Journal of Physics: Conference Series

PAPER • OPEN ACCESS

End-user activities context information management framework for sustainable building operation

To cite this article: Elena Malakhatka and Per Lundqvist 2019 *J. Phys.: Conf. Ser.* **1343** 012151

End-user activities context information management framework for sustainable building operation

Elena Malakhatka[1], **Per Lundqvist**[2]

KTH Royal Institute of Technology, Industrial Technology & Management, Brinellvägen 68, 10044 Stockholm, Sweden

1 elenama@kth.se
2 per.lundqvist@kth.se

Abstract The concept of sustainable buildings includes not only technological aspects related to energy efficiency and resources usage optimization, but also aspects related to end-users' comfort, wellbeing, and everyday needs support. To understand the end-users' life activities in general and their preferences in particular, is necessary to enrich standard Building Management Systems (BMS) with human-generated and personal data. In this conceptual paper, we present an end-user context information management framework, which includes a *reasoning layer*, an *acquisition layer*, and a *dissemination layer*. The proposed framework is currently implemented in the KTH Live-in-Lab – a fully equipped testbed for research and innovation in the build environment.

Keywords: *context-aware systems, context information management, sustainable building operation, human activities system*

1. Introduction

The concept of sustainable buildings is overlapping with the concept of smart buildings. Both concepts share central ideas of what building should be – interconnected, flexible, context-aware, energy efficient, and comfortable for the occupants [1]. The concept of sustainable buildings has expanded due to technological innovations and external pressure, such as the growing concern over climate change, which has amplified the importance of energy efficiency and the progressing level of building automation and Internet of Things (IoT) technology. Indeed, today, buildings generate a large amount of data on operations, energy, and other resources usage through systems such as the building management system (BMS), sensors and meters that can be used to evaluate building performance. This availability of information allows us to answer the question "How much resources were used in a building?" but it does not allow answering the question "Why?". In order to understand the reasons why a certain amount of resources is used, it is necessary to have a more detailed picture of the activities of tenants in a building, to understand their lifestyle and comfort related preferences.

Previous research has proven that reducing building energy use and increasing occupant satisfaction can be achieved concurrently [2]. However, without any direct feedback other than infrequent complaints, facility managers are forced to 'play it safe,' resulting in suboptimal operations. The existing BMS infrastructure of sensor networks and data management systems are not enough to capture the contextual information about the end-users to operate the building in a sustainable way. Thus, the building system boundaries expansion is needed, and from the standard BMS, we make the transition to BMS, enriched with Human Activities System (HAS) data, which include data from the personal devices and human-generated data.

2. Theoretical framework and research objectives

In this paper, we deal with the application of theories and methods from different disciplines. Often, all applied processes are accompanied by a partial synthesis of sub-disciplines. In our case, we will try to adapt context-aware theory from computer science to sustainable building operation from building engineering.

The main objectives of this paper are to:

- present the context information management framework, which could become a starting point for the development of context-aware (C-A) systems in the built environment;
- propose sustainable building operation KPIs for the reasoning (rule-based) layer;
- demonstrate an example and the preliminary outputs we can expect if we apply more end-user activities and contextual data in the BMS.

In this conceptual paper, we present the *end-users' activities context information management framework*, which includes: *reasoning layer*, *acquisition layer* and *dissemination layer*. The proposed framework is currently implemented in the KTH Live-in-Lab – a fully equipped testbed for research and innovation in the embedded environment.

3. Context-aware systems

The miniaturization process of electronics has made a wide range of small devices available with sensing and computing capabilities, taking the computational paradigm out of the desktop [3]. This has opened up new possibilities for interacting with technologies, bringing them closer to people's daily life experiences. The vision of Weiser [4], predicted a trend in which computers disappear by becoming embedded in our daily lives. His view has influenced research in new emerging areas such as Pervasive & Ubiquitous Computing, Intelligent Environments or Ambient Intelligence. The systems developed in these fields need to recognize the context in which they are executing. In this way, they can understand better the situations in which the user expects services delivered and in which way. The term '*context-aware*' was first used by Schilit and Theimer [5] in 1994. Since then, research into context-awareness has been established as a well-known research area in computer science. In order to implement systems that are able to use the implicit situational information, there is a need to understand the concept of context [6]. In the literature, several definitions can be found [6-12]. We highlight that Dey [13] has the most acknowledged one, considering it as:

"Any information that can be used to characterize the situation of an entity", where *"an entity can be a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves"*.

Context includes the environment, spatial, temporal, etc information that is used to infer the current activity. This encompasses the applications, services, devices, sensors and human users bounded within an environment [14], [15]. Baldauf [16] has defined context awareness as:

"Context awareness is the ability of systems to identify the users' context and deliver better services based on their needs".

4. End-users' activities context information management framework

The C-A system design always starts from the context information management system development. The techniques for context information management have been widely researched and are well understood [17-19]. In the following, the life-cycle of context information is used as a reference to better clarify the issues that this information management may entail:

- **Rules:** First, the rules that will determine the goals and scope of the C-A system should be defined.
- **Acquisition:** Second, the context information needs to be gathered. Generally, this happens from multiple and distributed resources, which makes the quality and authenticity of information difficult to achieve. On the other hand, sensors in general, are likely to provide inaccurate, overlapping, contradictory or missing data [20].
- **Modelling:** After the information is sensed, it needs to be translated into usable values. In this process, real-world concepts are translated into modeling constructs. A raw value of a user position may be in the form of non-understandable numerical data, which should be transformed into reasonable information, such as the name of a place, room type, *etc*.
- **Reasoning:** Based on the modeled data, different kinds of conclusions can be inferred, where this data can be seen as evidence to support the conclusion [21]. In this way, new knowledge and understanding is obtained, based on the available context [22].
- **Dissemination:** Finally, both low-level and high-level context need to be distributed to the consumer. The context information must have high availability, ideally to be provided it in real-time. Another desirable feature is to discover new services that could provide new context information [21].

4.1 Defining C-A system goal and rules

As mentioned earlier, the main goal of our research is to understand how the analysis of end-users' activities and contextual data could be used in the BMS to operate the building in a more sustainable way. But what do we actually mean with '*in a more sustainable way*'? There are many different concepts associated with the sustainable building operation and metrics describing these concepts.

We will take as a basis for sustainable building operation a concept that combines four sustainability dimensions: *Environmental sustainability*, *Social sustainability*, *Economic sustainability and Technological sustainability.* Each of these dimensions has its own indicators and measurable parameters, which could be used into the rule-based modeling. The selected indicators were derived from reformulated sustainability assessment methods that are the most frequently: BREEAM' [23], 'LEED' [24], 'CASBEE' [25], 'WELL Building Standard' [26]). A summary of the sustainable building operation KPIs is presented in *Table 1*:

Table 1. Qualitative representation of Sustainable Building Operation KPIs

Sustainability dimension	Key Performance Indicators (KPIs)	Chosen indicators for this paper (due to research framework)
1. Environmental Sustainability	Electricity consumption (kWh/m2) Water consumption (kL/m2) Waste recycle (kg/m2) Space optimization (%)	**Electricity consumption (kWh/m2)**
2. Social Sustainability	Indoor environment quality (%) Productivity (%) Daily tasks support (%) Social network (%)	**Productivity (%)**
3. Economic Sustainability	Economic performance (%) Affordability (%) Adaptability (%) Whole Life Value (%)	
4. Technological Sustainability	Intelligence and controllability (%) Communication and mobility (%)	

The calculation of the overall sustainability building operation index is a multi-parametric and complex task, requiring serious mathematical and computer efforts. The purpose of this article is to introduce the context-aware logic application, which is why we have made the decision to simplify our rules-based framework for this case study and selected only two dimensions of sustainability - environmental and social (partly).

4.2 IoT ecosystem and data acquisition

At this stage, it is important to understand available data sources in particular and the IoT ecosystem in general. As was mentioned above, the key role in this project is played by end-users' activities context information. We will focus on the concept of a *Human Activity System* (HAS) - model of the daily activities of the end-users and personal interaction with the building system (BS). The concept was defined by P. Checkland [27] and based on Human-Activities Recognition (HAR) [28] and Human-System Interaction theories [29]. One important task of HAS is to identify the activities of a person in the built environment, such as "sleeping", "watching TV", "cooking", etc. Figure 1 shows the IoT ecosystem that will allow to build a big picture of the HAS and BS data sources.

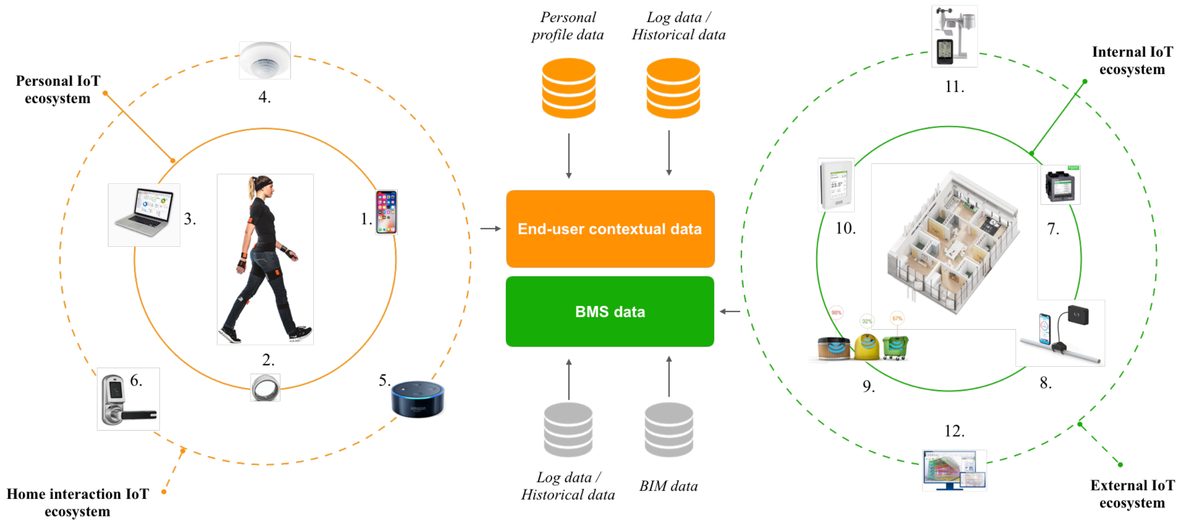

Figure 1. BMS + HAS IoT Ecosystem at KTH Live-in-Lab:1-Smartphone, 2-Ouraring (wearable device), 3-Personal laptop, 4-Amazon Alexa, 5-Indoorpositioning sensors, 6-Smart lockers, 7-Smart meters, 8-Ultrasonic water meters, 9-Sensored trash bins, 10-Air quality meters (particle detectors), 11-Local weather station, 12-BIM.

In order to continuously capture the data from HAS a stream reasoning process is required. By stream reasoning, we mean a logical reasoning process applied upon data streams in real time (Figure 2).

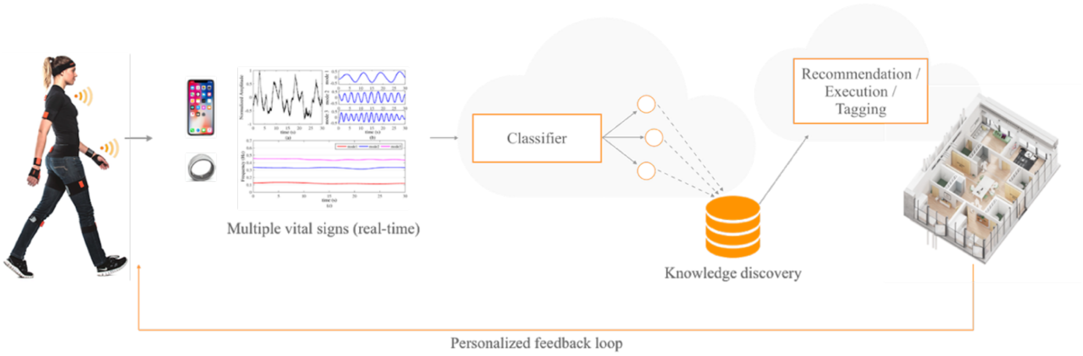

Figure 2. The real-time workflow of data sensing and responding

4.3 Modelling, reasoning and dissemination

At the early stage of designing the C-A system concept, it is rather difficult to plan the stage of modeling, reasoning and dissemination, but it is necessary to specify at least their scopes and areas of application. The main purpose of the C-A system concept design and applying the end-user activities context information management framework is to identify qualitatively at an early stage possible areas for further in-depth study.

The framework itself includes the *end-users' daily activities timeline* with and the *context information management life cycle*. By analyzing HAS data and identifying the context of these activities, we can observe some obvious interconnections with environmental sustainability dimension's metrics and determine what data and through which devices we should collect to describe these activities. Additionally, we can propose the modelling scopes, types of the reasoning and types of the dissemination. Figure 3 shows an example of the end-user activities context information management at KTH Live-in-Lab. As was mentioned before, in this example we have focused only on the end-users' productivity (and all parameters related to the productivity measurement) and electricity consumption.

Timeline	Type of activity	Additional activities	Acquisition		Modelling		Reasoning		Dissemination	
			HAS	*BMS*	*HAS*	*BMS*	*HAS*	*BMS*	*HAS*	*BMS*
00:00, 02:00, 03:00, 04:00, 05:00, 06:00, 07:00	Sleeping		*Heart rate*	*Air quality* T_{indoor}						
08:00	Showering		T_{body}	T_{water}, T_{indoor}						
09:00	Breakfast	Social media	*Ingredients*	*El kitchen*	*Nutrient planner*	*Cooking planner*	*Preferences*	*El usage*		
10:00, 11:00, 12:00	Studying	Social media	*Outlook data Heart rate*	*HVAC, Lighting*	*Daily planner*	*Air quality mode, Lighting mode*	*Type of activity (reading, computer work)*	*Air quality standard, Lighting standard*	*Presentation (textual, visual, voice)*	*Execution: (response-based, seamless)*
13:00	Lunch	Meetings	*Ingredients*	*El kitchen*	*Nutrient planner*	*Cooking planner*	*Preferences*	*El usage*		
14:00, 15:00, 16:00	Studying		*Outlook data Heart rate*	*HVAC, Lighting*	*Daily planner*	*Air quality mode, Lighting mode*	*Type of activity (reading, computer work)*	*Air quality standard, Lighting standard*		
17:00, 18:00	Sport	Listening music	*Heart rate GIS*	*Air quality* T_{indoor}	*Progress planner*	*Air quality mode, Lighting mode*	*Preferences*	*Air quality standard, Lighting standard*		
19:00, 20:00	Dinner	Social media	*Ingredients*	*El kitchen*	*Nutrient planner*	*Cooking planner*	*Preferences*	*El usage*		
21:00, 22:00	Leisure	Meetings / TV	*Heart rate GIS*	*El room*	*Daily planner*	*Air quality mode, Lighting mode*		*Air quality standard, Lighting standard*		
23:00	Sleeping		*Heart rate*	*Air quality* T_{indoor}						

Figure 3. End-user's activities context information management at KTH Live-in-Lab (productivity / El usage case)

5. Preliminary results and conclusion

During the initial stage of the project this framework allows for a comparison of the activities of the end-users, presented in the left column, and the context information life cycle: *acquisition*, *modelling*, *reasoning* and *dissemination*. At this stage, we have identified several categories for potential in-depth study, for example, an analysis of food preferences and the possibility of collective cooking by analysing social network and meeting schedule data and deeper understanding of the air quality modes adaptation to the different types of the daily activities. Additionally, we have defined based on the end-users' participatory Workshop, that both types of dissemination should be presented, due to different end-users' preferences and relations to privacy issues. The same primary analysis shows that more attention needs to be paid to social network analysis and outlook schedule data and mobile log data. The next step in the study will be the detailed development of the quantitative modelling of the cases mentioned above and its subsequent expansion by adding all the sustainable building KPIs. It has to be mentioned that context information will inherently contain important data related to the users, which raises some privacy issues. Privacy concerns may differ from user to user, and may also be dynamically changing over time. The balance between privacy and the system potential is delicate, where the developer may fall into ethical issues.

References

[1] Maarten De Groote, Jonathan Volt, Frances Bean 2017 *Smart Building Decoded*
[2] Peter O. Akadiri 2012 *Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector* (Buildings)
[3] Misty Blowers 2016 *The Future Internet of Things and Security of its Control Systems*
[4] Weiser M. 1991 *The Computer for the 21st Century* (Scientific America)
[5] Schilit, B., M. 1994 *Disseminating Active Map Information to Mobile Hosts* (IEEE Network)
[6] Dey, A.K., Abowd, G.D., Wood, A. 1999 *A Framework for Providing Self-Integrating ContextAware Services. Knowledge-Based Systems* (CyberDesk)
[7] Bazire and Brézillon 2005 *Understanding Context Before Using It* (Modeling and Using Context)
[8] Dourish P. 2004 *Where the Action Is: The Foundations of Embodied Interaction* (MIT)
[9] Zimmermann et al., 2007 *An Operational Definition of Context* (Modeling and Using Context 6th International and Interdisciplinary Conference)
[10] Jumisko-Pyykköand Vainio, 2010 *Framing the Context of Use for Mobile HCI* (InternationalJournal of Mobile Human Computer Interaction)
[11] Alshaikh and Boughton, 2009 *The Context Dynamics Matrix: An Approach to Modeling Context* (Software Engineering Conference Asia Pacific)
[12] Perera et al., 2013 *Context Aware Computing for The Internet of Things* (IEEE Communications Surveys & Tutorials)
[14] Schilit, Hilbert, & Trevor 2002 *Context-aware communication* (IEEE Wireless Communications)
[15] Mokhtar, Foumier, Georgantes, & Issamy 2006 *UML based Model of a Context Aware System* (International Journal of Advanced Pervasive and Ubiquitous Computing)
[16] Knappmeyer, Kiani, Reetz, Baker, & Tonjes 2013 *Handbook of research on human-computer interfaces developments and applications* (IGI Global)
[17] Dey, A.K., Salber, D., Futakawa, M., Abowd, G.D. 1999 *An Architecture to Support Context Aware Computing* (User Interface Software and Technology conference)
[18] Bettini, C. et al. 2010 *A survey of context modelling and reasoning technique* (Journal pervasive and mobile computing)
[19] F. Ramparany et al. 2007 *An open context information management infrastructure* (International Conference on Intelligent Environments)
[20] Henricksen and Indulska 2004 *Modelling and using imperfect context information* (IEEE Annual Conference on Pervasive Computing and Communications Workshops)
[21] Jonsson M. 2007 *Sensing and Making Sense: Designing Middleware for Context Aware Computing* (Journal Personal and Ubiquitous Computing)
[22] Bikakis et al. 2008 *Distributed Reasoning with Conflicts in a Multi-Context Framework* (23rd Conference on Artificial Intelligence)
[23] BREAM: BRE Environmental & Sustainability Standard (BES 5051: ISSUE 1.0)
[24] LEED v4 for BUILDING OPERATIONS AND MAINTENANCE Updated January 5, 2018
[25] CASBEE for Buildings (New Construction), 2014 edition
[26] WELL Building Standard: Performance Verification Guidebook. 2019
[27] Checkland, P. 1981 *Systems Thinking, Systems Practice* (John Wiley, Chichester, UK)
[28] Miguel A. Labrador, Oscar D. Lara Yejas 2007 *Human activities recognitions from wearable devices and smartphones* (Chapman and Hall/CRC)
[29] Celestine A. Ntuen, Eui H. Park 1996 *Human Interaction with Complex Systems: Conceptual Principles and Design Principles* (Conceptual Principles and Design Practice)