Semantic Description of Equipment and its Controls in Building Automation Systems

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1 Introduction

Building automation (BA) systems orchestrate and monitor the functioning of a wide variety of utilities in a building so that living spaces are kept comfortable, safe, and secure. The complexity of such a system which involves multiple disciplines (heating, air-conditioning, lighting, fire safety, security etc.), coming from multiple vendors, is compounded by the fact that each building differs in the way the equipment operate and coordinate.

So far, efforts involving semantic modeling of BA systems, like Haystack [3], IFC [2], or Brick [1], have been focusing on the description of the building topology, installed equipment, and to a lesser extent, the control strategy, the modeling of the *physical process* and the role of the control program. In addition, the *semantics of interaction* with the devices used in BA, which is essential to establish technical interoperability, has so far not been coupled to the BA semantic models. As a result, planners, project engineers, technical operators, and service technicians have to design and understand the working of the system by piecing together information from different sources.

From our experience at the Smart Infrastructure division of Siemens AG, we describe briefly in the following sections some key use-cases, the challenges faced by us while applying semantic data in BA, and finally describe our approach and its evaluation in real-life buildings.

2 Use Cases for a Holistic Semantic Description

Engineering: Availability of semantic data describing the structural aspects of the building, the equipment installed, the process goals, and the specified control strategy (often called the *sequence of operation*) will help in tracking and validating the installation, and also assists the BA engineer to understand the context during programming of the automation controller.

Fault detection and diagnostics: Automated Fault detection and diagnostic (AFDD) methods for BA systems largely rely on rules which are based on the (semantic) knowledge of the process, the control strategy, and the way to interact with the associated sensors and actuators (to retrieve information or trigger test conditions).

Process optimization: Apart from understanding the functioning of an equipment on its own, the coordination and dependencies at system level is also important to ensure efficient operation, and this often requires exchange of knowledge between sub-systems.

3 Challenges

We have pointed out the need to describe the equipment, processes, and controls in a comprehensive manner so that they weave seamlessly into our engineering process. When we started with the analysis to create such knowledge base in building automation domain, we encountered the following constraints:

- The engineering of BA systems is divided both horizontally in layers of field, automation, and management, and vertically amongst the disciplines. Engineering in each of these aspects is carried out by diverse set of vendors, tools, and information models.
- Though control programs are machine-readable artifacts, they do not express their role in achieving the process goals. Such programs need to be augmented with semantic description of their role in the system.
- Openly available ontologies only partially cover the concepts required to describe a real-life building. Also, combining multiple such ontologies requires hand-crafted bridging and this is cumbersome to maintain as the ontologies evolve.
- Our knowledge consumers, both human and artificial agents, require different levels of abstractions for their operation. Consumers such as those at enterprise-level operate with abstract discipline-independent terms, whereas planning agents need to understand the functional features, while control agents require the implementation details of the features and need to interact with the devices.
- Existing BA (and IoT) ontologies are restricted to describing the presence of a field device (like sensor or actuator) and do not address the need to describe how to interact with such devices (which is essential for applications such as AFDD).

4 Approach

Considering the challenges listed above, we decided to create proprietary ontologies. We realized that this would incur a trade-off between achieving higher semantic richness within our products and a lack of wider interoperability in multi-vendor scenario. So, as a middle-path, we adopted the following approach:

- We structured our proprietary ontologies in three layers (see Fig 1), such that the upper two layers of domain- and discipline-specific terms were designed in a manner that they either included or bridged to some of the openly available ontologies.

- The discipline- and product-specific ontologies resulted in natural vertical specializations since in the multi-disciplinary domain of BA, expertise is often divided on these lines (for e.g. HVAC, fire-safety, security, etc.)
- The usability of abstract terms was rather low for artificial agents (like AFDD) which needed to understand specific control and equipment configuration. Thus, the product- or system-specific ontologies provided these specialized concepts while relating to concepts in the upper two layers. The product-specific ontologies were meant to provide more flexible evolution.
- Integration of our ontologies in our engineering tools enabled bottom-up specification and extraction of knowledge from workflows where the control and construction aspects are inherently coupled. For example engineering tool meant for room HVAC control could refer to concepts such as *room* and *room segment* from the location ontology whereas the tool meant for lighting controls could define a collection of such *room segments* as a *lighting zone*. As a result, a consumer relying on abstract discipline-specific terms could still understand that the *room segments* had lighting function associated to it.
- The discipline-specific ontology included description of processes like heating, ventilation, lighting, etc. and allowed linking the description of control strategies to the process goals. For example, a cascade control loop could be linked to its role in heat generation process.
- *Things* like sensors, actuators, and controllers need to be integrated as first-class citizens in the semantic description so that agents can discover and interact with them. We achieved this by using the Web of Things semantic *Thing Descriptions (TD)* [4] in way that terms in all three layers could be linked to TDs.

5 Evaluation

The feature of the upper-most domain-wide ontology helped foster re-usability while the discipline-specific verticals enabled experts to formulate their concepts more precisely.

We used our ontology suite to help our engineering tools generate knowledge graphs for five real-life buildings and evaluated its effect on our use-cases. The

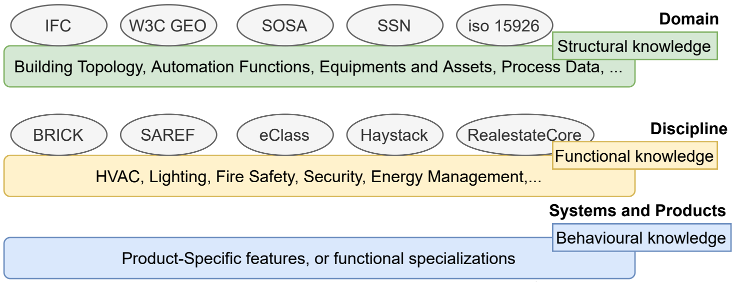

Fig. 1. Layered ontology for BA.

ability to describe control functions and their context of operation enabled our AFDD agents to reason about faults [6]. The description of building structure and related automation functions has facilitated research on its use to automate and manage engineering processes [5]. To demonstrate that our layered ontology can support construction of queries based on different levels of abstraction, we customized the SPARNATURAL[1] UI such that the user could query using broader terms based on open ontologies like BRICK, and then dive into discipline- or product-specific details. Finally, the ability to link entities in our knowledge graph to things representing the field devices (via TDs) enabled both human and artificial agents to interact with the BA system without requiring off-band understanding of protocols and information models.

6 Summary

We have shown that a bottom-up description in building automation should include the physical processes, its automation, and the construction aspects to facilitate software agents like engineering tools and AFDD to reason about the functioning of the system. This requires a flexible and extensible knowledge base which is product-agnostic and yet open to linking against industry-wide ontologies. When such knowledge bases are made available to the engineering tools, it enables the domain expert to create a comprehensive bottom-up description of the system.

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[1] https://sparnatural.eu/