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Modeling Building Semantics: Providing Feedback and Sustainability

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Abstract: Even minor changes in user activity can bring about significant energy savings within built space. Many building performance assessment methods have been developed, however these often disregard the impact of user behavior (i.e. the social, cultural and organizational aspects of the building). Building users currently have limited means of determining how sustainable they are, in context of the specific building structure and/or when compared to other users performing similar activities, it is therefore easy for users to dismiss their energy use. To support sustainability, buildings must be able to monitor energy use, identify areas of potential change in the context of user activity and provide contextually relevant information to facilitate persuasion management. If the building is able to provide users with detailed information about how specific user activity that is wasteful, this should provide considerable motivation to implement positive change. This paper proposes using a dynamic and temporal semantic model, to populate information within a model of persuasion, to manage user change. By semantically mapping a building, and linking this to persuasion management we suggest that: i) building energy use can be monitored and analyzed over time; ii) persuasive management can be facilitated to move user activity towards sustainability.

Keywords: *Semantic Modeling, Energy Use, User Behavior, Building Performance, Persuasive modeling*

1. Introduction

The cost and environmental impact of inefficient energy use in buildings, in combination with increased focus on legislation, has increased pressure on users to assess and adjust their behavior in order to lower energy consumption. Whilst users are aware of these issues, and often have a positive attitude towards a change in behavior, they are not provided with sufficient information to manage change towards sustainability. Whilst several standards exist for analyzing building energy efficiency (i.e. BREEAM, LEED, HK-BEAM and GB Tool), they largely focus on building structure and components without taking into account contextual information dynamic building usage, i.e. occupant behavior, organizational culture, etc.

To facilitate positive change, information concerning the building, user energy use and attitude, has to be monitored in order to provide contextually relevant feedback to persuade the user to change behavior towards target behavior (i.e. sustainable energy use). Since existing standards provide insufficient information structures to inform users of their energy usage, in context of building and environmental variation, we must find and use alternative means of informing persuasion techniques. In this paper we propose the use of a semantically rich building model. By storing information relating to building usage (occupant numbers, activities, organizational culture, location etc.) we are able to group and compare energy consumption and energy efficiency of building with similar factors, and/or as a result of user activity. This information can be used to facilitate and inform persuasion management techniques, and therefore supports change in activity toward target behavior.

2. Problems with Building Performance Assessment

Building performance assessment methods and tools have been developed worldwide, to assess the energy efficiency of physical building structures. Current building performance assessment methods can be crudely split into two categories: i) those based on criteria and weighting systems - e.g. BREEAM (UK); or ii) those that use a checklist of building performance aspects - e.g. LEED (US). If such assessment performance is properly applied, they can provide a useful set of tools to identify Key Performance Indicators (KPI) and monitor improvements in the environmental performance of the building structure [1], however such performance assessment often fail to consider energy sustainability in context of building type, location and/or use.

Current building assessment techniques are applied on a voluntary basis, fail to support the full life-cycle of the building, and make it hard to understand the impact of user behavior (i.e. the social, cultural and organizational aspects of the building). Research conducted by Foresight [2] shows that building usage is significant to an individuals overall energy usage. Mackay [3] also argues that minor changes in the way we live and work within buildings, such as personalized heating / lighting settings, can bring variation in energy savings. Users currently have limited means of determining how sustainable they are, especially when energy capture via meter feedback ignores contextual information relating to building type and/or business activity. To facilitate long-term sustainability, buildings assessment must be able to monitor energy use over time in order to determine areas of potential change in context of building type, building structure and user activity. Only by providing feedback in light of live semantic context can appropriate persuasion be provided to users to encourage manageable change.

3. Semantic Building Information Modeling

In order to place building energy assessment in context of building use and user activity, we need to be able to create associations between the data and the specific characteristics (intrinsic) and context (extrinsic) properties of the building. This is important since it allows us to more precisely define acceptable and unacceptable energy usage for buildings based on numerous contextual factors. Buildings in colder climates, for instance, are likely to spend more resources on heating, which will in turn affect their energy efficiency. Publically comparing otherwise identical buildings in different climates will result in a range of energy usage levels.

The more specific we can be regarding the characteristics and use of buildings, the more detailed we can be when considering energy analytics, the better we can support a move towards sustainability that considers both building fabric and building use. By applying MEASUR methods, as proposed in [4], we suggest that the following factors should be considered as KPI when adding contextual information to building space:

- Physical building structure: including building size, floor space, number of floors and size of rooms.
- Building material: old/new building, presence of double glazed windows, energy efficient technologies etc.
- Building Occupants: number, average time spent in the building, average start/end times, occupancy variance.
- Building Usage: common occupant activities, presence and usage of building systems and electrical appliances.
- Social/Organisational: Building occupant usage policies, organisational culture.

- Geographical Context: location, climate, weather, temperature sun-light level variance, seasonal changes.

Assessment of buildings, in relation to their intrinsic and extrinsic properties, allows us to compare and identify buildings with similar properties. This enables us to quantifiably determine energy waste and therefore key areas of change that could improve sustainability. In contrast simple monitoring of energy usage readings, which provide only basic information with no reference to context, we can separate energy consumption and efficiency as being a result of either building structure and/or building use. Energy readings alone are unable to define whether a building is being used in an efficient or inefficient manner, yet the comparison between buildings with similar key properties allows direct comparison of energy performance, indicating whether a particular building is being used well or not. Such information can only be determined by semantically populating a live model of the building with temporal information about energy use.

Semantic building models can be developed through the specification of building property types and activity use definitions. When activity information is linked to as-built CAD drawings, existing building assessment methods, BMS (Building Management System) data streams, energy usage policies etc., a considerably flexible and semantically rich energy model can be developed.

4. Model Data Storage and Temporal Issues

We advocate that semantic building data models, using records to represent buildings along with their properties, should be represented using a historical relational database. The relational functionality supports arbitrary data structures, powerful data manipulation and querying capabilities. Use of a historical database supports temporal analysis of building use.

Most database systems are referred to as 'snapshot' databases, since they record the state of their domain at a single point in time. This means that any updates made to a record, results in the previous value being permanently lost. Likewise, any entities that are deleted imply that those entities never existed. In contrast, historical databases never delete records and only update and insert new records in order to maintain an object's historical audit trail. This supports data mining and the recognition of trends as a result of object states. Moreover analytics can effectively consider changes to building use over time. Such temporal databases manage time values in one of two ways: i) valid time and ii) transaction time. Valid time denotes the time period during which a fact is true with respect to the real world. Transaction time is the time period during which a fact is stored in the database [5].

The application of a temporal database to the problem of recording semantic building models is appropriate since user attitude and occupant behavior patterns (and therefore energy usage) are likely to change over time; and we need to be able to represent the impact of change or behavior in context of the specific time scale and/or season during which it was deemed accurate.

Whilst the use of a temporal database adds significant complexity to the semantic model, such systems allow increasingly powerful queries of stored information, which supports the provision of contextually persuasive feedback and management of user change towards sustainable energy use. In order to manage positive user change, towards target behavior, we must first understand how persuasion management is facilitated via information provision.

5. Persuasive Management

The issue of user persuasion is becoming increasingly incorporated into systems design, and is used in areas including social networking, online videos, and mobile devices, etc. [6]. Research in this area shows that there are multiple means of changing user behavior and this has a strong relationship with user current activity and attitudes. Fogg [6] stipulates that a change in behavior occurs at the moment at which the user has sufficient motivation, i.e. feels able to make the change; which often occurs as a result of external triggers acting on the individual. By understanding the user's current behavior towards energy use, and by managing triggers by providing relevant stakeholders with appropriate feedback / information, persuasive management can be used to enthuse users towards target behavior. In this work we used the 3D-RAB persuasive model [7] to support persuasive feedback management. To understand this model, and how it relates to energy sustainability and persuasion management, the following sections introduce information concerning: assessment of current behavior, attitude toward target behavior, attitude towards change, and behavior state change.

5.1. Assessment of Current Behavior (CB)

Current behavior is defined as the existing actions of a person in relation to the environment. Such actions may be conscious or subconscious, overt or covert, voluntary or involuntary. In order to measure behavior, and support a positive movement towards target behavior, current behavior must be assessed. This is to say that appropriate user behavioral change, and therefore information feedback, must be personalized. For simplicity, behavior is measured as being either positive or negative, when considered in context of energy sustainability. A user, either a person or organization, is considered to have a positive behavior if current behavior is the same as the target behavior, i.e. actions that make efficient use of energy. CB can be defined as being positive or negative by analyzing BMS energy streams in the semantic model. By looking at specific energy use, i.e. that identified as being related to a specific activity, over the defined time scale of the activity, and by placing this information in context of the building type and fabric we are able to assess energy use against personalized targets.

5.2. Attitude towards Target Behavior (ATTB)

User attitude towards target behavior is defined as the like or dislike of target behavior; and is, for the purpose of simplicity, defined as being either positive or negative in this research. If someone's attitude supports energy sustainability then they are deemed as having a positive attitude towards the target behavior. Interestingly, user's attitude towards behavior is not always consistent with current behavior. ATTB is captured via experimentation, normally involving decision making results and / or questionnaire feedback.

5.3. Attitude towards Changing/Maintaining Current Behavior (ATCMB)

Attitude towards change is a measure of whether, in a particular case, a person is positive, negative or neutral towards change. This measure is considered to be positive when a user agrees to change to the target behavior, or when they are willing to maintain positive current behavior. Aronson [8] argues that changing a user's behaviour can result in attitude change, since new attitudes are formed to justify behavior. He explained that people adjust their attitudes to fit new behaviours in order to reduce or eliminate the "tension of dissonance". The theory of cognitive dissonance proposes that two cognitions are considered to be in dissonance if one opposes the other creating an unpleasant psychological tension [9]. The foundation of this theory is based on the fact that in order to eliminate dissonance, a user changes their belief, action, or perception of the action. ATCMB is captured via experimentation, normally involving decision making results and / or questionnaire feedback.

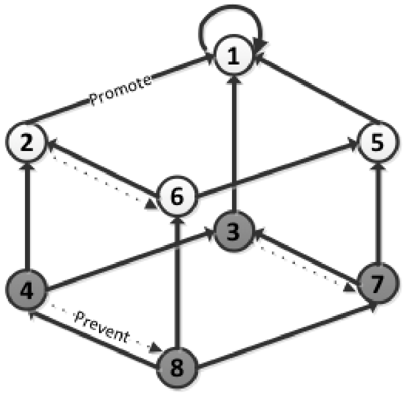

Fig. 1: Transitions in 3D – RAB

5.4. 3D- RAB Model

The 3D-RAB model [7] enables the persuader (i.e. the stakeholder interested in obtaining sustainability) to categorize users into groups depending on CB, ATTB and ATCMB being positive or negative. In total, eight categories of user were identified (see figure 1). The various states are analyzed, in context of energy use, in order to ascertain possible transitions for persuasion. Combining Figure 1 and Table 1, we can see how states are either stable or unstable, and explains how users in unstable states can transfer states as a result of persuasive feedback. The relationship of, and transition route of users, is based on the theory of cognitive dissonance, which is defined as being: i) strong, ii) moderate, iii) weak or iv) absent.

Table 1: Definition of current behavior, attitude and its impact of dissonance

State	Current Behavior	Attitude towards target behavior	Attitude towards changing/ maintaining current behavior	Cognitive Dissonance	Stability of state	Natural State tendency	Targeted state for Persuasion
1	+	+	+	No	Stable (+)	1	1
2	+	+	-	weak	Unstable (+)	1	1
3	+	-	+	moderate	Unstable (-)	7	1
4	+	-	-	Strong	Unstable (-)	8	2 or 3
5	-	+	+	Strong	Unstable (+)	1	1
6	-	+	-	moderate	Unstable (-)	8	2 or 5
7	-	-	+	weak	Unstable (-)	8	3 or 5
8	-	-	-	No	Stable (-)	8	4 or 6 or 7

Strong cognitive dissonance is formed when there is a very strong disagreement between one’s attitude and current energy use and it results in a strong unpleasant psychological tension and produces a greater probability that one may change his/her attitude or behavior in order to eliminate the dissonance. At such a state the user experiences a very uncomfortable cognition state that he/she recognizes the need for a change in attitude or behavior. For example, if a user wishes to save energy and/or cost, providing his/her with information about energy waste of equipment being left on overnight, may result in the user turning off the devices at the end of the day. When there is a weak or moderate dissonance the disagreement between one's attitude and behavior is not enough to motivate change. In the case of no cognitive dissonance, user attitude agrees with his/her energy use and there is no psychological tension. Variation in dissonance therefore creates stable and unstable states that can be positive or negatively towards the target behavior.

In states 1-4 (see Figure 1) the user is already performing the target behaviour (i.e. positive and/or sustainable use of energy). Accordingly feedback information should be given to move the user towards, or keep in the state 1 (positive action and attitude, low dissonance). If current behaviour is in states 5-8, then a change is required toward positive activity. This change can be facilitated by providing energy feedback information, either directly to users or, depending on the user state and level of dissonance, to related stakeholders (i.e. user / activity / building managers). Such feedback is likely to increase stakeholder level of dissonance, due to financial and/or energy targets. To remove this dissonance, alternative external triggers can be placed on the user (e.g. loss of bonus, or enforced process change). By changing user incentive (e.g. bonus), which ideally leads to a change in user or user attitude, or by enforcing change in current behavior, a transition in user state occurs towards a more positive stable state. Information provision and regular use assessment, supported by analysis of the semantic temporal model, can be used over time to facilitate positive change, whilst identifying and highlighting existence of negative state transitions.

6. Conclusions

Currently building assessment methods largely ignore building context and / or activity. We are therefore unable to define whether a building is being truly used in an efficient or inefficient manner. In this paper we have discussed how using a dynamic and temporal semantic model, to populate information within a model of persuasion, can be used to manage users towards lasting behavioral change.

If Building Management System, building structure, and activity information can be captured and integrated within a temporal semantic building model, then personalized feedback concerning user energy usage can be used to prompt positive change in either, occupant and / or related stakeholder attitudes or current behavior to minimize cognitive dissonance. By combing physiological principles with information from live semantic temporal building models, we can identify energy waste in context of building, context and activity type. Such modeling approaches, although still largely unsupported by mainstream building modeling and database technologies, would provide huge potential when integrating energy information about building structure, systems, context, and users.

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