User Activity Simulation and Evaluation Model for the Improvement of Space Planning in Office Buildings

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Abstract

User activity is the first thing need to be considered in the process of space planning design. Many methods are applied to generate or optimize the space planning alternatives based on the single objective function, graphical theory or global constraint methods. However, most of these works are not user-centered and implemented on plane. In this paper, an outline of a user activity simulation and evaluation model (UASEM) is introduced, which aims to simulate and predict the scenario of users' activities in 3 dimensional virtual environments. Based on this model, users and architects can evaluate the geometrical and topological attributes of the spaces in office buildings during the briefing and early design stage. Thus the suggestions are generated after the evaluation, which can be used to optimize the space planning of the office building. For the aim to facilitate the users and architects to specify their requirements and evaluate the design, an evaluation system containing subjective and objective indicators is also introduced in this paper.

Keywords: space planning, user activity simulation, virtual reality, design evaluation, briefing

1. Introduction

Buildings play a role of accommodating user's organizations and equipment, and enable their activities. The buildings provide users with indoor climate, technique services, and platforms for activities. They also protect users from intruders, wind, rain and other bad weathers. The relation between the user and the building is mediated through the spaces where the activities take place (Ekholm, 2000). Bjork (1994) reminded that functional spaces are very important for the architects in the early stage of design, and Ekholm (2000) described "functional space" as "represents the accumulated geometrical extension of the organization during an activity." Ekholm also remarked that in the bubble diagrams used in space planning process, the activities are the criteria to define the size and relationship between these bubbles (representing spaces), but not the building's spaces themselves. This remark emphasised the significance of the users' activities. Thus, to analyze the function of the space (or functional space) to see whether if it could accommodate users' activities effectively and efficiently is crucial in the design process.

Function analysis can play a significant role in briefing process by identifying the clients' functional requirements on the projects they have invested. An important part of the design process is to integrate the function analysis results into paper drawings or computer models thereby closing the synthesis gap between pre-design function analysis and the design solutions. One of space's primary functions is to accommodate people's daily activities, and it contains many properties which affect the outcome and efficiency of these activities. Such as sufficient area, reasonable adjacency and public access, comfortable indoor environment, suitable daylight and view, convenient facilities, as well as privacy.

This paper is focused on the analysis and evaluation of the space planning design which containing geometric properties and topological properties of the building space. The geometric factors like area, shape influence the size and shape of space boundaries, and affect the scope of the activities. The topological factors like the adjacency and workflow affect how one space relates to another, and influence the location of activities. Other factors as the thermal comfort and lighting etc. will also affect users' activities, but which are beyond the discussion of this paper.

Space planning problems focus on the allocation of activities to space which meets the set of criteria and to optimize some objectives. These problems have been studied by researchers from several fields for a long period such as architects, engineers, interior designers, computer scientists. The research scope also varied widely, which from the layout design of large facilities such as office building, hospital, campus, or department stores to plant or production facilities and layout of electronic circuits.

While the development of the solutions of space planning problems, some deficiencies in computer-aided space planning are concluded: The methods aiming at optimization of single objective seldom take the area and shape of each space into account, and only consider the single criteria such as cost associated with communication; The graphical method, as the conventional SLP method, the adjacency relationship between diversity activities are decided by rule of thumb, and the representations of the activities and relationships are circles and lines which can not reflect the communication such as workflow or human movement directly; Most of the space plans are represented in a two dimensional interface, and the human movement patterns are assumptions or imaginations in designer's mind (Liggett, 2000).

In this paper, the structure and components of a user activity simulation and evaluation model (UASEM) is introduced, so as to solve the problems mentioned above. The UASEM provides an immersive environment for users to understand the preliminary design given by architects, and it also provides an evaluation module which can produce an evaluation report at the end. The prototype of UASEM is also introduced based on a campus project.

2. Related work

Many different building simulation tools have been developed at the building level such as the energy systems, building physics, building services, building construction process and air/smoke dispersion. More powerful models can be built to simulate the physical processes of building in a short period due the increasing computer development. Most of these models do not take the users' activities into account, but only consider the performance of building. Figure1 shows different categories of building performance simulation models which can be divided into two categories: users involved and users not involved simulation models.

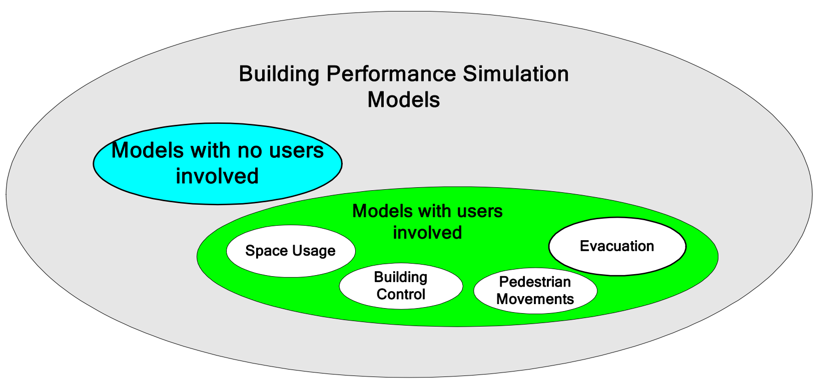

Figure 1: Categories of building performance simulation models

The research is poor in the filed of human behaviour and building usage simulation (Tabak, 2005a). The early static building models which contain the user activities were built by Eastman and Siabiris (1995). Some extension work has been done after then (Eckholm and Fridquist 2000, Zimmermann 2001). Many researches are focused on the prediction of pedestrian movements in urban planning and evacuation in a building which is on fire, or a sinking ship (Meyer-Konig T. et al., 2005). The simulations of such circumstances are very important since the real life experiments prohibit themselves. The simulation of users' activity in shopping mall or office building also have been conducted by Tabak et al (2006a) for the aim of evaluating the building performance such as HVAC design. Several experiments for the aim to observe the motions of real users have been done by Tabak et al (2006b). For the aim of improving the lighting control system, the user activity models are made respectively by Zimmermann (2006) and Mahdavi et.al. (2007). Zimmermann (2007) built a more sophisticated user activity model to improve the heating and cooling system which is an extension of his lighting control model. Lertlakkhanakul (2008) built a system can be used to simulate not only how space will look like but also how users interact with the smart environment based on predefined scenarios.

In architectural practice, it has been realized that there is a considerable gap between the architects and users which always brings about the failure in real design or built environment in which users do not satisfy and never expect. The problem usually results from users cannot imagine how the design will be emerged after construction phase (Lertlakkhanakul, 2008). It is necessary to build a model which can reflect the relationships between users and buildings by which the designer can predict the building performance and facilitate the users to specify their requirements.

3. The modelling Environment

3.1 Rationale of the UASEM

The ultimate aim of this research is to build a model to facilitate the early design stages, in which users and designers can use this model to specify their requirements and communicate more efficiently, then to improve the value of the design. Figure 2 shows the rationale of UASEM.

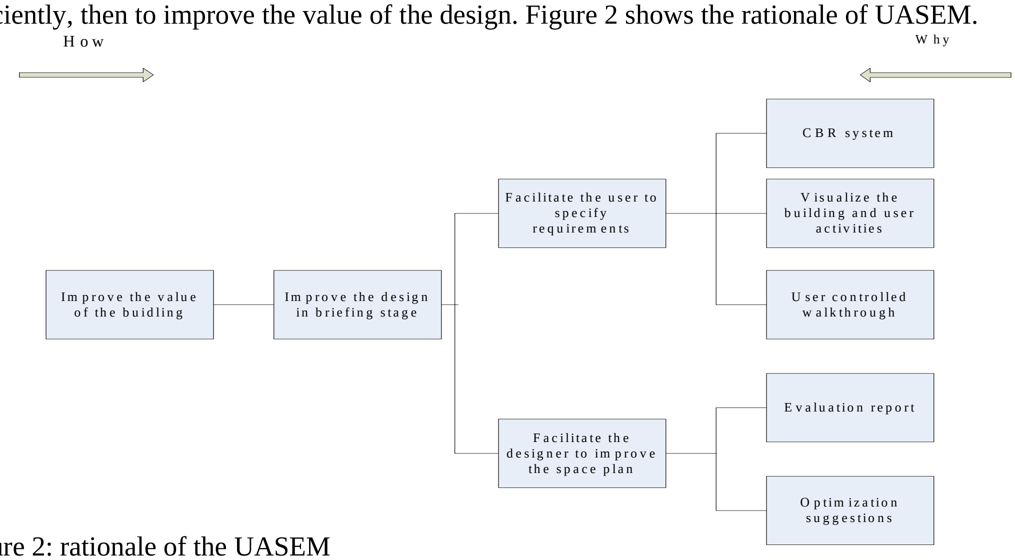

Figure 2: rationale of the UASEM

The potential benefits of using UASEM are listed as follow:

- Facilitate the clients to specify their requirements: at the information gathering stage, UASEM can predict and show the working scenarios rather than simple static 3D models of the buildings to the clients. The prospective users can "walkthrough" the models and "interact" with the "colleagues" and "see" the future arrangement of their offices. In such an immersive environment, it is easier to express the requirements and evaluate the design;

- Facilitate the architects to make decisions on allocating activities: Visualization is the basic function provided by UASEM, at the same time calculation and statistic functions are added to enhance its capability. For example, UASEM can calculate the walking distance of each user, record the interaction times between two employees, and represent the workflow of the whole organization. Theses functions are more important to the architects, because it is not easy for them to obtain these data in conventional design process.

The UASEM involves mainly two groups of people: architects and clients. According to the outline of design process (RIBA, 2000), the primary stage of applying the UASEM is outline proposal stage. In which a design concept based on the strategic brief is usually prepared, and the output includes partially developed project brief, outline proposals, an estimate of the construction cost and special presentation material. The UASEM is focused on the analysis of the solutions to functional and circulation problems encountered in the outline proposal.

Table 1: Outline of the architectural design work (RIBA, 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 3 shows how designers and clients interact with UASEM. The clients specify their requirements and input into the UASEM, and more specific requirements are generated by the support of UASEM (including building simulation, activity simulation and other techniques). The simulation models are built based on architects' preliminary design. The next step is the evaluation process, which involves the users' evaluation input and statistic analysis generated from the UASEM (such as walking distance, interaction frequency and adjacency relationship). Finally, the evaluation report containing the design suggestions is generated for the designer's further revision.

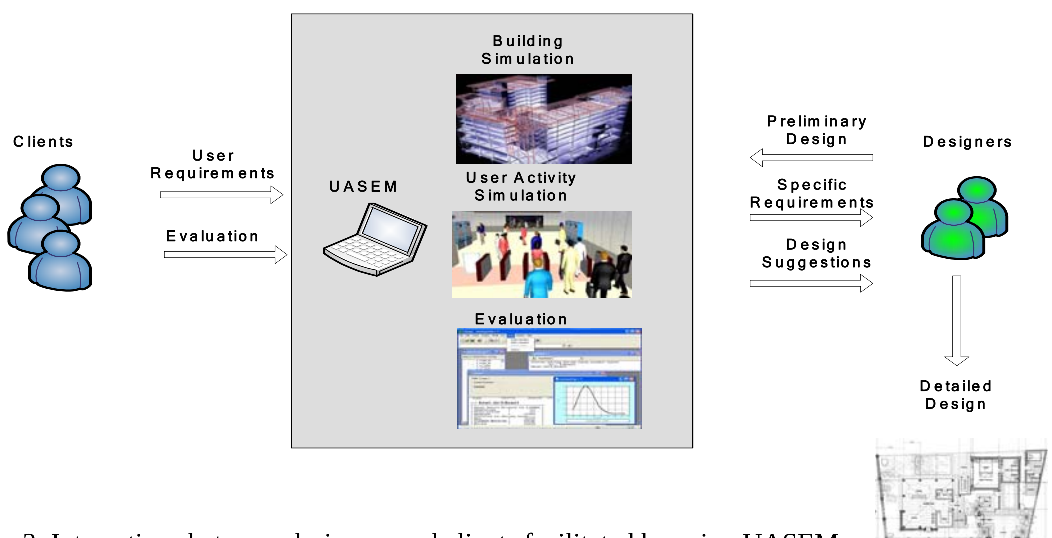

Figure 3: Interactions between designers and clients facilitated by using UASEM

3.2 System architecture of the model

The inputs of the UASEM are: (a) functional space diagram, (b) organization activity schedule and (c) the preliminary space plan. And the outputs of this model are: (a) user activity simulation scenarios; (b) evaluation report; and (c) design suggestions for the generation of optimized design.

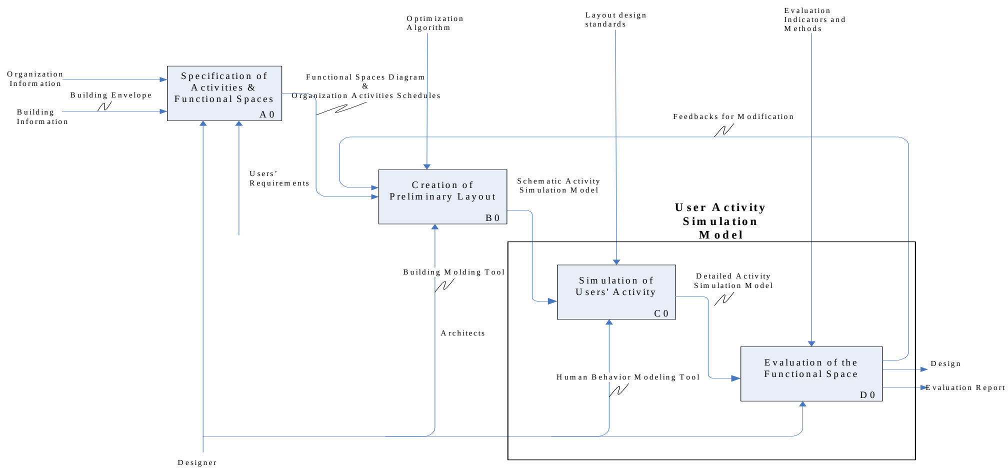

Figure 4: System architecture

Figure 4 shows the system architecture including four modules: (a) activity and spaces specification; (b) preliminary space plan creation; (c) user activity simulation and (d) function evaluation (in terms of space).

3.3 User activity simulation module

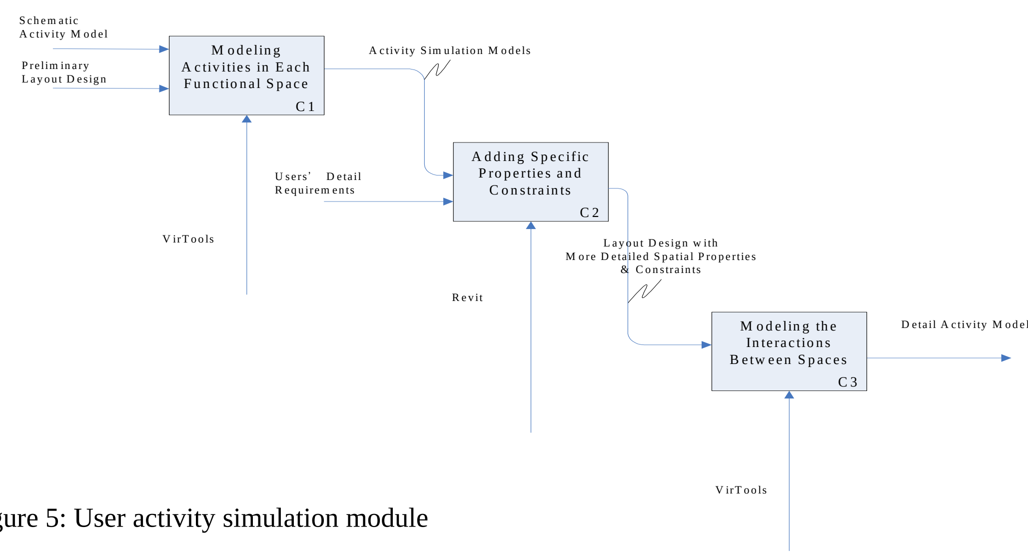

Figure 5: User activity simulation module

This module is a crucial part of the whole model, because it simulates key users' activities in the 3D building models and provides the scenarios of their daily activity for further evaluation and improvement of the space plan. It is assumed that the workflow of each user in current organization will not change when housed in the new building. For the aim to improve the calculation efficiency, typical users from each functional space rather than all the users of the organization are selected. So after interview with these "key" users in current organization, the daily workflow is recorded in forms of schedules.

3.4 Function evaluation (in terms of spaces) module

The function evaluation module is a significant part of this model. The users' requirements on the spaces of buildings can be specified as geometrical, topological and aesthetic factors listed in the lower part of the Table 2 (not limited to).

Table 2: Factors needs to be concerned in space planning

Evaluation factors / *Perspectives*	*Geometrical Factors*	*Topological Factors*	*Subjective Factors*
Buildings	*Area*	*Adjacency*	*Visual Factors*
	Shape	*Location of each room*	*Psychology*
	Height	*Public access*	
Users	*Usage of each room,*	*Workflow*	*Visual feeling*
	Usage of circulation area	*Interactions*	*Preferences*
		Location of each activities	

According to the factors need to be concerned during the space planning stage, a list of space planning performance evaluation indicators (Figure 6) are compiled to evaluate space planning performance while users are involved. These evaluation indicators are divided into two main categories: subjective indicators and objective indicators.

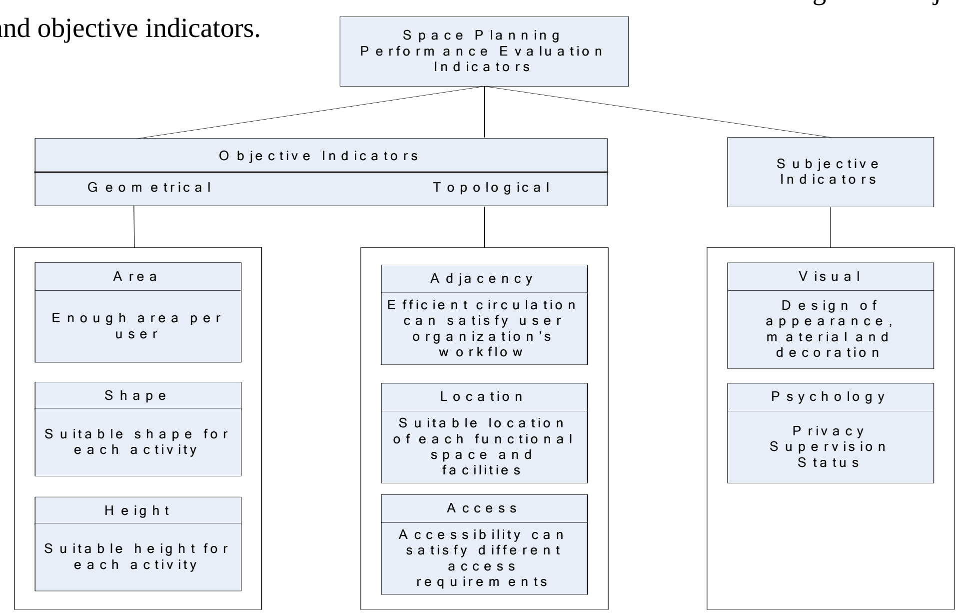

Figure 6: Space planning performance evaluation indicators

The USAEM provides two methods for the users to conduct the evaluation:

- A virtualization environment for immersive observation and subjective evaluation;
- Automatically generated statistical data for objective evaluation.

Users can choose one 'role' in the future office to observe other users' activities to evaluate the design, while this process is supported by the UASEM evaluation module. Users can check whether the spatial attributes such as area, shape, and height could satisfy the scope of their daily activity, they can also check the view from the window, lighting, material, decoration and etc. The psychological factors like the privacy, supervision from the manager and status also can be evaluated in the visual environment based on the virtual scenarios. For example, professors can check whether he can have a good view (supervision) of his/her while passing by the window of the lab. People who do not like direct visual access to their monitor also can check the arrangement of their workstation by using this model.

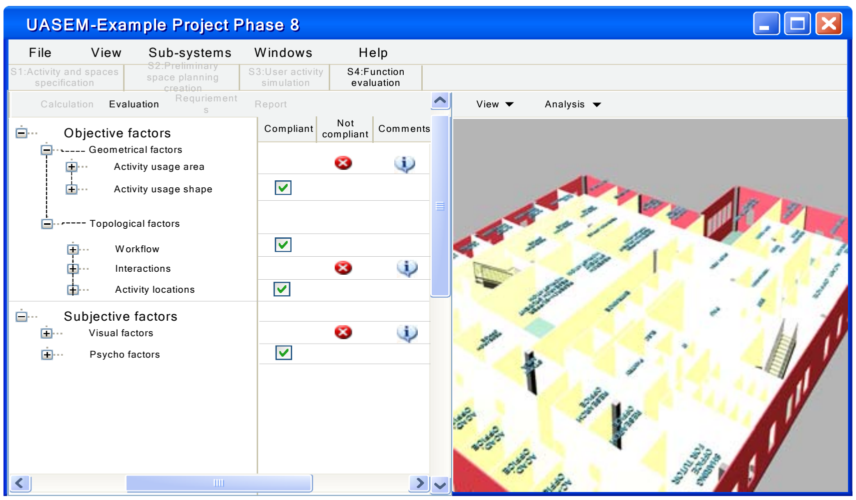

Figure 7: Interface of the user activity simulation module

Figure 7 is the interface of evaluation interface of UASEM. The main function is to help user conduct the evaluation in an immersive environment with support of the analysis data in the mean time. For instance, the user can evaluate the 'visual factors' which subject to the subjective factors while observing the building model displayed on the right part. The user should specify their requirement on each factor and input into the USAEM in advance. Then they can evaluate the space planning according to these requirements and give the result like "compliant" or "not compliant" with "comments" (Table 3).

For the aim to evaluate the topological indicators such as adjacency relationship between each functional room, some data is calculated by the UASEM and displayed in real time, such as the walking distance between two rooms, walking distance per day of one user, and number of users in each room. In the mean time, the spatial attributes of each functional room and personal information of each user are also displayed on the screen when triggered by mouse click (Figure 8).

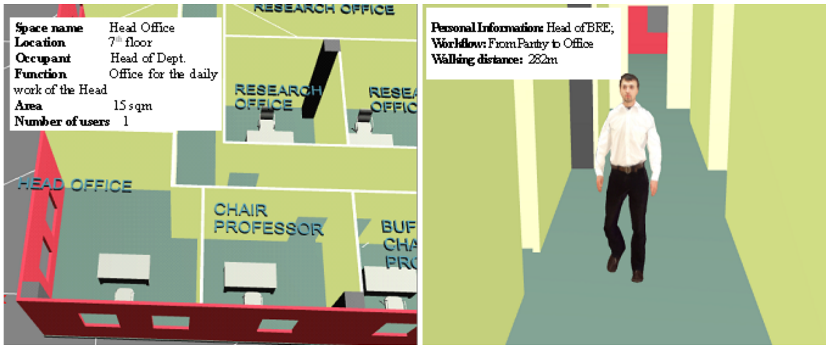

Figure 8: Real time information display in UASEM

Table 3: Evaluation report generated by UASEM

Evaluation results / *Evaluation factors*			*Requirements*	*Compliant*	*Not compliant*	*Comments*
Subjective factors		*Visual factors*				
		Psychological factors				
Objective factors	*Geometrical Factors*	*Activity Area*				
		Activity Shape				
	Topological Factors	*Activity Location*				
		Communication Efficiency				
		Accessibility				

After obtaining data as the walking distance of per user, the circulation efficiency is described by the sum of the total walking distance of the key simulation roles, and the communication frequency also can be measured by the interactions times of per user. The USAEM can generate the evaluation report as shown in Table 3 when users finishing the evaluation. The comments are collected for architects to revise the preliminary space planning design.

4. Prototype and case study

The UASEM is applied on the new project in authors' university. One of the departments is selected for the case study. This department will be housed on the 7th floor and 10th floor of the new building. Figure 9 shows the preliminary layout design and space information of the 7^{th} floor provided by designers.

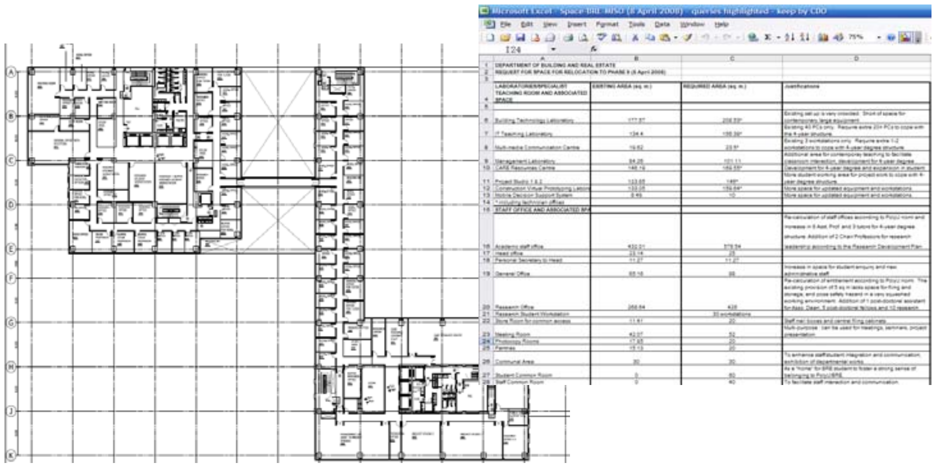

Figure 9: The plan of 7th floor of Phase 8

The user activity simulation model of the USAEM is developed by using software as Revit, 3DS MAX, and VirTools. Revit is for the building model producing, and then it is imported into the Autodesk 3DS MAX for rendering. After the mode of building is built, users' activities such as walk, desk work, and interaction are added into the building model by VirTools. Some functions such as display and calculation of the spatial attributes are based on the secondary development of VirTools. The user evaluation interface is developed by using C#. Some of the users of this department are invited to evaluate the design by using UASEM. Requirements and comments of the design are recorded and some of the suggestions are adopted by the architects in further revision. Figure 10 shows a revision according to suggestions made by users who prefer a more "impressive" entrance and require replacing the preliminary partition walls with glazing walls.

Figure 10: A suggestion made by users after using UASEM

5. Summary and future work

This paper introduced the research background and structure of the user activity simulation and evaluation model (UASEM). It can be used in the early architectural design stage to facilitate the collaborative working between users and architects, especially in forms of consultation meeting. It aims to help users to understand and evaluate the space planning of the future project, and collect suggestions from users for the architects to improve the preliminary design. While there are still some problems need to be solved in the future work: parts of the functions of the UASEM are under development, such as the workflow of users will be extracted after the real scenario simulation for circulation analysis and optimization. After the development of the whole system, the UASEM needs to be applied in more case studies for validation.

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