly different from the clients' requirements. Then Kiviniemi designed a building requirement IFC specification to manage requirements information during design process and provide the possibility of linking requirements to the objects of the design model. Although such requirements models were established, there is still demand for a framework/method to guide the clients to define, manage and track changes of the requirements, and facilitate them to review design against requirements in communication process with designers, especially in the context of virtual environment.

For the aim to solve the problems mentioned above and enhance the efficiency and effectiveness of the designer-client communication, in this paper, a user pre-occupancy evaluation method (UPOEM) is proposed.

First, virtual reality technologies will be applied to improve clients' understanding of their built environment. A virtual environment which can demonstrate both the building and users' activities in the built environment will be established. The reason of simulating end users' activities is that the buildings usually play a key role of accommodating user's organizations and equipment, and enable their activities. Ekholm and Fridqvist (2000) stated that, while the development of bubble diagrams in space planning process, the activities are considered as the criteria to define the size and relationship between these bubbles (representing spaces), but not the building's spaces themselves. Therefore, it is helpful to visualize the end-users' activities and provide a platform for them to evaluate to what extent the built environment could match their requirements.

Second, a *requirements and feedback interface* will be designed to facilitate the clients to manage requirements and review the design. This interface is intended to remind clients of the requirements of the given design solution, and guide them to evaluate the design against these requirements. Both the requirements and evaluation results are recorded as the attributes of each room will be saved in a database during the development of the design process.

RELATIVE WORKS

To achieve the specific objectives, the building information modeling (BIM) technology is used in the UPOEM to provide accurate building information, and the structured requirements documentation method is used to build up the pre-occupancy evaluation module. Thus this section introduces the relative works of these two aspects.

Features of BIM tools

Building information modeling (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 modeling software to increase the productivity during the process of design and construction (Holness, 2008). This process produces the Building Information Model (BIM), which includes building geometry, spatial relationships, geographic information, and quantities and properties of building components. On one hand, the building information model can provide "earlier and more accurate" visualizations of a design. On the other hand, it is an object-based parametric model, which contains not only the geometry and topology attributes, but also carries various properties if they are analyzed, priced, interpreted and procured by other applications. Most of the current BIM tools default to a minimal set of properties for most objects and provide the capability of adding an extendable set, so users or an application can add properties to each relevant object to conduct certain kind of cost estimate, simulation (Eastman et al., 2008). Since the BIM tools can generate accurate building models for the demonstration of design, and the extendable object-based properties can provide a possibility to store the information generated during the designer-client communication process, the BIM technology is therefore used as the basis of the UPOEM.

User activity simulation in buildings

Lots of literature has addressed the user activity simulation models, which aim to simulate and predict occupants' activities in a given building and to evaluate the building or organization performance such as evacuation, circulation, building control system, energy saving, and space usage. In the early time, static building models including the user activities were built by Eastman and Siabiris (Eastman and Siabiris, 1995). After that, much research have studied on predicting pedestrian movements in urban planning and emergent evacuation in buildings (Kerridge, 2001; Kuligowski and Peacock, 2005).These studies have enriched the area from many perspectives, such as the environmental consideration. Zimmermann (2006) used the multi-agent technology to simulate individual's activities in a building for energy saving purpose. Lertlakkhanakul et al. (2008) built up a collaborative virtual environment for end users to interact with building models of smart houses. In order to investigate the space usage of the buildings, Tabak et al. (2007) used workflow model and activity schedule model to simulate users' activities in office buildings. Lately, Tabak (2008) has also developed a human behavior simulation system named USSU to mimic the behavior of human beings when scheduling activities. The output of this system is a movement pattern in terms of end users' activity schedule, including relevant moving routes in a building. However, the system requires a large amount of user input data, and has no connection with the building information model.

To facilitate the designer-client communication, the UPOEM in this paper will therefore establish an alternative simplified user activity scheduling method based on Tabak's work, which allows the end users to specify their activities in a new building within a relatively short time. In addition, these end users' activities are simulated within the 3D building model generated by BIM tools, and the communication is further supported by structured requirement documentation.

Requirement documentation and hierarchies

The clients' *requirements and feedback interface* designed in the UPOEM aims to connect the design solution with clients' requirements and feedback. This section therefore introduces the related requirement documentation methods or hierarchies.

Most of the time, the documentation of client requirements is in form of traditional building program, which is generated mostly by interviewing clients, owners, and end users. In many cases, the original client requirements are not clear, and designers have to turn them into more accurate requirement descriptions or requirement attributes (Whelton and Ballard, 2003). Kamara (2002) summarized several structured requirements capturing and documentation methods, including Quality Function Deployment (QFD), Client Requirements Processing Model (CRPM), Total Quality Management (TQM), and Failure Mode and Effects Analysis (FMEA). As for the research about requirements hierarchies, there are also a lot of relevant works. The International Centre for Facilities (ICF) has published several volumes documenting their standards for Whole Building Functionality and Serviceability (WBFS) since 1992 (ICF, 2009). The purpose of these standards is to help organizations to define their functional requirements for the buildings and serve as a checklist together data and evaluate the existing buildings from the portfolio management or tenant viewpoint. Though the WBFS provides a high-level, strategic view for evaluation of building, it has no connection between requirements and design tools. On the other hand, EcoPro, a software application developed by VTT (Technical Research Centre of Finland), is intended to help building owners to define the sustainability requirements for their building projects (Kiviniemi, 2005). Kiviniemi then designed a building requirement IFC specification based on the requirements hierarchies of the WBFS and EcoPro. The research aims to manage requirements information during design process and provide the possibility of linking requirements to the objects in the design. A solution for cascading requirements which simplifies the database structure significantly is also identified. However, there is still no attention given to the clients for collecting their feedback against these requirements. In this context, Kiviniemi's requirements specification has become part of the research basis for the requirement documentation method used in UPOEM. In addition, a feedback questionnaire is used with the requirements specification together to facilitate the clients to review design solutions in this study.

DESIGN OF THE UPOEM

The rationale of UPOEM

In the conventional architectural design process, clients first specify their requirements, such as space program, and then the designer proposes the preliminary design according to this brief.

The rationale of UPOEM is to build up a 3D virtual environment not only contains the building but also the end users' activities. This integration aims to facilitate the clients and designers to understand how the end users' organization will be accommodated in the given building, such as, the location of end users' activities in the new building, or the adjacency relationship between different functional rooms. During their "daily" activities, end users can evaluate their working or living environment in a "familiar" way. So this simulation provides a platform for the clients (including end users) to conduct a post-occupancy evaluation of their built environment in the virtual reality environment.

Therefore, the UPOEM provides two more processes based on the conventional process: (1) user activity specification and simulation; and (2) pre-occupancy evaluation

Components of the UPOEM

Three components are designed in UPOEM to support the designer-client communication process (as shown in Figure 5).*Building information module:* this module's purpose is to use BIM tools to build up and update the building information model based on the design given by the designer. *User information module*: this module is intended to collect end users' information, facilitate them to specify their activities and generate the activity simulation model. *Pre-occupancy evaluation module*: this module aims to conduct a pre-occupancy evaluation based on the virtual environment and collect users' requirements and feedback.

Framework of applying UPOEM

The UPOEM is usually applied in the consultation meeting involving the designers and the end users in the architectural design stage. The timing of this meeting is usually after the outline proposal is created by the designer. Then users are invited to discuss the design and give their feedback. The times of such interactions depend on the scope of the projects and duration of the design period, and sometimes would last until the design solution is finalized. There are four main steps for the implication of the UPOEM in practice:

Preparing the building information model: The building information model is built by BIM tools based on the drawings given by architects. When users give feedback on the design, the building information model needs to be updated for further evaluation.

Specification of user activities: By using the user organization information module, users specify their activities and the functional spaces they will use in their future working environment.

Simulation of the user activities: After preparation of both building model and user information, the activity simulation model is generated for the pre-occupancy evaluation.

Pre-occupancy evaluation: The users' feedback or further requirements are collected in this step via the pre-occupancy evaluation module.

User activity simulation

This user information module is to specify user information including roles and activities of the organization and generate the users' activity schedules. Then an activity simulation model is generated based on the end users' activity schedules (Table 1).

The activity specification method applied in this paper is a simplified and easy to use activity scheduling method based on the work of Tabak (2008). Tabak divided users' activities into skeleton activities and intermediate activities. He used different scheduling method to schedule the individual skeleton activity, interactive skeleton activity and intermediate activity. It mimicked the behavior of real human beings when scheduling activities.

Table 1: *An example of user's activity schedule*

Activity	Start time	End time	Location
Research work	09:00	11:30	Office
Teaching	11:30	12:30	Lecture room
Lunch	12:30	14:00	Canteen
Research work	14:00	18:00	Office
Leave	18:00		Exit

Activity scheduling method applied in UPOEM

In the UPOEM, the users' activities are also divided into skeleton activities and intermediate activities. But it made no distinction between planned, unplanned skeleton activities.

Scheduling the skeleton activities: all of these skeleton activities are treated as planned activities referring to users' working routines. Users are requested to arrange their skeleton activities in the new building via a user activity scheduling interface.

Figure 3 shows the interface for the users to specify their activities in the new building. End user can specify their skeleton activities including start time, end time, and location of each activity based on their daily working routines or agenda of one specific working day. They can specify their locations of each skeleton activity by inputting name of rooms directly or picking the room name from the 2D layout by clicking the button representing each room.

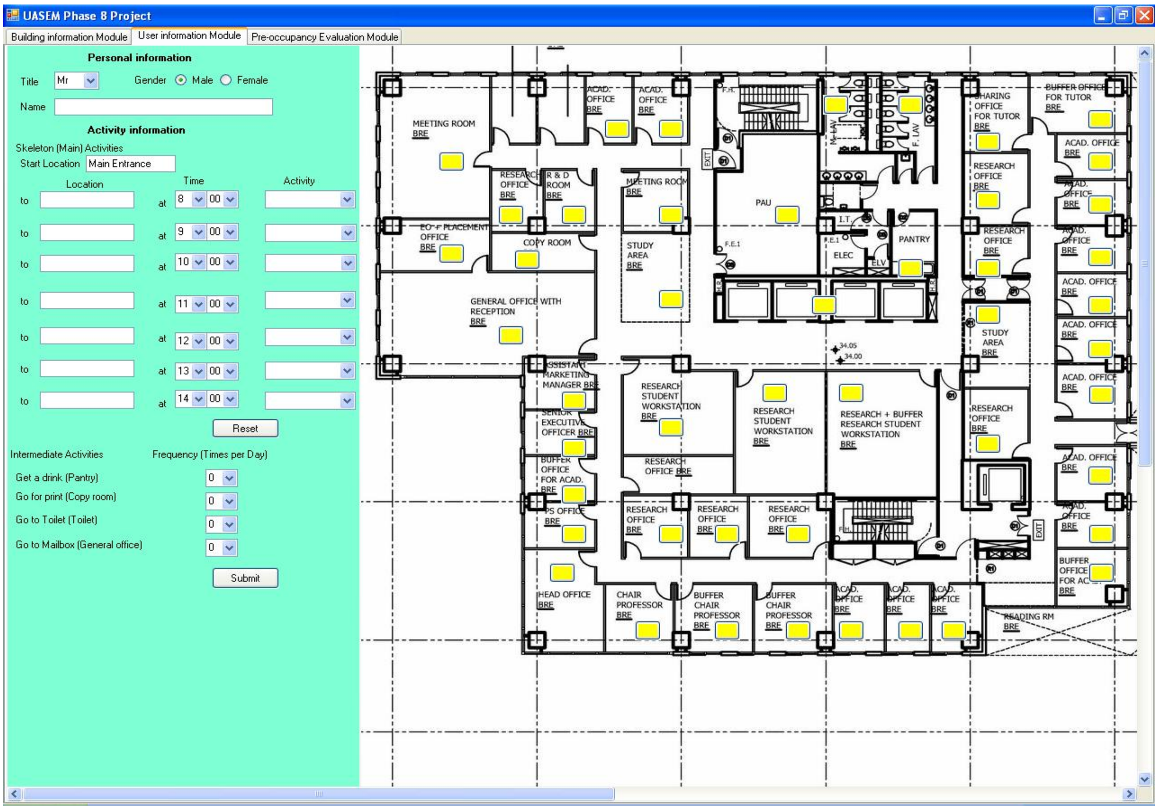


Figure 3: *Interface for user activity specification and scheduling*

Scheduling the intermediate activities: The method of scheduling the intermediate activities in UPOEM is less concerned with predicting the accurate occurrence time of each intermediate activity, but demonstrating the spatial factors of the design solution mainly (such as, adjacency relationship, circulation, walking distance and traveling time between two location in the building). The process of demonstration is usually proportionally shortened to several minutes for adoption in real life designer-client consultation meeting (e.g. 16 minutes represents 8 hours a day). Therefore a simplified intermediate activity scheduling method is proposed for this purpose. It has two features: (1) the occurrence time of all these intermediate activities depends on the time elapsed since the previous occurrence; and (2) a linear probability distribution method is used to simplify the S-curve method used by Tabak. This simplification saves the time of determining the shape of the S-curve, and is easy for the users to describe their daily activities. The intermediate activities (such as get a drink, go for print, go to toilet and go to mailbox) are described by daily frequency. And the mean duration of these intermediate activities are assumed to be a certain time for each.

The algorithm to calculate the occurrence time of a given intermediate activity in a certain time span with an N frequency is as follow:

```
Step 1. RC = Random (0,1.00).
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 are given the definition 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 equals to ST at the beginning.

RC = The probability of an activity will happen at random. Ranged 0 – 1.00.

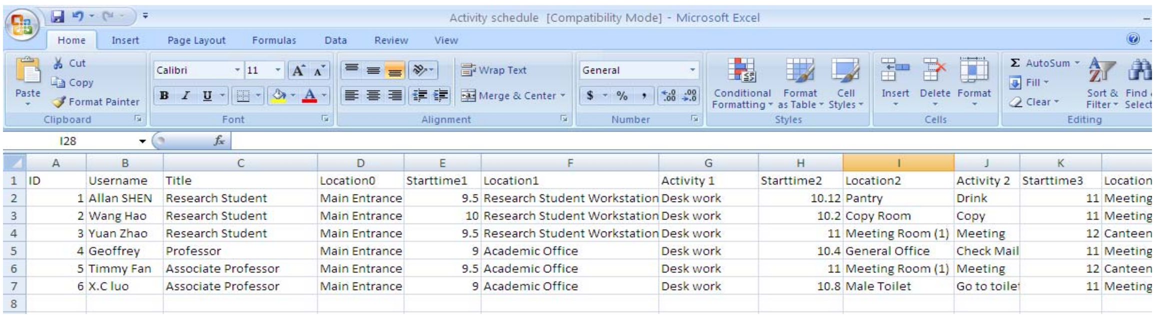
N = Frequency of the activity. (Times of occurrence of the activity take place during the simulation, and are inputted by the users.)

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

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

$$PC = (CT - PT) / ((ET - PT) / (N - AC)) \quad (1)$$

After determining the occurrence time, these intimidate activities are inserted into the intervals of the skeleton activities. Then the whole activity schedule including both skeleton and intermediate activities is generated and saved into the database (Figure 4). The activity simulation tool will generate the end users' activity based on this schedule.



ID	Username	Title	Location0	Starttime1	Location1	Activity 1	Starttime2	Location2	Activity 2	Starttime3	Location
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: *Saved user activity schedule information*

Activity simulation model

This activity simulation model demonstrates the single or groups of users' activities in the 3D environment. It is built up based on the users' activity schedules and building information model via the virtual reality software 3DVIA Virtools. A program is written for loading the users' activity schedules in the format of excel files and generating the activities in relatively short time. In this model, both graphical information (3D avatars representing different users) and non-graphical information (text instruction, activity statistical data and symbols) are provided to facilitate the demonstration and data analysis.

Graphical information to enhance users' virtual experience of the built environment

Usually the demonstration time is shortened proportionately to adapt to the communication duration. During the demonstration, users can follow the movement of the avatars to observe their daily activities in the new building according to their schedules. They can choose different end users and switch between them. Multiple observation angles are provided to observe each user's activity, such as overview (with zoom in and zoom out function), third person and first person view to enhance their virtual experience within the built environment. End users can easily change different angles to observe their working environment (Figure 5). One of the advantages of this kind of navigation is that, users can observe the design model as they already live in this building and avoid aimless roaming. This can improve the efficiency of the designer-client communication, especially when there is time constraint.

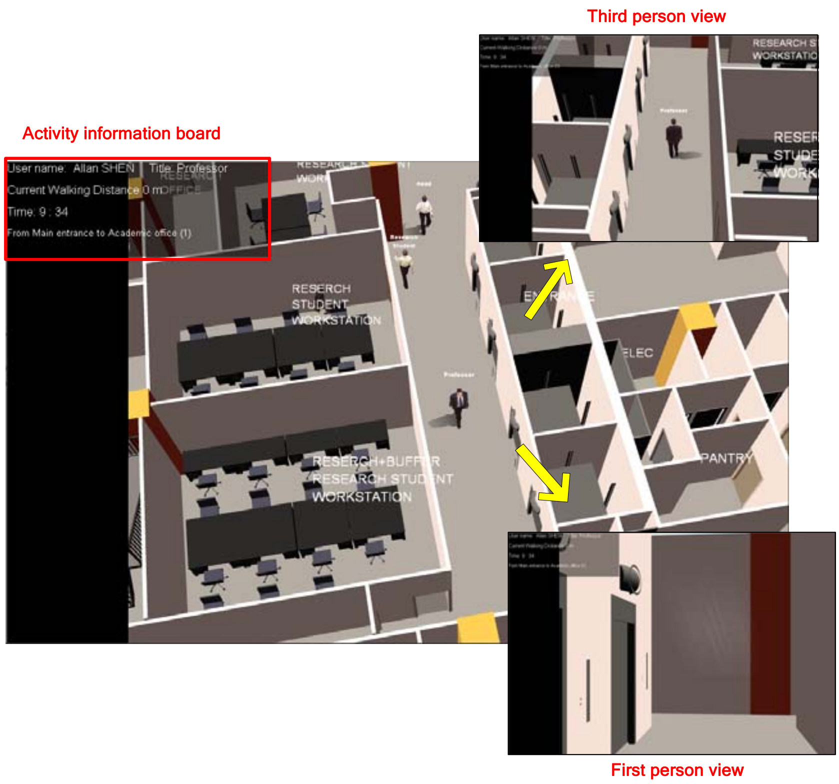


Figure 5: *The activity simulation model*

Except following the avatars, users can switch to the normal observation method as the same as those functions provided by other design (or review) software (e.g. Revit Architecture) to exam the design. The self-control walkthrough and flythrough are also available in this activity simulation model.

The activity simulation model can not only demonstrate individual user's activity but also accept multiple users' activity schedules and simulate the interactive scenarios such as meeting and teaching. Figure 10 shows five users attending a meeting according to their schedule on a certain working day. As the involvement of the avatars, users can obtain a sense of scale in the room and the "feeling" of it being crowded or spacious. They can also have the sense of distance while they are following their aviators from one location to another. The focus of this model is to facilitate users to understand the factors most related to users' movement and spatial comfort.

In the process of design development, more details are added into the building model. Then the users can understand more specific design details besides the layout, such as the interior decoration, lighting and the view outside the building, which depends on the capabilities of the building simulation model.

Non-graphical information to support the demonstration

Besides the graphical walkthrough, one of the features of this activity simulation model is that it provides statistical information to illustrate users' activities. For example, Figure 9 illustrates a normal working day of a department in a university, when one of the professors is walking from main entrance to his academic office. The activity information board on the left-up corner of the model displays the name of users, title, time, current activity and walking distance.

During the designer-client communication, questions such as "will the layout design ease the communication between employees?" or "will traffic flow easily?" are always raised by the designers, especially when users' traffic efficiency is emphasized in the design (e.g. airport and hospital projects). The users also usually concern about whether it is for him/her to travel around the building. So the walking distance or travelling time is a crucial index to measure the convenience or efficiency of the design. In this model, the distance is measured and displayed during users' movements. 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 purpose.

Movement patterns are also important for designers to evaluate the layout. The movement path can be traced to illustrate the connection between different functional rooms (Figure 6 left). These movement tracing curves can help users to understand the adjacency relationship between different functional rooms easily. This is easy for them to specify adjacency requirements during the communication process. In the meantime, movement tracing curves with different color are used to show the movement pattern of different roles in one organization. For example, in a campus office building, the circulation of professors and research students are illustrated by different colors (Figure 6 right). This can support the circulation design in the organization and avoid disturbance between different roles.

Figure 6: *Tracking curve of user movement*

Pre-occupancy evaluation

Pre-occupancy evaluation is the application of post occupancy evaluation (POE) in the pre-construction, pre-occupancy or pre-project stage. Post-occupancy evaluation is defined as "the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time" (Preiser, 1988). It systematically evaluates the buildings in use from the perspective of the people who use them. It also assesses how well buildings match users' needs, and identifies ways of improving building design, performance and fitness for purpose. The British Council for Offices (BCO) illustrates that “a POE provides feedback of how successful the workplace is in supporting the occupying organization and individual end-user requirements” (N.A.Oseland, 2007). Virtual reality techniques have been used to conduct the pre-occupancy evaluation in some research work (Palmon, Sahar, Wiess, & Oxman, 2006).

In the virtual environment based pre-occupancy evaluation process, the evaluation objects are the building models. There are many building performance simulation tools can generate rich building information for this evaluation, such as architecture, lighting, thermal, and acoustic. In this paper, the evaluation factors focus on the spatial properties of the layout in the early architectural design stage. It is because during the designer-client communication, the functional factors (size, location and adjacency) and visual factors (appearance and view) are the basic factors most concerned by the clients.

Based on the activity simulation model, this pre-occupancy evaluation module aims to: (1) Remind the clients the defined requirements; (2) facilitate the clients to specify more requirements; and (3) collect the feedback from the end users against these requirements and save these requirements and feedback in a systematic way.

Therefore, this module aims to provide a platform to systematically manage the following information: (1) Pre-defined requirements from the brief; (2) Information from the existing design model; (3) Further requirements developed by clients during communication; and (4) Feedback from the clients on the design solution.

A database containing clients’ requirements, feedback and data from existing design model is designed to support the pre-occupancy evaluation process. The requirements of building project covers space requirements mainly including requirements on area, location, adjacency, circulation, flexibility, fixtures and etc. The extension of this evaluation method in other aspects such as site, building envelope or HVAC system will be discussed in future research.

Kiviniemi (2005) categorizes the space requirements into two main requirements objects: (1) space program instance (SPI) and (2) space program type (SPT). The space program instance contains the requirements of space such as area, occupancy type, max occupancy number, location, number of space units, adjacent spaces. The space program instance can be linked to several space instances in the design model. The space program type defines the identical requirements shared by several space instances in the requirements model. It contains the requirements about activities, function, space program fixtures, indoor climate, acoustics, lighting, flexibility, safety, comfort and etc.

According to virtual environment provided by the activity simulation model, some requirements from the space program are selected for the basis of pre-occupancy evaluation. The space program instance and space program type is also distinguished in this pre-occupancy evaluation module (Figure 7) .

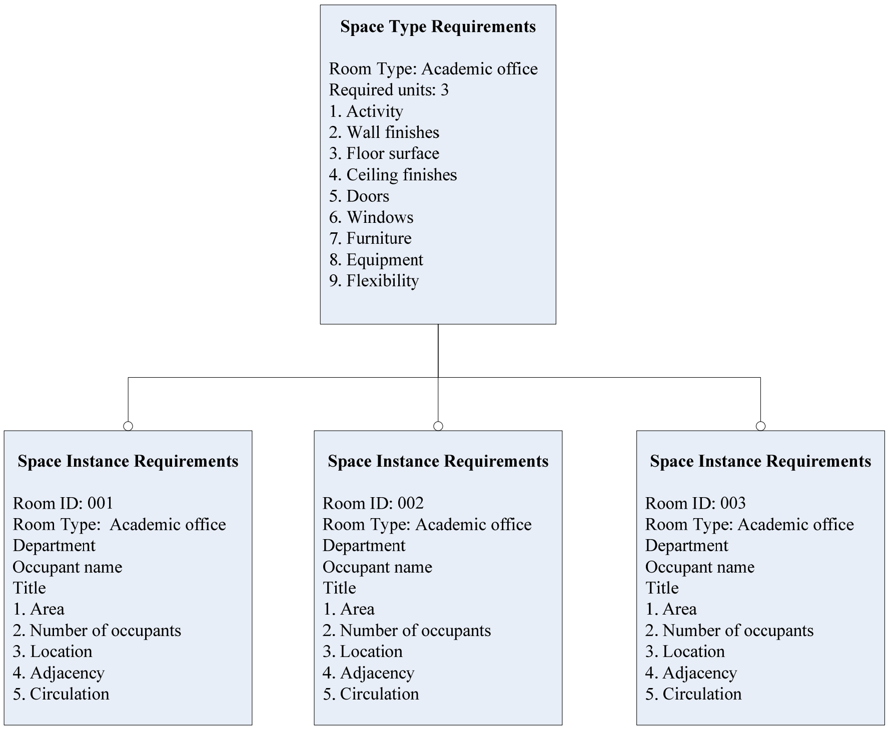


Figure 7: *relationship between space type requirements and space instance requirements*

In this way, the structure of requirements model can be simplified significantly. According to this structure, the clients' feedback of the design solution is also combined with the requirements information.

Pre-defined requirements: these requirements are extracted from the existing project brief. During the design-client communication process, new or more specific requirements may be continually generated, thus this module can record the change and generation of project requirements during the communication.

Design solutions: during the designer-client communicating, most of the design information is illustrated in the form of user activity simulation model (containing building model). Therefore clients are asked to give their feedback during the observation of the user activity simulation model. Some of the non-graphical information, such as area of each room, is extracted from the building model and stored into the database of the pre-occupancy evaluation module.

Clients' feedback: Questions about end users' spatial satisfaction are asked to obtain feedback on the design solution, for example, "Does this room have enough space to work without crowded feeling?", or "Does the layout can match your daily workflow?" The users can give response at different levels or give comments. The feedback is saved directly into the database in form of excel files. Designers can easily get access to these files and find them classified by different user names thereby facilitating the management of these files.

Design of the clients' requirements and feedback interface

On the pre-occupancy evaluation interface, users can trigger the user activity simulation model to observe the design solutions during their "daily life". After observation, they are requested to fill in the space instance requirements and feedback form of the rooms they observed. The room ID is the link between the user activity simulation model and the requirements and feedback interface. For example, when a client observing the user activity simulation model, the room ID is shown on the top of each room, and the client can open the corresponding clients' requirements and feedback form on space instance via the interface (Figure 8). A 2D layout is used to help the clients to give feedback on each room. Clients can press the button representing each room and the space instance requirements and feedback form is popped up. The space type requirements and feedback form can be opened by clicking the space type requirements button.

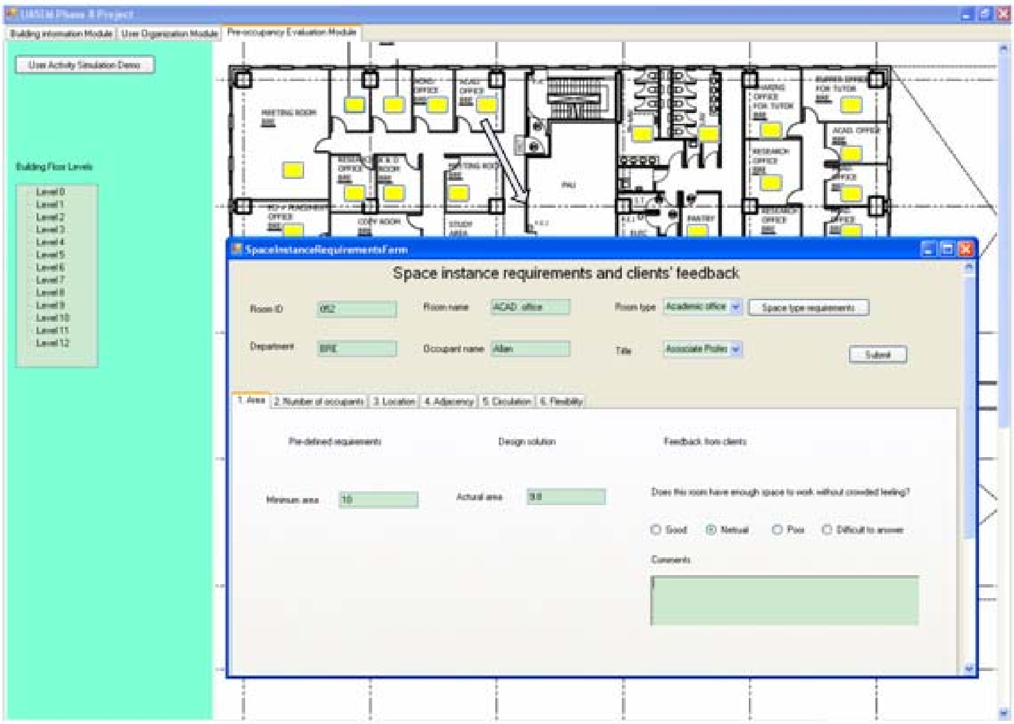


Figure 8: *Pre-occupancy evaluation module interface*

CONCLUSION AND FUTURE WORK

This paper proposed a BIM based user pre-occupancy evaluation method (UPOEM) to facilitate the design-client communication in architectural design process. User activity simulation technology is used to enhance the visual experience of the clients, and a requirements and feedback interface is designed to facilitate clients to develop requirements and review design solution. A framework of implementation of the UPOEM in real project is also proposed. It is expected that the clients can have a better understanding of their future built environment via observing the user activity simulation model. The efficiency of design review will be also improved by the support of the requirements and feedback interface.

This method will be tested in a campus project in further study, which aims to validate the effect on improving the clients' performance during the designer-client communication.

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