Towards an ontology for holistic building occupant information modelling

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Abstract. Occupant behaviour (OB) is a critical factor affecting the building performance from aspects such as energy/comfort management, emergency planning, space management, and safety/security. Several ontologies were previously developed to formalize modelling/exchanging occupant-related information for each of these applications. The present study aims to provide a holistic occupant ontology to support integrated building management solutions. Rather than offering a brand new ontology, we integrate the existing models, and create the linkages required for semantic integration among them. Two main dimensions framing our occupant ontology include: building function and occupancy information. We mapped the available ontologies (within and outside the domain of OB), to capture existing gaps for semantic integration across multiple use-cases, within each of these dimensions. The gaps were then translated into competency questions, and from there, we developed meta-classes and relations required for the high-level occupant ontology. Upon the completion and deployment, the proposed occupant ontology can result in better information exchange and integration with building simulation models for various use-cases.

1. Introduction

Advances in building automation systems and new technologies such as Building Internet of Things (BIoT) are giving rise to an overwhelming amount of information generated and stored for indoor environment. Knowledge extraction from the building big data and using the data to offer new solutions (including optimization, what-if scenario simulation, and automation) requires formal knowledge models to capture various components of the built environment and the social context around it. Several ontologies are proposed over the past few years for modeling the knowledge of physical built environment. Since the occupant is the common factor among most applications in building lifecycle management, capturing and modeling occupant information is also critical. Recently, some ontologies are developed to model occupant information, for specific domain applications. The fast-growing building automation and building management applications make more and more connections among those domains of application. E.g. building security solutions require access to the space management systems; evacuation planning under the hazard needs real-time information from both physical components and occupants’ position/behavior; and optimization for trade-off between comfort and energy efficiency at the same time must consider facility management constraints. Such interdependencies add to the frequency of communication among different software systems in building management; and hence make the interoperability an even more critical issue. To support the great amount of data exchange in the Cognitive Building Management (CBM) systems, it is important to develop a holistic ontology of the occupant to support interoperability across various use-cases, which entertain the occupant information. An integration of different domain knowledge, such as BIM
(Building Information Modeling) and OIM (Occupant Information Modeling) is proposed in this study. The relationships between these domains are specified in multiple dimensions and their dependencies are investigated. Such integration will be necessary to propose smart building solutions to enhance efficiency, sustainability and resilience of the built environment.

2. Previous Works

Several attempts are listed in the literature for developing ontological models within the domain of building engineering. Moreover, domain ontologies are proposed in other areas, which are closely related to building automation (such as sensors and Internet of Things and BiIoT). The present study is taking advantage of those models, however with the centrality of OB modeling. Our main scope comprises: Energy/comfort management; emergency planning; space management; and safety/security as the four main use-cases benefitting from OB models the most. Table 1 summarizes the most related ontologies, which are used in proposing our upper level model.

| Domain                          | Ontology  | Description                                                                 | Online |
|---------------------------------|-----------|-----------------------------------------------------------------------------|--------|
| Security and privacy            | SOUPA [1] | Defining generic vocabularies for building pervasive computing applications. | Yes    |
| Smart homes                     | DogOnt [2]| Modelling devices and technologies typically part of an indoor IoT network.  | Yes    |
|                                 | SAREF [3] | Building space and devices.                                                 | Yes    |
|                                 | IoT-O [4] | Proposing a vocabulary to describe connected devices and their relationship with spaces. | Yes    |
| Building energy efficiency and user comfort | EEOnt [5] | Representing functionality and characteristics of the energy consuming devices and systems. | No     |
|                                 | obXML [6] | Providing a connection between the occupant drivers and needs and their decisions in interacting with building systems. | Yes    |
|                                 | EEPSA [7] | Focusing on energy efficiency and thermal comfort in buildings.              | Yes    |
|                                 | HBC [8]   | Specifying the domain of Indoor Environmental Quality (IEQ) in multiple dimensions. | Yes    |
| Sensory Information (Modelling) | SSN [9]   | Proposing a conceptual schema for describing sensors, and their capabilities.  | Yes    |
|                                 | SmartEnv [10] | Proposing a generic ontology for sensorized environments with occupants. | Yes    |
|                                 | S3N [11]  | An extension of the SOSA/SSN ontology.                                      | Yes    |
| Building Components Modelling   | BOT [12]  | Providing extra vocabularies for describing the building elements, which are not included in the SAREF4BLDG ontology. | Yes    |
|                                 | BIMSO [13]| An alternative to IFC.                                                      | No     |

3. Building Occupant Information Modelling (BOIM) Ontology Development

An ontology engineering method called “METHONTOLOGY” [14] is used in this study to develop the proposed upper level ontology. This methodology consists of seven phases called specification, knowledge acquisition, conceptualization, integration, implementation, evaluation, and documentation. An overview of the first four phases required to create the proposed ontology are described in the following sections.

3.1. Specification

The ontology specification phase determines the aim of the ontology, the scenarios in which the ontology is used, and its end-users. The scope of the ontology including the set of terms to be represented, its characteristics and granularity are also defined in this phase [14]. The BOIM ontology covers scenarios that provide integrated building management solutions. This mainly includes energy/comfort, emergency, and safety/security management.

Using competency questions helps to convey ontology requirements, its main elements, and their relationship, which create the ontology vocabulary (terminology). Competency questions are used to test the ontology requirements’ satisfiability by using ontology axioms and answer checking [15]. These questions should also be evaluated using different use-cases.
3.2. Knowledge acquisition

Knowledge acquisition is mainly done concurrently with the ontology specification phase and it gradually decreases while moving forward in the ontology development process. Expert interviews, literature reviews, brainstorming, and other ontologies are the main sources of knowledge when developing an ontology. Concepts classifications trees of different ontology classes are built based on the knowledge acquired during the ontology development process [14].

3.3. Conceptualization

One of the long-term goals of the building industry is to design and operate cognitive buildings in a way that could satisfy occupants’ comfort requirements, enhance the performance of energy consuming systems, and guarantee the occupants’ safety in terms of security and evacuation planning and management [16]. There are different models to predict each of these scenarios and suggest recommendations and actions accordingly. Occupancy is the common entity in these models and some similar occupancy attributes exist between them. However, the unique attributes to each use-case need to be identified and considered in a holistic model. To achieve this goal, standardization and consistency between different ontology models, covering the above-mentioned use-cases, are required. According to the ontology requirements, existing ontologies are used to develop the holistic occupant ontology. Based on the ontology specification and its use-cases, three main areas are identified as follows:

3.3.1. Energy/comfort management. The first and foremost use-case around occupant modelling is comfort and energy management. For this use-case, our ontology considers competency questions such as “what is the thermal comfort at different times/spaces?”; “how the open/closed state for the windows/doors influences the comfort level of occupants?”; and “what schedule for the mechanical system can optimize energy efficiency, at the same time with meeting occupants’ comfort constraints?”.

Some ontologies have been developed in previous studies to formalize modelling and exchanging occupant-related information. These studies, however, have a limited scope, aiming to address a particular problem. For instance, Hong et al. [17] focused on energy-related building occupant behaviour and suggested an ontology called Drivers-Needs-Actions-Systems (DNAS) framework to standardize the energy-related occupant behavior modelling. DomoML [18], DogOnt [2] along with ThinkHome [19], SAREF [3] and SAREF4BLDG [20] ontologies represent extensible models for all building devices as a part of local Internet of Things inside a smart environment. In all these ontologies, the occupancy class is either missing or is very abstract; and their roles in the interaction with building spaces and components are not properly represented.

Emergency/evacuation management– Emergency planning (to involve evacuation behavior of occupants under natural or man-made hazards) is another important use-case that involves building occupants. Some informal competency questions we considered in developing our ontology include: “what is the safest/shortest egress?”; “which exit path will the evacuees naturally select?”; “is there any occupant confined with the hazard?”; “are there occupants with physical or mental limitations?”.

Relevant studies that can help to answer such questions include: (i) tracking and (ii) simulation of the egress behaviour under the incidence of different indoor hazards. At a high level, the evacuation behaviour depends on three major classes of components: The building, the hazard, and the occupants.

Evacuation behaviour is studied for individuals and groups of the occupants. Li et al. suggest a three-phase model for evacuation behaviour upon sensing an indoor hazard: (i) initial judgment; (ii) global assessment; and (iii) path/exit choice [21]. All the three phases are highly dependent on the attributes of occupants and the building. The exit choice of individuals is usually stochastic and is governed by attributes, such as their physical characteristics [22], psychological repulsive or compressive tendency (i.e. willingness to follow the crowd or avoid them under the hazard condition); knowledge of the space [23], building characteristics such as junction angles [24] and availability of obstacles [25], exits’ characteristics (i.e., door width [26], exist signs and emergency lighting on/around the egress [27], etc.).

While the group behaviour can be initially perceived as the aggregation of individuals’ micro-behaviours, there are some feedback loops, which can change individuals’ behaviour in a crowd, and subsequently control the group dynamics under the incidence of a hazard. Homogeneity of the group is
one important attribute to be considered. This can include items such as gender mix ratio [28], age distribution, and the proportion of occupants with mobility limitations (e.g., visual impairment [29], physical or mental disabilities [30]).

“Herding” is found to be one important mechanism governing the behaviour of occupant groups during evacuation [31]. Another phenomenon influencing occupant groups’ egress is the “faster-is-slower” effect (i.e. the clogging happening due to the impatience of evacuees) [32]. Occupants’ position and proximity to physical components controls individuals exit selection, as well as the efficiency of the evacuation as a whole. High density and low flow of evacuees around the egress (i.e. jamming) is realized as an important factor in emergency evacuation, by both analytical and experimental studies [33] and [34]. Other group effects include arching and clogging [32], queuing, and irregular outflow [25], most of which become more sever under the panic condition.

Figure 1. Overview of the upper level ontology.

3.4. Integration
In this phase, a conceptual model of the domain knowledge is developed that shows different ontology modules in terms of the domain vocabulary identified in the ontology specification phase. The conceptual model is created in a way to address the ontology requirements to provide the ontological commitments required by our competency questions. More importantly, apart from the competency questions considered for each individual use-case, the holistic ontology is meant to answer cross-domain competency questions such as: “what is the impact of open-closed state of windows/doors on the safety of evacuation paths?”; “which occupants must be provided access to each space, based on the space management schedule?”; and “how to control the lighting level in different spaces to minimize energy consumption, yet provide the level of security required?” Figure 1 shows an overview of the proposed ontology. The ontology main classes, subclasses, their attributes, and the relationship between them are illustrated in this figure.
4. Conclusion and Discussion

Despite the comprehensiveness of available ontologies proposed in different areas of interest, which are mentioned as the four main use-cases, occupants and the occupancy, as the common elements among them, are missing in many cases. In response to this need, our proposed ontology aims to incorporate classes and relationships required for capturing this knowledge, by mapping the models previously proposed in the literature. The model is formalized around the occupant, hence incorporates the occupants’ and spatial attributes deemed necessary by the previous studies, and links them to the relevant classes of our ontology.

While the proposed model competently covers use-cases such as energy management, comfort and emergency planning, the current version of the model may lack required classes and relations to support application such as security, safety and space management. These concepts will be added to the model in the future developments. Also, the current version lacks in-depth axioms which can support integrated solutions among multiple use-cases from various sectors. The future steps of the research also include verification and validation of the model in a wide range of use-case scenarios and implementing it to offer cross-sectoral building automation solutions.

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