Challenges and suggestions in dealing with flexible space in predicting space utilization

Xingbin Chen[1] and Tae Wan Kim[2]

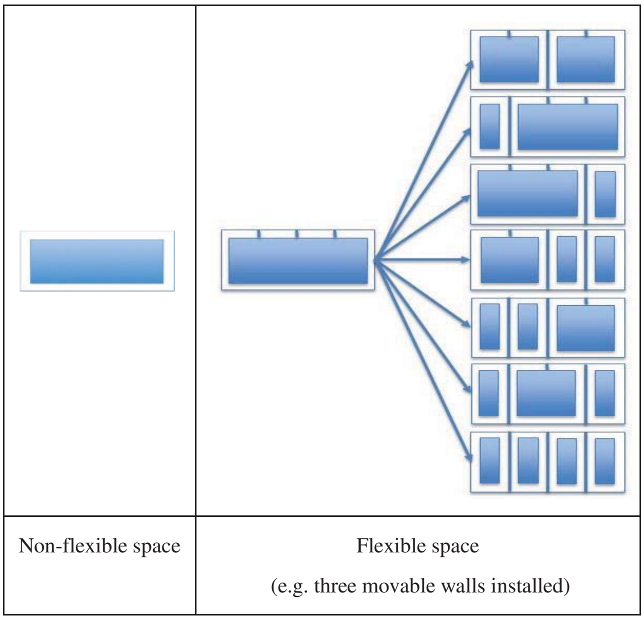
Abstract: Flexible space is an adaptable space that has been increasingly used in many office and academic buildings as it increases the use of the space available and reduces the unnecessary building area. However, the architectural, engineering and construction (AEC) industry lacks a formalized method that helps architects predict and update the space utilization of flexible space during the project development, as such prediction aims to maximize the use of the building space available without exceeding the target utilization policy. Consequently, current manual utilization prediction results in lower accuracy level and limits the maximized use of the flexible space, which has multiple space-use types that affect the prediction of utilization. To address this problem, we identified eight space-use type differentiators (SUTDs) based on the literature review and observations and discussed the use of them in automated space-use analysis (SUA), which can predict the utilization of flexible space via a computer program. This research builds on SUA and contributes to flexible space planning by providing a means of a more comprehensive and accurate SUA.

Keywords: flexible space; space-use analysis; space utilization; flexible-space-use type differentiator; user activity

I. Introduction

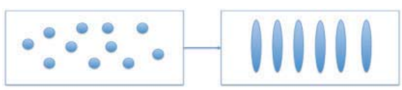
Flexible space (Figure I) is an adaptable space that can be used as one single unit to support an activity for a big group of users, or can be divided into a number of adjacent units to accommodate different activities for several small groups of users at the same time, e.g. a meeting room with movable partitions installed. Therefore, in flexible space, space configuration can quickly change via the movable components (e.g. walls, partitions) (Woodman 2010). Because the automated space-use analysis (SUA) will map user activities onto spaces by computer itself before computing the space utilization (Kim and Fischer 2014), it is necessary to classify spaces so that a computer program can choose an appropriate space-use type for an activity and determine spaces from the space program accordingly. In this paper, based on whether the space configuration can be changed or not by using movable components, we classify spaces into the following two types: flexible space and non-flexible space (Figure I). Non-flexible space is not adaptable as it can only be used as one unit, i.e., the space configuration of non-flexible space cannot response to quick reconfiguration through movable components such as movable walls and partitions.

FIGURE I
SPACE CLASSIFICATION IN SUA



Flexible space is different from open space, which has also gained in popularity as it makes higher net usable area available in buildings (Brennan et al. 2002; Kim and de Dear 2013; Oldham and Brass 1979). In SUA, open space can be classified as non-flexible space due to the absence of internal walls or partitions within the space (Oldham and Brass 1979), i.e., there are no movable components available within the space. Therefore, open space can only be used as one unit, and the space configuration cannot be changed. In such a space without interior physical barriers, people are located together along with the geometry of the layout, which reflects the pattern of users' groups (Brennan et al. 2002). Although there are some mobile furniture within the open space, such as desks and chairs, it is different from flexible space because flexible space is not just the space that can rearrange desks or chairs but relates to the change of spatial configurations by moveable components (Woodman 2010) (Figure II).

FIGURE II
OPEN SPACE



[1] PhD Student, Department of Architecture and Civil Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, xbchen2-c@my.cityu.edu.hk (*Corresponding Author)
[2] Assistant Professor, Department of Architecture and Civil Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, taewkim@cityu.edu.hk

Flexible space has become the trend and driving force in space planning (Steiner 2005). It is frequently found in commercial office buildings and academic buildings (Cheung 2009; Greden 2005; Pearce et al. 1992). There are some economic benefits available from its applications, such as ease of re-configuration, higher net usable area available, and increase in occupant density. However, it is difficult to maximize the use of the flexible space in an optimum degree without automated space-use analysis (SUA), because flexible space can be divided into a number of adjacent units, along with the multiplicities available in the space-use pairs and design options, the relationships between these three perspectives would become more complex as a result. SUA is used to predict the utilization of the space occupied by users and the related activities in a facility (Kim and Fischer 2014). With the result of SUA, the space of the building can be planned in an efficient manner by reduction of the improperly used space. Kim et al. (2013) defined the concept for SUA in three interrelated perspectives, i.e. space, user, and user activities. However, because this theory is not tailored to flexible space, architects still need to manually predict the utilization of flexible spaces. To address this problem, this research will identify space-use type differentiators (SUTDs) specifically for flexible space and discuss the implementation of them in automated SUA.

II. Motivating Case

The Haahtela Project Management Group, located in Finland, was employed as a planner in the Cygnaeus High School renovation project in 2003 (Pennanen 2004). In this project, the City Department of Education wanted to reduce the net spatial area of the school from 6,926m^2 to 6,508m^2 without losing its functions and activities. During a group meeting, the planner pointed out that the utilization of the auditorium for education (270m^2 area) is only 2% as it just accommodates a user-group of 220 students participating in final examinations before graduation. Considering that such examinations require a large amount of space area but take only a small amount of hours, the planner suggested the formation of three adjacent 80m^2 classrooms into a flexible space. Normally, this flexible place can be used as three classrooms for teaching activities with movable walls installed that are good at sound insulation. When final examination comes, this flexible space can be used as an auditorium to accommodate such an activity.

Although the planner could suggest the use of flexible space to delete the unnecessary space (i.e., auditorium) and save the building area in the school project, this work was done ad hoc because the planner did not have any automated tool to predict the utilization of flexible space. Without such a tool, manual utilization prediction cannot maximize the use of flexible space. In current automated space-use analysis (SUA), before computing the utilization, a computer program would map user activities onto the appropriate spaces. This is divided into three steps, i.e. choosing spatial requirements, finding spaces, and mapping the activity onto spaces (Kim and Fischer 2014). However, the automated SUA cannot deal with mapping the user activities onto flexible space due to the following reasons:

First, there is no property related to flexible space within the ontology for representing user activities. Only the properties of whole room use requirement or equipment use requirement related to non-flexible space are available in current automated SUA. Taking this case as an example, when the computer proceeds "finding spaces", if a lecture requires occupying a classroom (160m^2), and the lecture specifies a space type it needs, the computer will find "all spaces" that are not designated and whose type is the same as the specified space type. However, "all space" found in this step only includes the non-flexible space and the whole flexible space (e.g. 240m^2- combined all the three sub-units of the flexible space), without dividing the flexible space into appropriate configurations (e.g. 160m^2- combined two sub-units of the flexible space) and letting the remaining vacant part support other activities. In this case, the architect would expect to map this lecture onto two adjacent sub-units of the flexible space and let the remaining one to accommodate other activities.

Second, a computer cannot map the activity onto part of the flexible space (one sub-unit or several adjacent sub-units combined) based on current SUTDs because they do not deal with the differences between flexible space and non-flexible space. In this case example, if a lecture requires occupying a classroom (160m^2), and it does not require designated spaces, then a computer maps the lecture onto the found spaces and generate the activity-space pairs. However, based on the found spaces (i.e. non-flexible space and whole flexible space) in the "finding space" step, a computer cannot map the lecture onto part of flexible space (e.g. 160m^2- combined two sub-units of the flexible space), letting the remaining one unit to support the other activity, and generate the correct activity-space pairs. Therefore, architects should manually map user activities onto appropriate flexible space before computing the utilization of flexible space, and this mapping process has multiple space-use types that affect the prediction of utilization.

III. Points Of Departure

We reviewed the prior work related to SUA in order to analyse the current research domain and space utilization theory. The way to get the result of the space utilization is dividing the total amount of activity loads by the sum of open hours of the space. The following three parts provide the useful backgrounds to this research: (1) architectural programming; (2) workplace planning; (3) automated SUA.

Architectural programming is solving the planning problems by providing the design options via research and decision-making processes (Cherry 1999). Cherry (1999) introduced space utilization formula in an educational building project for determining the spaces needed. Therefore, with the predictable schedules and number of users available, it can calculate the utilization and use it as a measurement of the space-use. However, the quantitative relationships between the space, user, and the space utilization are not formalized within the architectural programming (Kim et al. 2013). In addition, architectural programming depends heavily on architect's experience. As a result, predicting the space utilization via this way would be inconstant across different architects.

Workplace planning is facilitated in the programming phase of the project, as it can be used to plan the number of spaces by considering the activities, sizes, utilization degree and the total net area (Pennanen 2004). According to Becker (2008), the policy on utilization functions as one of the performance requirements. Therefore, based on Pennanen's practice in office buildings and hospitals (2004), 50% utilization means that this space can be used without waiting; 50% to 75% means that this space needs to be scheduled; 80% or above utilization means that the space is not sufficient in number to accommodate activities. However, workplace planning does not consider the detail of mapping activities onto spaces at a sufficient level to create the automation of this process (Kim et al. 2013).

Based on the previous research efforts, Kim et al. (2013) introduced the automated SUA. Given user profiles describing the user activities and spaces, the automated SUA predicts the utilization of each space. As utilization functions as a metric for space-use, Kim et al. (2013) defined four utilization levels for spaces as follows: (1) utilization ranging from 0 to 0.5 means that the activities can be held in this space without waiting; (2) utilization ranging from 0.5 to 0.75 means that the activities held in this space may need to be scheduled; (3) utilization ranging from 0.75 to 1.0 means that the activities need to be relocated; and (4) the utilization that is larger than 1.0 means that the space is not sufficient to accommodate activities. However, as the current automated SUA defines the space configuration as fixed (non-flexible space), it does not predict the utilization of the flexible space. Therefore, the architectural, engineering and construction (AEC) industry lacks a formalized and automated approach to help architects predict and update the space utilization of flexible space during the development of the building projects.

IV. METHODOLOGY

In order to contribute to a more comprehensive automated SUA that can predict the utilization of the flexible space, this research will identify the SUTDs to formalize the space-use types of flexible space based on literature review and observations. Because the motivation is making the related SUTDs available, we will first determine the characteristics of the user activities that are accommodated by flexible space. It can then derive the SUTDs related to flexible space from the identified characteristics. These SUTDs will be used to derive the space-use types before proceeding the automated SUA program. Once the automated SUA encompasses the space-use types defined in this research, it will be able to predict the utilization of flexible space and to update the prediction in a quick, consistent and accurate way when the related data changes, supporting decision-making about space planning since utilization is a performance attribute for SUA (Cherry 1999; Pennannen 2004).

V. FINDINGS

User activities have seven characteristics, five of which could be applied to flexible space (Table I). Therefore, it is difficult for architects to analyse these characteristics without the help of a computer system. The characteristics can indicate how the space-use types will be considered in the SUA process (Kim and Fischer 2014). As this research aims to extend the current automated SUA, developed by Kim et al. (2013), to predict the utilization of flexible space, the space is categorized into two kinds according to whether or not the space configuration can be changed, i.e. non-flexible space and flexible space. Since the non-flexible space is already covered in current automated SUA (Kim et al. 2013), this research only focuses on the flexible space domain. Table I also represents which kinds of space the characteristics can be applied to.

TABLE I
CHARACTERISTICS OF USER ACTIVITIES

Characteristics of user activities	Non-flexible space	Flexible Space
C1: Some users have more stringent spatial requirements for their activities than the minimum requirements supports (Cherry 1999).	✓	✓
C2: Some activities require a designated space, e.g. a professor's office (Pennannen 2004).	✓	
C3: Some activities require occupying one whole unit of space or occupying several adjacent units of space, while others need a piece of equipment of a space.	✓	✓
C4: Some activities are conducted in a specifically named space while others are conducted in any space providing certain features (Kim 2014).	✓	✓
C5: Some activities are atypical activities, which are not conducted on a regular basis. Atypical activities are not taken into account in utilization computation, although they are predictable events and must be accommodated by the design (Cherry 1999).	✓	✓
C6: Some activities require high degree of sound insulation (> 55db).	✓	
C7: Some activities require visual privacy between the adjacent units of space.		✓

A particular space-use type of a user activity can be described as a set of choices for each SUTD. The current automated SUA (Kim and Fischer 2014) has six SUTDs, from which 288 space-use types that affect SUA are derived. In order to predict the utilization of flexible space, in addition to SUTDs 1, 2, 3, 4, and 8, which are already available, we add SUTDs 5 and 7 and modified SUTD 6 so that the SUA can cover the utilization prediction of flexible space (Table II). Since the SUTDs 4 to 8 belong to constraints or preferences, when preferences are not identified and equal to constraints, the number of the space-use types is 192 (=2×2×48). When the preferences differ from constraints, the number of the space-use types is 9216 (=2×2×48×48). All of these 9408 (=192+9216) types must be gone through and treated differently for each space in SUA including those for flexible space. In addition, the relationships between the characteristics of user activities and SUTDs are summarized in Figure III. Therefore, the SUTDs found in this research must be used in choosing spatial requirement and finding the spaces before mapping the activities onto spaces within the automated SUA.

TABLE II
SPACE-USE DIFFERENTATIOR (SUTD)

No.	Content	No.	Content
SUTD1	Typical activities		
*2	Atypical activities		
SUTD2	Important user		
*2	Regular user		
SUTD3	Constraints= preferences	SUTD4	Requiring designated space
*48 & *2304	*48	*2	Not requiring designated space
		SUTD5	Requiring high degree of sound insulation (>55db)
		*2	Requiring normal degree of sound insulation (≤55db)
		SUTD6	Requiring an equipment
		*3	Requiring one whole unit of space
			Requiring several adjacent units of space combined
		SUTD7	Requiring visual privacy between the adjacent units of space
		*2	Not requiring visual privacy between the adjacent units of space
		SUTD8	Requiring specifically named space
		*2	Requiring space with certain features
	Constraints≠ preferences		
	*2304	SUTD4	Requiring designated space
		*2	Not requiring designated space
		SUTD5	Requiring high degree of sound insulation (>55db)
		*2	Requiring normal degree of sound insulation (≤55db)
		SUTD6	Requiring an equipment
		*3	Requiring one whole unit of space
			Requiring several adjacent units of space combined
		SUTD7	Requiring visual privacy between the adjacent units of space
		*2	Not requiring visual privacy between the adjacent units of space
		SUTD8	Requiring specifically named space
		*2	Requiring space with certain features

VI. CONCLUSION

To inform architects quickly and consistently about the performance of the flexible space in terms of utilization, research efforts must be put into the extension of automated SUA so that it can deal with the flexible space domain. However, the current theories, such as architectural programming, workplace planning, and automated SUA, lack the definition of space-use types related to flexible space. Therefore, this research identified eight SUTDs for formalizing the space-use types that encompass the use of flexible space. To predict the utilization of the flexible space in a quick, consistent and accurate manner, the current automated SUA must be extended to represent the SUTDs we identified and map user activities onto appropriate flexible spaces with the understanding of the SUTDs. To enable the extension of the automated SUA, the following studies must be conducted in the future: (1) developing the ontologies of the user activities and spaces for flexible space; (2) formalizing a method for mapping the user activities onto appropriate flexible spaces; and (3) extending the automated SUA into flexible space domain. Studies in such directions would result in a more comprehensive version of automated SUA.

ACKNOWLEDGMENT:

The work described in this paper was supported by a grand from City University of Hong Kong (Project No. 7200360).

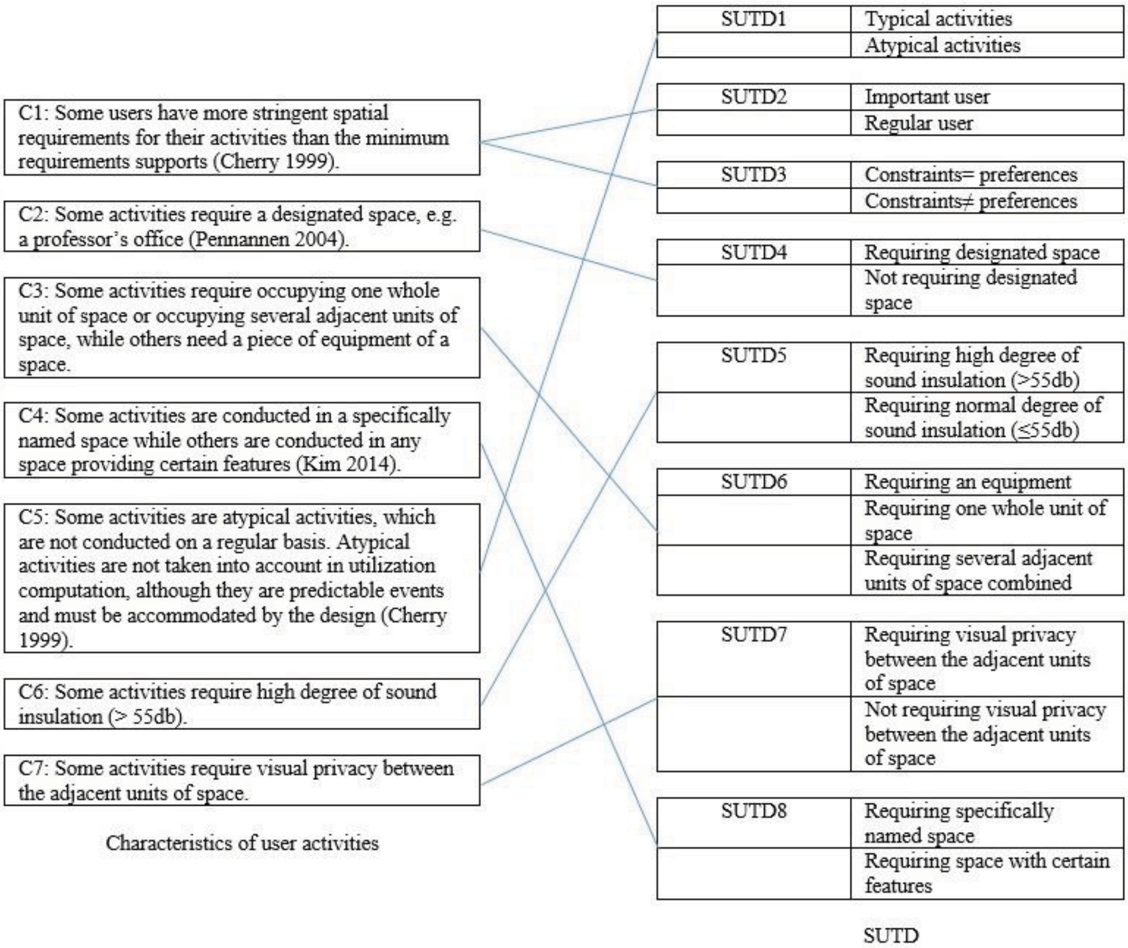


FIGURE III
RELATIONSHIP BETWEEN THE CHARACTIERSIC OF USER ACTIVITIES AND SUTD

REFERENCES

[1] R. Becker, "Fundamentals of performance-based building design", *Building Simulation*, vol. 1, no. 4, pp. 356-371, 2008.
[2] A. Brennan, J. S. Chugh, T. Kline, "Traditional versus open office design a longitudinal field study", *Environment and Behavior*, vol. 34, no. 3, pp. 279-299, 2002.
[3] E. Cherry, "Programming for design: From theory to practice", John Wiley & Sons, 1999.
[4] T. Cheung Chan, "Do portable classrooms impact teaching and learning?", *Journal of Educational Administration*, vol. 47, no. 3, pp. 290-304, 2009.
[5] L. V. Greden, "Flexibility in building design: a real options approach and valuation methodology to address risk", Doctoral Dissertation, Massachusetts Institute of Technology, 2005.
[6] T. W. Kim, M. Fischer, "Automated Generation of User Activity–Space Pairs in Space-Use Analysis", *Journal of Construction Engineering and Management*, vol. 140, no. 5, 2014.
[7] T. W. Kim, M. Fischer, "Ontology for Representing Building Users' Activities in Space-Use Analysis", *Journal of Construction Engineering and Management*, vol. 140, no. 8, 2014.
[8] T. W. Kim, R. Rajagopal, M. Fischer, C. Kam, "A knowledge-based framework for automated space-use analysis", *Automation in Construction*, vol. 32, pp. 165-176, 2013.
[9] J. Kim, R. de Dear, "Workspace satisfaction: The privacy-communication trade-off in open-plan offices", *Journal of Environmental Psychology*, vol. 36, pp. 18-26, 2013.
[10] G. R. Oldham, D. J. Brass, "Employee reactions to an open-plan office: A naturally occurring quasi-experiment", *Administrative Science Quarterly*, pp. 267-284, 1979.
[11] M. Pearce, A. K. Goel, J. L. Kolodner, C. Zimring, L. Sentosa, R. Billington, "Case-based design support: A case study in architectural design", *IEEE Expert*, vol. 7, no. 5, pp. 14-20, 1992.
[12] A. Pennanen, "User activity based workspace definition as an instrument for workplace management in multi-user organizations", Haahtela-kehitys, 2004.
[13] J. Steiner, "The art of space management: Planning flexible workspaces for people", *Journal of Facilities Management*, vol. 4, no. 1, pp. 6-22, 2005.
[14] K. Woodman, "Re-Placing Flexibility: An investigation into flexibility in learning spaces", *Articles évalués/Refereed Papers*, vol. 21, pp. 477, 2010.