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Automated updating of space design requirements connecting user activities and space types

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ABSTRACT

Architects need to update design requirements whenever user information changes during project development. However, they often do so manually because current theories do not effectively capture the rationale behind the generation of requirements, which is often related to the activities of building users. In this paper, we formalized the relationship between design requirements and the user information in support of automated updating of the requirements. We then developed an automated requirements updating method comprising three phases: updating of user information, updating of the requirements for each space type, and adjustment of the numbers of space types to satisfy target utilization. We validated our method by comparing, for the same case example, the performance of a prototype system with that of experienced architects with respect to updating design requirements according to user information changes. Deployment of this method would allow architects to update design requirements quickly and accurately during project development.

1. Introduction

To achieve greater design effectiveness, the architecture, engineering, and construction (AEC) industry needs to improve not only design performance to satisfy design requirements, but also the performance of requirements engineering and management. While the requirements engineering process focuses on identifying and formalizing the requirements of a project, requirements management focuses on keeping these requirements usable and up to date throughout the project [1]. To manage design requirements, therefore, the following conditions must be met: (1) monitoring to ensure that a design solution satisfies the requirements and (2) updating of the requirements when project information that affects those requirements changes. Due to recent advances in integrating design requirements with design spaces [2–4], existing tools, such as dRofus (http://www.drofus.no/) and Roomex (http://www.granlund.fi/en/software/roomex/), assist architects to satisfy the first condition. However, no existing tool allows the second condition (updating requirements when project information changes) to be satisfied, because design requirements are not sufficiently linked with the user information, a key part of the project information that affects the requirements. Consequently, when user information changes during project development, architects must interpret the effects of the changes and manually update the design requirements on an ad hoc basis. Such a practice is error-prone and time-consuming for the following reasons:

- Architects do not systematically document the rationale behind requirements engineering with regard to user information. Often the rationale exists only in the architects' minds and is therefore difficult to track over time.
- Architects need to deal with the complexity that arises from many types of requirements, many types of space in a building, and many types of users and their activities.

To address these issues, this study first aims to model design requirements in a computer-interpretable way and to formalize the relationship between these requirements and the user information for use in automated updating of requirements. Second, it aims to develop a method for updating design requirements automatically according to the following changes in user information: (1) an added or removed user group, (2) a changed number of people in a user group, (3) an added or removed activity of a user group, (4) changed requirements of a user activity, and (5) a changed space type that accommodates a user activity. In this paper, a "user model" is a computational representation of user information that can be used to track these five changes. Architects also need to consider other types of information, such as project cost and scope, building quality, environmental and technological constraints, and regulation and codes [5,6], during updating of design requirements. However, in this paper we focus on the relationship

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between user information and design requirements because this relationship is a reference for setting up space programming regarding how people use and explore built environments. In addition, this study focuses on space design requirements (or space requirements), as these constitute the largest of seven requirements groups, including site requirements, building requirements, and circulation requirements [2], and user activities can mostly be accommodated by the space level of a building. Typical examples of space design requirements are area, adjacency to other spaces, indoor environmental quality, and furniture.

2. Methods

Following the ontology development methodology suggested by Noy and McGuinness [7], we first represented design requirements as a vocabulary for the automated requirements updating method. This process enabled the information relating to users, spaces, and requirements to be interconnected in support of automated updating of requirements. Based on this representation, we then developed a method for updating requirements automatically when user information changes. This paper represents the method using Unified Modeling Language (UML) activity diagram symbols. Finally, we validated our method by developing a hypothetical but realistic case example based on our observations of university buildings and comparing the performance of seven architects with an average of 11 years of experience with that of a prototype system we developed in Structured Query Language (SQL).

3. Points of departure

Through a review of the requirements engineering and management literature, we found that user information is not linked with requirements at a level that is sufficient to support automated updating of requirements. We also reviewed the workplace planning theory and user activity representation models to obtain the fundamental knowledge required to build links between user information and requirements.

3.1. Existing methods for requirements engineering and management

Requirements engineering is described as "finding what shall actually be built," and requirements management entails ensuring that the engineered requirements are usable and up to date throughout the project [1]. In requirements engineering, many researchers have formalized processes to assist architects to systematically capture and document requirements [8–10]. Based on these processes, computer tools to guide the requirements engineering process and foster collaboration between an architect and other project participants have been developed [11–14]. Requirements hierarchies for fostering a systematic and comprehensive approach to requirements engineering and management have also been developed [2,15]. Despite the improvements in the specification and documentation of requirements provided by these research efforts, they do not explicitly integrate user and requirements information, and, therefore, automated updating of requirements according to user information changes remains unviable.

In requirements management, automated monitoring of requirements by connecting a product (i.e., space) model with design requirements has been well researched. For example, Kiviniemi [2] contributes to the body of scientific knowledge by specifying each requirement in a form that can be connected to Industry Foundation Classes (IFC), a well-known representation of a product model. Some requirements management frameworks have been developed to analyze occupancy based on space and user information [16] or to readily trace design requirements for computer-aided design [4]. Bhatt et al. [3] represent requirements as relationships between spaces and pieces of equipment on three different levels (conceptual, qualitative, and quantitative) such that computers can determine whether or not a design satisfies the requirements. However, all of the existing methods require architects to update space requirements manually when user information changes, because they do not capture the rationale behind the generation of requirements, which is often related to the activities of building users.

3.2. Workplace planning

The traditional approach to determining the number of space types, one of the most important design requirements, is to use standardized parameters based on either personal experience or surveys, e.g., 1.33 exam rooms are required per physician for healthcare facilities [13]. This approach can respond to changes in the number of people in a user group but cannot respond to changes in the activities of the group or to changes in a client's preference regarding the use of the space. For example, clients may want high utilization (levels of use) in some spaces to reduce building costs, and low utilization in other spaces to increase scheduling flexibility and avoid long queues for activities in these spaces [8]. To overcome these challenges, workplace planning [17] allows architects or planners to set up target utilization levels for each space type and to determine the number of space types required based on user activity information such as frequency and duration in each space. If the utilization of a space is less than 0.50 (50%), activities can be conducted in this space without waiting. If the utilization of a space is less than 0.75 (75%), activities accommodated by this space may need to be scheduled [17]. Hence, our research uses workplace planning as a mechanism for automatically updating the number of each space type required during project development according to pre-determined target utilization levels.

3.3. User activity representation

User activity is a key concept for connecting user models and requirements models because requirements are closely related to user activities. Although many AEC researchers have developed representations of construction activities for various purposes [18–21], few research efforts have represented user activities in relation to requirements management. Tabak et al. [22] classify user activities into skeleton activities (those that form a sequence) and intermediate activities (physiological or social activities) and model them separately to generate activity schedules. Pennanen [17] models user activities as having properties for computing the utilization of space types, such as activity driver (i.e., user group), load (i.e., hours that an activity demands from spaces), and group size. Although these models provide background knowledge on user activities in buildings, they do not clarify the relationships between requirements and user activities.

Kim et al. [23] formalize the relationships between spaces, users, and user activities to support automated mapping of user activities onto spaces. Specifically, they represent user activities as the tuple <User> <Action> <Spatial requirements>, where "Spatial requirements" is defined as the properties of a space that a user activity requires for occupying that space. Although this model reveals a relationship between requirements and user activities, it does not include the collectively exhaustive relationships between the two because some space requirements are not spatial requirements. For example, "having power-saving bulbs in a laboratory" is a space requirement, but is not a spatial requirement because it is not directly linked to a user activity. A method for representing all types of space requirements in such a way that they can be connected simultaneously to user activities and spaces is therefore lacking.

4. Formalization of the relationship between space requirements and building users

This section describes a representation of space requirements and how users, spaces, and design space requirements can be connected to each other. Our work provides an explicit structure that specifies different requirements in terms of their relationships to user information.