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Building automation systems: Concepts and technology review

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ABSTRACT

Despite the popularity of the subject, one surprising aspect of building automation (BA) is the scarcity of authoritative literature references regarding the topic. This situation hampers communication between developers and contributes to the well-known problem of heterogeneity where there is difficulty in integrating solutions from different manufacturers with each other.

This article systematizes fundamental concepts and requirements of BA systems, defining each aspect based upon established literature standards. Using these aspects as guidelines, the main BA technology specifications available are then reviewed with respect to their coverage of features. We then proceed by showing that none of the analyzed specifications are able to totally cover the expected standard functionality span of BA. Finally, we conclude that none of the existing approaches are able to fully overcome the problem of heterogeneity by satisfactorily addressing all the aspects of BA endorsed by the standards.

Contents

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1. Introduction

A building automation system (BAS) consists of a system installed in buildings that controls and monitors building services responsible for heating, cooling, ventilation, air conditioning, lighting, shading, life safety, alarm security systems, and many more. A BAS aims at automating tasks in technologically-enabled environments, coordinating a number of electrical and mechanical devices interconnected in a distributed manner by means of underlying control networks. These systems may be deployed in industrial infrastructures such as factories, in enterprise buildings and malls, or even in the domestic domain.

Building automation has been receiving greater attention due to its potential for reducing energy consumption and facilitating building operation, monitoring and maintenance, while improving occupants' satisfaction. These systems achieve such potential by employing a wide range of sensors (e.g., for sensing temperature, CO_2 concentration, zone airflow, daylight levels, occupancy levels), which provide information that enables decision-making regarding how the building equipment will be controlled, aiming at reducing expenses while maintaining occupant comfort [1].

The engineering practice of BA has primarily emerged from manufacturer documentation, and was followed by technology standards such as BACnet [2], KNX [3], LonWorks [4], Modbus [5], ZigBee [6,7] or EnOcean [8,9], which are not in agreement with regards to concepts and terminology. One example of literature disagreement concerns the application of LonWorks and KNX at the management level of a BAS [10, p. 23,11]. Similarly, the definition of the concept of datapoint is also inconsistent across literature (compare [12, p. 54] with [13]). Moreover, with the evolution of BAS and technology in general, some related literature references became outdated, no longer offering coherent definitions in this topic. One example is the large number of literature references describing Supervisory Control and Data Acquisition (SCADA) systems that are unable to provide a sufficiently generic description of the SCADA systems' most common architectures [14–20]. Some of these references are outdated, thus their accuracy with respect to the current SCADA systems is questionable [13, Section 3.61 Note 7] [21]. Indeed, BA is a multidisplinary field where definition inconsistency and disagreement are recurring issues and for which almost no authoritative text exists.

The lack of commonly agreed field-knowledge and the existence of functionality gaps leads solution developers to repeatedly redefine basic concepts, creating their solutions bottom up instead of relying on the existing body of knowledge. Despite the fact that this problem has been identified and acknowledged in previous surveys and even considered by some authors as the "*potential barrier for BA technologies around the turn of the millennium*" [22–24], an inclination to create custom solutions persists, which greatly explains the heterogeneous nature of BA. Most solutions (i) are not able to inter-operate with other vendors' solutions without additional overheads, locking costumers to specific product lines—a major issue if such lines get discontinued—, (ii) have closed specifications, (iii) are too complex to be used by non-specialized personnel, whether they are end-users or system developers, (iv) only perform satisfactorily in the exact conditions they were tailored for, not performing so well if the working environment changes, thus lacking flexibility, and (v) do not cover all the desired functionalities expected in a BAS.

Over the years several interoperability solutions that target the problems of heterogeneity have emerged from BA technology standards with variable degrees of success. Despite a few scattered literature references, a principled discussion on how interoperability solutions cover the main features of BA has never been carried out.

This article starts by introducing and unifying the basic concepts of building automation systems with the goal of contributing with up-to-date definitions in this field. In addition, a set of features that, according to documented standards, should be implemented in building automation systems, is detailed and the extent to which most common BA technology specifications cover the expected functionalities of a BAS is evaluated. Finally, the main solutions for interoperability are analyzed with a special focus on the Service Frameworks that have been created within the BA field.

By analyzing information models of standard BA technologies we conclude that none is able to fully cover the breath of functionality expected from BAS, and that distinct technologies are required in order to create a fully functional system. However, the interoperability of these technologies is hampered by the fact that, as we observe, a number of concepts cannot be mapped between them. As a direct consequence of this circumstance, manufacturers have been led to create their own proprietary extensions thereby exacerbating the problem of heterogeneity.

2. Building automation concepts

As discussed earlier, current literature references leave readers with several unclear definitions and terminology that, in the long run, promotes heterogeneity among BA technologies.

This section draws on established literature references to systematize fundamental concepts of BAS prescribed by the ISO 16484-3 [25] and EN 15232 [26] standards and characterizes the scope of functionality expected from the typical BAS that will late be used to evaluate the coverage of each technology standard.

2.1. Level architecture

A BAS is a distributed system oriented to the computerized control and management of building services, also referred to as building automation and control system (BACS) [10]. The architecture of this distributed system can be organized into three layers [27]: (i) The lowest layer is known as the *Field Layer* where the interaction with field devices (sensors, actuators) happens, (ii) the middle layer is the *Automation Layer*, where measurements are processed, control loops are executed and alarms are activated, (iii) the top layer is the *Management Layer*, where activities like system data presentation, forwarding, trending, logging, and archival take place [13, p.52].

Modern BAS tend to separate the automation logic from the user interface through service-oriented abstractions, providing flexible access to the BAS from several different platforms and locations [28,19,20].

2.2. Communication networks

The backbone of the field level is the *fieldbus*, a digital data bus that allows communication between devices at the field level such as controllers, sensors, and actuators [10, p. 23, Chapter 2] [29,30]. A fieldbus aims at improving communication quality in comparison to previous analog communication buses, and at reducing installation costs by cutting down on the required wiring, since devices connected through fieldbus only communicate digitally. Devices connected to a fieldbus network are expected to have some computational power, and may even replace several analog devices simultaneously, further contributing to decreasing installation costs [31].

While fieldbuses are used at the field level, it is common to aggregate data via a common (IP-based) backbone at the management level. The overall installation consisting of fieldbus segments and the backbone is frequently referred to as *control network*. A plethora of different control network technologies currently exist on the market with specifications that vary according to requirements of their application [10]. Besides many vendor specific solutions, the main standards used today are BACnet [2], KNX [3], LonWorks [4], Modbus [5], as well as wireless buses such as with ZigBee [6,7] and EnOcean being notably to mention wireless representatives [8,9].