Towards Semantic Facility Data Management

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***Abstract*—Nowadays, facility management is realized with different information systems, which provide a comprehensive view for the management. Building Information Modelling (BIM) encompasses a computer model of a facility, which is utilized throughout the life-cycle of the building. To enable a more holistic view on facilities' conditions (e.g., energy efficiency, indoor environment, maintenance and repair) we present an approach which enhances the BIM model with semantic indoor measurement data. The enhanced semantic information provides more contextual information about the building; history of conditions, current conditions, and even predictions about the future conditions. In addition, the system ties facility users into the process of facility management by allowing them to view the current indoor conditions and give feedback about the conditions of the building. The resulting semantic facility data management approach was tested in an experiment in which the system was applied in a school building environment.**

Keywords—facility management, semantic technologies, BIM, user-awareness, indoor conditions, sensor measusrements

I. INTRODUCTION

The field of facility management refers to the coordination and maintenance of physical spaces and infrastructures such as office buildings, schools, hotels and government institutions. Efficient facility management requires understanding and engaging different stakeholders including building users, owners and operators. Additionally, although good facility management is traditionally measured by a reduced operating cost, more attention has been given to the impact of the overall qualitative aspects of the work environment on users' perceived satisfaction and ability to work [1].

The requirements of facility management have increased tremendously during the recent years. Especially the growing role of computerized support systems has led to more complicated facility management operations. For example, Building Information Modelling (BIM) has attained widespread attention [2]. BIM represents the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a facility [3]. BIM models are computer generated data-rich and object-oriented representations of facilities from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions [4]. For facility management's perspective, the BIM models are useful especially for renovations, space planning and maintenance operations [3].

The recent technological advances in pervasive computing and wireless sensors have enabled also new types of facility services. The examples of applications are span from security and surveillance to monitoring of consumption of facility resources (e.g., measuring, logging and comparing water and electricity consumptions). Novel types of building performance measurement methods such as sensor network systems allow extensive heterogeneous information generated within facilities providing valuable information about the current state of a building. While extensive sensor data is collected from different environments there are still significant challenges in converting such data into useful information needed by different facility stakeholders [5].

The utilization of semantic technologies facilitates the management and interpretation of data collected from facilities. For example, the use of resource describing metadata enables more intelligent machine-to-machine interactions, such as reasoning, deduction and semantic searches [6][21]. Moreover, the abilities to merge heterogeneous data and derive high-level context information from low-level measurement data expand the scope of use of semantic technologies in the domain of facility management. While the quantity of data represented with semantic techniques has increased enormously, powerful database techniques for storing, managing and querying semantic data have been developed both by research community and industry [7][8][9].

Although there have been several approaches to utilize semantic technologies in the field of facility management [10][11][12], the potential of semantics is still yet to be fully realized. For example, the benefits deriving from the integration of static BIM data to dynamic facility monitoring data are not extensively exploited or understood. Additionally, more information about field tests and experiments in which these emerging technologies are applied in practical real-world settings taking into account the users' satisfaction perspective is sorely needed.

In this paper, a novel approach for semantic facility data management is introduced. The approach integrates and interprets facility information collected from heterogeneous sources and represents it for different stakeholders, including facility users, maintenance workers and owners. Furthermore, the approach allows facility users to give feedback about the conditions of a building.

The semantic data management approach was tested in an experiment in which it was applied in the Tervaväylä School. Tervaväylä is a state-funded special school and centre for development in special needs education and it is located in Oulu, Finland.

Besides the semantic data management approach, the test environment included a building automation system and a wireless sensor network that provided sensor-based measurement data, a server machine that hosted a semantic database and a tablet computer that held a Graphical User Interface (GUI) that allowed the users to examine the visualized facility information and interact with the approach.

The results of the experiment show that with the semantic facility data management approach it is possible to effectively merge and interpret heterogeneous facility data and produce interactive visualizations for different stakeholders. Furthermore, field tests conducted as a part of the experiment indicate that the possibility of examining sensor-based condition (temperature, energy consumption, etc.) information is perceived as a useful feature by the facility users. Moreover, the user interface that allows users to navigate through the school building and give feedback on the conditions of different rooms were found to increase user satisfaction. Additionally, the facility maintenance workers perceived the system as a valuable information resource that offers potential to support their daily activities, work processes and interaction towards the facility users. The suggestions for improvements that were derived from the experiment include fine-tuning the GUI and the visualizations provided by the approach.

The rest of paper is organized as follows. Section II gives a description of the test environment. In Section III the results of the field tests are discussed in more detail. Section IV concludes the paper.

II. TEST ENVIRONMENT

In Fig. 1, the different components of the test environment are presented.

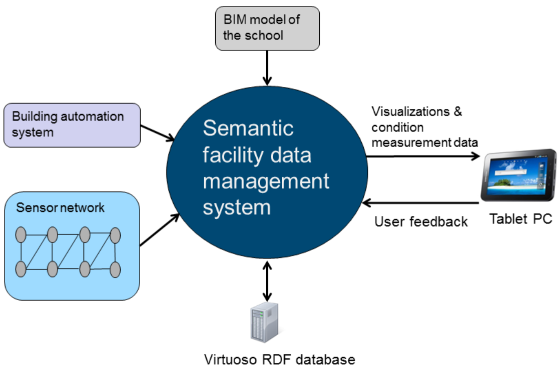

Fig. 1. The test environment used in the experiment

A. Building automation system

The building automation system in Tervaväylä School was accessed via RAUInfo [13], which is a service designed for the owners and maintenance workers of properties and which provides continuous monitoring data accessible via web-service interface. RAUInfo offers comprehensive monitoring data on, for example, heating, cooling and water and energy consumption of Tervaväylä School.

B. Wireless sensor network

The facility data acquired from the building automation system is augmented with additional measurement data provided by sensors mounted to selected rooms in Tervaväylä School. The sensors were installed to spaces that were uncovered by the building automation system but are actively used by the facility users. The additional sensors provide the following measurement values: temperature, illuminance, carbon dioxide level, moisture, and humidity.

C. BIM model of the school

The BIM model of the Tervaväylä School contains information about physical and functional characteristics of the facility. The BIM model represents the design of the building including spaces, objects and other building components. The integration of the BIM model into the overall system architecture provides several benefits. For example, by using the BIM model the different data providing sensors can be located and discovered more easily.

D. Virtuoso RDF database

The semantically described facility data is stored to Virtuoso [9], which is a database management system for RDF [14] data. Virtuoso offers numerous data access and storage mechanisms and interfaces. Virtuoso has been widely used platform and is continually developed further and is thus mature enough solution as the RDF database for the facility data. In addition, Virtuoso supports the storage and querying of very large datasets, which is essential in this context, since building automation and additional sensors can provide a large amount of information.

E. Semantic facility data management approach

The architecture of the semantic facility data management approach contains three main layers: a data collection and storing layer, a data processing layer, and a data representation layer. The data collection and storing layer is responsible for acquiring, semantically annotating and finally storing the facility-related data into the semantic database. The data processing layer enables interpreting semantically described facility data into more meaningful context information. For example, it realizes SPARQL [15] querying functionalities, manages different user profiles and provides necessary information for visualization views. The semantic data processing capabilities provided by the data collection and storing layer as well as the data processing layer are enhanced by the extensive utilization of ontologies.

Ontologies are commonly used to formally represent a set of concepts within a domain and the relationships between pairs of concepts. Ontologies support modelling a domain and performing reasoning about different entities. Ontologies also specify a shared vocabulary and taxonomy which represent a domain including its concepts and their properties and relations [17]. In semantic facility data management approach, ontologies are utilized for formally representing domain specific concepts and their relationships, and metadata that enables the system to better understand, and reason about the structure and purpose of the data. Moreover, ontologies enable the integration of various data sources by resolving semantic heterogeneity between them.

To support the functionality of the framework, three novel ontology definitions were constructed: Building ontology, Sensor ontology and Feedback ontology. The ontologies are described in more detail in the following sub-chapters.

a) Building ontology

To enable the semantic modelling of data contained within BIM models a new ontology was developed. The resulting ontology for semantically storing BIM data is sketched in Fig. 2.

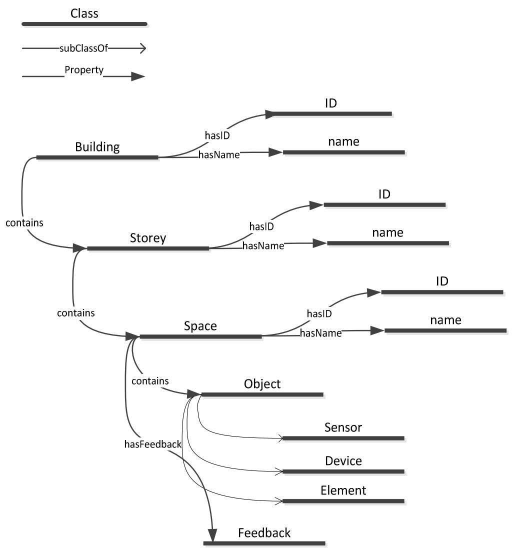

Fig. 2. Building ontology

As presented in Fig. 2, the Building ontology contains four main classes – Storey, Space, Object and Feedback. The next level of the ontology contains subclasses that represent different types of objects, for example, devices. Moreover, each sub class holds its own object type specific properties that provide more specific characteristics about the entities they represent. The Sensor and Feedback classes represent linkages to the other ontologies which are described in more detail later in this section.

Currently, there exist some [18][19][20] approaches that define their own ontologies for semantically describing BIM models. However, for this study it was decided to design a new BIM ontology that adopts some elements from the existing approaches but is especially adapted and optimised for visualisation and monitoring purposes. This more lightweight and flexible ontology is unencumbered by the burden of semantically describing all the concepts and content contained by BIM models. On the other hand, the defined ontology structure offers enough expressiveness for providing comprehensive visualizations and performing sophisticated diagnosis and analysis operations. Additionally, the BIM ontology is general enough to be easily expandable for future needs.

b) Sensor ontology

The system defines a sensor ontology to enable semantic modelling of sensor-based measurement data. Additionally, the sensor ontology facilitates the extraction of high-level context information from various streams of continuous sensor data. In Fig. 3, the designed sensor ontology is presented in more detail.

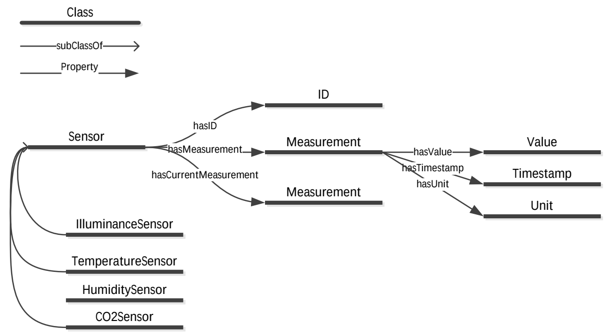

Fig. 3. Sensor ontology

The ontology contains the different types of sensors and their measurements. Every measurement has a timestamp, unit, and value, which are used, e.g., in visualizing the measurements. Each sensor is attached to a specific location in a room in the Building ontology. The location of the sensor can be used in analysing the indoor environment of the target building and to make reasoning about possible events, e.g., heating failure, that would need maintenance

c) Feedback ontology

The feedback provided by facility users is modelled and stored using an ontology description. In Fig. 4 the feedback ontology is presented in more detail.

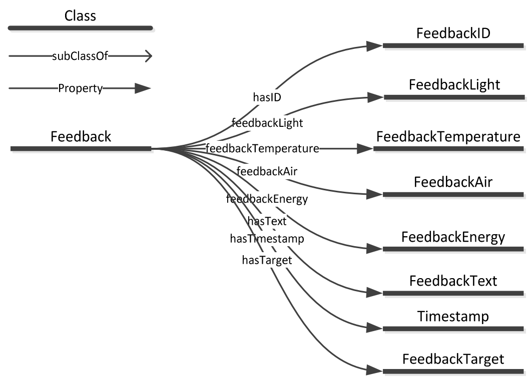

Fig. 4. Feedback ontology

The feedback ontology includes values for the specified feedback attributes: lighting, temperature, air, energy, and free text. The free text field can be used to give plain text feedback about the space. The other fields are numerical values ranging from 0 to 100. For example, in the temperature field a value of 0 corresponds to very cold and a value of 100 corresponds to very hot. The end-user uses a slider with visual cues and a text describing the situation. The feedback is tied to a specific location target (e.g., room) in the building. The feedbacks are given a timestamp so that they can be easily compared to the measured indoor conditions from the building automation and additional sensors.

d) Graphical User Interface

The role of the data representation layer is to implement the GUI, which is responsible for creating visualization views and managing interaction between the end-users and the system. The GUI is implemented with HTML5 [16] utilizing graphical libraries optimized for mobile devices. The application is a full web-based application run with a web browser; no native programming language was used. Thus, the application can be used in multiple platforms and devices ranging from computers to tablets and mobile phones. In this experiment, a Samsung Galaxy Tab 10.1 and a laptop were used.

The objective of the GUI is to enhance user awareness by providing means to explore building-related data through visualizations that represent different aspects of the building. Different spaces of the building are represented from an isometric perspective, which provides an overview of the contextual environment and facilitates the discovery of spatial relationships between objects. Moreover, the isometric visualization contains a summary of the measurement information that is provided by the different sensors that are monitoring the conditions of spaces in real-time. The Isometric visualization of a space is shown in Fig. 5.

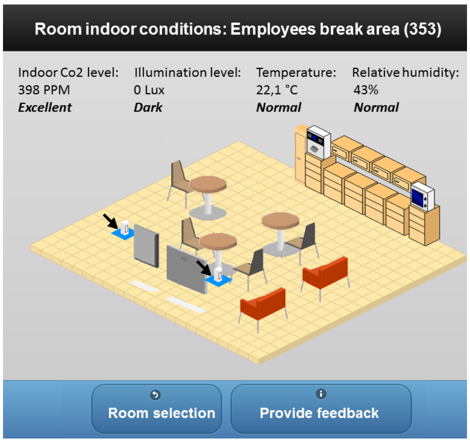

Fig. 5. A visualization of a space

From the isometric visualization the user is able to access a feedback section in which the user can give either general feedback or feedback concerning the existing indoor conditions of a certain space. The approach enables giving either verbal or scaled feedback. Scaled feedback is given by using special sliding clutches in estimating the current status (e.g., from too warm to cold) of four parameters that are temperature, air quality, lighting and energy consumption.

The facility maintenance workers are able to see indoor environment conditions (e.g., temperature, humidity, etc.) of the selected room in line chart visualizations over a selected period of time, e.g., a day or a week (see Fig. 6). Additionally, the facility maintenance workers can view the received feedbacks from the facility users to specific locations in the building.

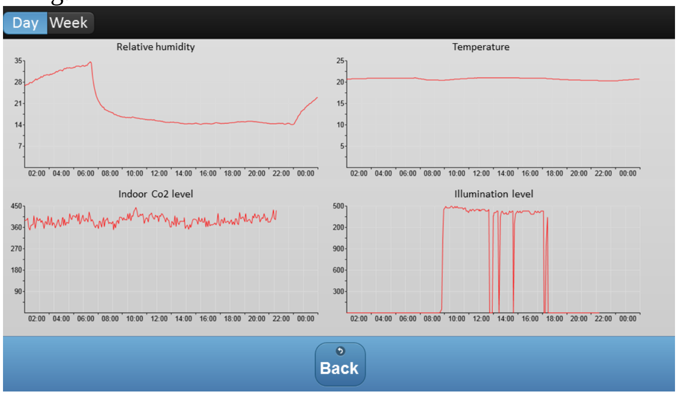

Fig. 6. A historical condition data representation

III. Field Tests

The field tests were conducted in order to achieve the following objectives:

- To validate the functionality of the semantic facility data management approach in real-world settings.
- To examine the usage rate of the semantic facility data management approach among the users.
- To study the effects of the semantic facility data management approach on facility user satisfaction.
- To provide information about how the facility users perceive the existing conditions of the school.

A. *Experiment execution*

During the field test periods the tablet running the GUI of the system was located in the school employees' break room, where it was available for the personnel to use. The number of people involved in the experiment was approximately 55. In total, three separate test periods were performed and between each period the semantic facility data management approach was improved according to the received user feedback. The times of the test periods are shown below.

Field test 1: 4/12/2012 – 4/1/2013

Field test 2: 1/2/2013 – 15/2/2013

Field test 3: 26/3/2013 – 12/4/2013

B. *Experiment results*

After the field tests the usage metrics were analysed. Furthermore, an additional questionnaire was prepared in order to measure the perceived ease-of-use and perceived usefulness of the approach. The questionnaire used a five level grading system, where five is the best and one the worst grade, three being the average. Users were able to answer the questionnaire anonymously.

1) Results of usage metrics

The usage metrics indicate that the interest towards the approach was at its peak during the first field test period, in which the different features were used the most frequently. During the second and the third field test periods the users were probably more familiar with the approach and hence used it only when they were interested in the conditions of a certain room or wanted to give feedback about a specific deficiency, for example. A condensed summary of the data obtained from the usage metrics are shown in Table I.

TABLE I. SUMMARIZED USAGE METRICS DATA

	Field test 1	Field test 2	Field test 3
Main page opened	164	12	11
Info page opened	102	40	21
Feedback sent	18 (of which 7 written)	2 (0)	5 (3)

1) Results of the numerical feedback

According to the numerical feedback received the school employees were mainly satisfied with the indoor environment. However, temperature conditions in different spaces received some negative feedback. When comparing the negative feedback to other facility data managed with the approach it was discovered that the outside weather had an effect on how people perceived the indoor temperature. More precisely, during a cold winter day the indoor temperatures were usually perceived too low whereas a sunny day had an opposite impact. Additionally, when analysing the visualizations of different spaces it was discovered that the negative temperature feedbacks were focused on rooms that contained large windows, which apparently strengthen the effect of warm or cold outside temperatures.

2) Results of the questionnaire

To summarize the questionnaire results, the visualizations offered by the semantic facility data management approach were considered as an important and useful information source by the facility users. However, the usability of the approach was found to require improvements. Moreover, it was perceived as difficult to give written feedback with the tablet. In addition, some data representation techniques used by the visualizations were regarded as difficult to understand. The background knowledge of the end-users on using tablets probably has an effect on the overall satisfaction on the user interface.

The possibility to give feedback anonymously was considered a very positive feature. In more detail, the users felt more convenient to give feedback with a tablet than, e.g., a bigger info screen (if the user wanted to give textual feedback, he/she could do so privately with the tablet). However, according to the questionnaire results a small portion of the employees were not interested in learning to use the tablet PC or the GUI of the approach, which hindered their participation.

3) Feedback from the facility maintenance workers

Besides the field test periods, the approach was introduced to the facility maintenance workers of the Tervaväylä School. The facility maintenance workers were familiarized with the approach and they were given an opportunity to test it. Afterwards, the facility maintenance workers answered a questionnaire that measured the perceived ease-of-use and perceived usefulness.

According to the questionnaire results, the tablet was considered as a useful tool and the user interface of the approach was perceived as clear and easy to use. The possibility to receive feedback directly from the users of the building was considered as an interesting feature. However, the facility maintenance workers were a bit concerned whether they have enough resources to react on every comment made through the system. A suggestion made by the facility maintenance workers was to use some kind of filter to extract the most important notices of defects or service requests from the received feedbacks.

In general, the facility maintenance workers appreciated the idea of having a single interface that is used for observing the information of the building. Currently, the information that they need is scattered in three different systems. Also graphical representations of sensor-based measurement data received positive comments. However, according to the facility maintenance workers the approach should offer more flexibility in setting the time range for observing different sensor data measurements. The final conclusion that emerged from the questionnaire was that more advanced means to give additional information through the approach should be provided. For example, it would be useful to inform the facility users about the water or heating system outages or the testing of fire alarms.

IV. CONCLUSIONS AND FUTURE WORK

In this work, a novel approach for facility data management was introduced. The approach utilized semantic technologies to integrate heterogeneous facility data and interactive visualizations to improve user awareness. The approach also offered efficient and easy-to-use mechanisms for providing feedback. Moreover, the approach aimed at aiding the work of facility maintenance workers by offering a unified interface to examine building data and to interact with the facility users.

Results of an experiment, in which the approach was used in real-world settings, were also presented in the paper. The results indicate that by providing real-time information about indoor environment in a meaningful form and by offering convenient ways to give feedback, the customer experience for the facility users can be improved. Furthermore, with the approach the facility maintenance workers are able to better adjust the conditions according to the needs of the users and be aware on users' perceived satisfaction and ability to work. Moreover, semantic techniques were found to be adequate in terms of performance and scalability in real world facility data management activities. Finally, it was discovered that the existing indoor conditions in Tervaväylä School are in a satisfactory level.

The future work includes improving the deficiencies found during the experiment as well as further developing the approach. The possible developing activities include, for example, integrating the approach with existing energy management systems, providing enhanced visualizations that facilitate the visibility of maintenance services to the facility users and utilizing the collected information in the proactive prevention of problems. Furthermore, in order to improve the abilities of the approach to support the tasks of different stakeholders (e.g., maintenance workers, facility owners) a more throughout analysis of their needs and requirements should be conducted.

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