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Enhancing smartness and interoperability of building management systems in non-residential buildings

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Abstract

In smart and sustainable cities, smartness of buildings is expected to evolve. A smart building should enhance its users' productivity and minimize its environmental impact. Although these objectives are seemingly common, the development of the smartness of buildings is actualized in the form of an incoherent combination of standards and solutions. The emergence of the IoT (Internet of Things) is expected to bring major improvements in the development of smartness, but at the same time, it may even worsen non-systematicity. Such inconsistency creates barriers to the commercialization of innovations and poses challenges to technical building management. Here, we clarify the situation between the conventional building management system approach and the IoT-based entrants. We analyze the different approaches to building automation systems' interoperability by means of a literature review, professional interviews and smart readiness indicator impact evaluation. The study forms a general view based on the presented information and suggests approaches for specifying technical building systems, which are expected to improve their schematic clarity and reduce performance gaps of buildings. This study can be used as a practical tool by technical building managers, and it discusses issues needing consideration to the benefit of policymakers, industry and academia.

Keywords

Smart buildings; building management system; interoperability; Internet of Things

1. Introduction

Buildings are major consumers of energy, accounting for more than 40% of the final energy consumption in the EU (Odyssee-Mure, 2022). By developing their smartness, the energy efficiency and general in-use performance of buildings can be improved (European Commission, 2022). However, as the number of various smart devices and systems in buildings increase, greater complexity can lead to challenges during buildings' lifecycles. They have been identified as the complexity of the selection of optimal devices during the design phase of building management systems (BMSs) (Mai et al., 2013), increased costs of installation during construction, and contributing to the performance gaps during the operation of buildings (KNX Association, 2019; Pellegrino et al., 2016; Rasmussen & Jensen, 2020). An often-proposed solution to these issues has been the adoption of integrated, open protocol BMSs. Ensuring interoperability among different functionalities from different manufacturers has been claimed to result in increased smartness of buildings, decreased installation costs and reduced dependence of building owners on vendors (BOMA International Foundation, 2000 KNX Association, 2019).

Meanwhile, the use of the Internet of Things (IoT)-based solutions is expected to increase in smart buildings due to their architectural simplicity, effectiveness when combining data from miscellaneous sources and reduced system costs (Curry et al., 2013; Ke et al., 2020; Mataloto et al., 2019; Minoli et al., 2017). However, arguments in favour of traditional building management solutions over IoT still exist. A common IoT application layer standard, which would be comparable with the existing building automation standards, is seemingly unavailable (Curry et al., 2013; Minoli et al., 2017; Sembroiz et al., 2018). Often, IoT components are battery powered and/or they have a short service life, which increases maintenance costs and reduces reliability of systems (Abadia et al., 2022; Plageras et al., 2018). Communication between IoT devices and cloud services can be perceived as a parallel channel of communication with existing BMSs, which increases complexity and can diminish the clarity on the share of responsibilities between technical systems and building automation in general. There is a growing diversity of solutions available on the smart building market; at the same time, building owners try to reduce fragmentation of technologies in their building stocks. For today's technical building managers and consultants, choosing among various systems and solutions, while aiming towards systematicity and future-proof buildings, is far from self-evident.

In this paper, we clarify the situation between the conventional BMS approach and the IoT-based entrants. We focus on the technological choices for non-residential buildings that are under construction or undergoing major refurbishments. Home automation and automation for other domains, such as industry, are outside our study's scope. We formulate the first research question as follows: What is the preferred schematic approach to enhance smartness and interoperability of BMSs from the viewpoint of building owners targeting sustainable, resilient and cost -efficient buildings?

In addition to the first research question, a case of a past technology programme is expected to provide a historical perspective on the activities that endorse integrated BMSs. Many of the previously mentioned challenges have been recognized in the smart building industry as early as decades ago, and the use of open protocol fieldbuses has been proposed as a solution. In Finland, the emergence of building automation fieldbuses has also received public support. The innovation-funding organization Tekes initiated the technology programme "Samba – smart and modular building automation" in 1995, which aimed to develop Finland as a pioneer in intelligent building management, favouring the LonWorks (LON) standard from the United States as the core technology. However, after the completion of the technology programme, the use of the LON started to decline and apparently, it has now become obsolete in the Finnish market. To a certain extent, it has been replaced by KNX, a fieldbus standard that originated in Germany. KNX has not gained similar public support. Therefore – or nevertheless – the success of KNX can also be judged as modest, at least for the time being.

The original value propositions used to endorse the use of open protocol fieldbuses still appear to be current and valid. However, we do not observe them being applied to the anticipated extent. This leads us to the second research question of our paper: How has the technology programme Samba influenced the development of smart buildings?

This paper's contributions lie in enhancing clarity in the various means to integrate automation systems in non-residential buildings, for the benefit of industry, building owners, policymakers and the academic community, and offering a perspective to explain the essence of the present-day smart buildings.

2. Integration – definitions and approaches

The increasing complexity of technical systems in buildings has been a long-lasting trend. Bi-metallic thermostats have been replaced with communicating room-heating sensors. Airflow is controlled by ventilating systems instead of mechanical ventilation. Presence detection with constant light control has replaced manual light switches. The earlier approach, where each function was installed as a separate system with dedicated sensors, actuators and cabling, has become impractical.

Integration is a logical deduction of the theory that access to information and controls from any single point improves the overall efficiency of the involved systems (BOMA International Foundation, 2000). Data from a single sensor may be shared among several applications, which reduces the number of pieces of equipment and cables. Integrated systems provide functionality that cannot be offered by any single system, as well as reduce the costs associated with separate databases and overlaps (Sinopoli, 2010). When several manufacturers use the same protocol, it is possible to put out tenders for the procurement and installation of systems, and during the use of a system, it could be possible to replace a broken or an old device with a similar one from another brand (Järvinen et al., 2011). This reduces the building owners' dependence on single vendors and thus decreases maintenance costs and risks. It may also be possible to expand such a system later with a solution that was unavailable when it was installed (Kastner et al., 2011).

However, as more functionalities are integrated, it becomes apparent that the objective of having all information available at all points will become virtually impossible to achieve. Room temperature information only requires a few bytes of data, and the interval between telegrams may take minutes, while a single data point in a video surveillance system may require several megabytes per second. Providing the latter's communication capacity to all field-level devices would be unreasonable. It is impractical to closely follow the principle of having all information available at every point of a system; therefore, in building automation installations, more than one technology is required (Domingues et al., 2011; Piikkilä, 2017).

The architecture of distributed building automation systems is commonly organized into three layers. The lowest one is known as the field layer, where interactions with field devices (sensors and actuators) occur. The middle one is the automation layer, where control loops are executed. The top one is the management layer, where activities such as system data presentation, forwarding, trending, logging and archiving take place (International Organization for Standardization, 2004). Communication between the management and the automation layers in modern systems is implemented with IP (Internet Protocol) networks. Field devices have conventionally communicated with controllers on the automation layer with hard-wired binary or analogue signals. In modern systems, fieldbuses may have replaced hard wiring, or fieldbuses and hard wiring are used in parallel (Kastner et al., 2011).

Vertical integration is used to provide communication between hierarchy levels, while horizontal integration contributes to data exchange between domains on the same hierarchy level (Soucek & Loy, 2007). Two levels of interoperability may be distinguished: technical interoperability is concerned with the translation of telegrams from one protocol to another, and semantic interoperability refers to how management-level concepts from different technologies are interchanged and processed (Domingues et al., 2011). Technical interoperability between devices or sub-systems and a building automation system can be identified as implemented with at least four different approaches: physical integration and fieldbus integration on the field layer, and software-level and cloud-level integration on the management layer (Silver, 2018) (Figure 1). These approaches are discussed next.

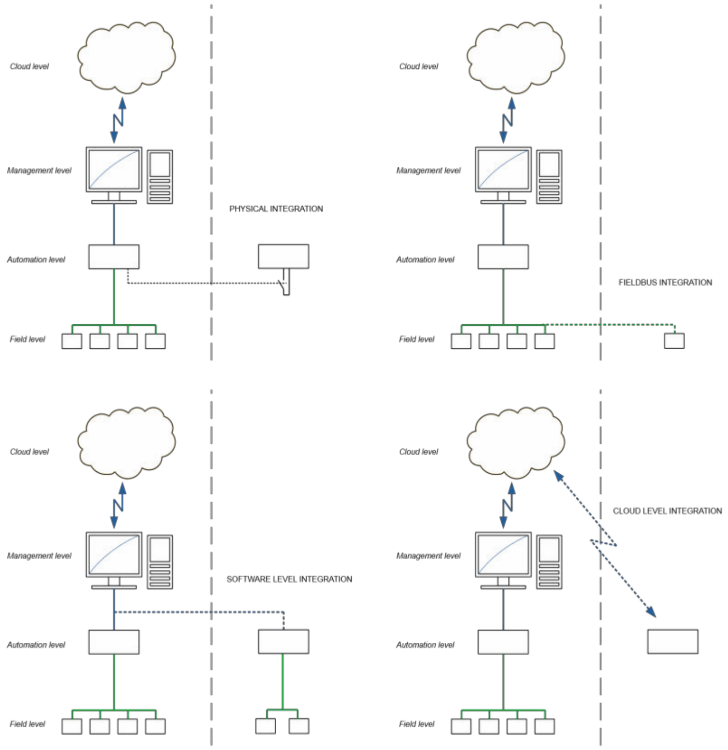

Figure 1. The architecture of building automation systems and the different approaches used to implement technical interoperability with external systems: physical integration (top left), fieldbus integration (top right), software-level integration (bottom left) and cloud-level integration (bottom right).

2.1. The four technical interoperability approaches

Physical integration is the simplest approach used to transfer information, where a system sends a signal via a binary (or analogue) output, which is interpreted by another system via an input. It is easy to implement, but its limitations are obvious. Each signal requires individual hardware, and for complex data types, it is not suitable at all. However, physical integration may be the only practical solution available, for example, if a system to be integrated does not support the same communication protocol or is a safety system required to solely consist of certified devices (Silver, 2018).

Fieldbus integration refers to the transfer of data between systems using a standardized protocol, allowing the establishment of communication between products from different vendors. Compared with physical integration, the clearest advantages of fieldbus integration are the simplicity of cabling and the wide range of possible data types. The commonly experienced problem with fieldbus integration is that although devices from different vendors meet the same standard, they are nevertheless incompatible. Not every need has been foreseen in the specifications, which has resulted in manufacturers implementing their own proprietary extensions, thus hampering interoperability (Domingues et al., 2011).

Systems can be integrated at the management level by means of software-level integration so that different functions can be administered from a common user interface. In this case, it is possible to obtain a comprehensive overview of the entire technical operation of the building from a single graphical user interface. Data can also be exchanged between two or more systems, allowing the data to be utilized in implementing automated functions (Fernbach et al., 2011). The classical approach to allow a system to communicate with another is the use of gateways. However, when additional systems are integrated, the complexity increases exponentially, and the gateway also becomes a single point of failure in the system (Soucek & Loy, 2007).

In cloud-level integration, data are transferred outside the actual buildings, where different cloud services communicate with one another. This creates new opportunities to utilize data in creating new innovative services, particularly in developing artificial intelligence. Due to issues involving data security, communication delays and functional reliability, critical process control cannot be implemented through cloud-level integration. The IoT could be a substitute to the three-level BMS solution, or it may expand its functionality. The suggested objectives of cloud-level integration include the integration of building services into enterprise resource planning (ERP) systems (Ghaffarian Hoseini et al., 2017; Soucek & Loy, 2007) and decision-making tools (Marinakis and Doukas, 2018; Yu et al., 2015); interoperability between a BMS and the smart grid (Mauser et al., 2016), demand-side management (Lukovic et al., 2010; Tzovaras et al., 2010; Wang et al., 2018) and enhancement of the functionality of an existing BMS (Alanne & Sierla, 2022; Mataloto et al., 2019).

A review of the academic literature suggests that developments in BMS integration have not received much scientific attention over the years. There is scarcely a principled discussion on how interoperability solutions could reduce the number of isolated systems or contribute to developing smart building technology to be structurally clearer and more straightforward to maintain. The existing research acknowledges the emergence of IoT-based automation in non- residential buildings, but the influence of IoT-based systems on conventional building automation is apparently neglected. On the contrary, the recent upsurge of interest in the IoT has created a profusion of new device manufacturers, which develop their proprietary solutions, again resulting in increased heterogeneity (Abadia et al., 2022; Domingues et al., 2011; Sembroiz et al., 2018).

3. The expected influence of the adaptation of the smart readiness indicator

The European Commission has developed the smart readiness indicator (SRI) to raise awareness among building owners and occupants of the value behind smart building systems. The SRI implementation by each EU member - state's legislation has not yet been finalized, but it is expected that the SRI shall be used as a collective tool to benchmark and assess the smartness of buildings. Likewise, the SRI score given to a building can be anticipated to have an impact on its commercial value, advancing investments in smart technologies, which otherwise may be considered unattractive due to lack of immediate value (Kinch et al., 2021). To understand and foresee the outcome that the SRI implementation will have on smart buildings, we acquired an assessment tool (European Commission, 2022) to perform SRI assessments on two sample buildings and create scenarios to discover what kinds of improvements are valued by the SRI.

Building A represents a typical school building. It was built in 1971 and completely renovated in 2016. It has a building automation system controlling heating and mechanical ventilation (de facto in Nordic non-residential buildings). DALI lighting and other technical sub-systems have not been integrated. Building B is a major office building, completed in 2020 and considered modern. It has electric vehicle charging stations, and a dynamic envelope on its southern facade. M-bus energy metering has been integrated with the BMS, but this has not been the case with KNX/DALI lighting and most of the other sub-systems. Both buildings are connected to district heating, and Building B is also connected to district cooling, without any local energy storage capacity. Data from the BMS and energy metering are sent to a cloud-based supervisory system from both buildings.

We first performed SRI analysis on the buildings. Next, we developed two scenarios. In the first scenario, we evaluated what would be the score improvement if the BMSs were horizontally integrated. For instance, this would allow information from lighting control presence detectors to be used also for heat emission control, improving the SRI score. In the second scenario, we evaluated the score improvement if vertical integration would be fully implemented, allowing comprehensive automatic process control between the field level and cloud computing. Additionally, we evaluated the resulting score if both scenarios were implemented. The results are shown in Table 1.

Table 1.SRI score for the buildings and the effect of speculative improvements.

Building	SRI score, original	SRI score, horizontal integration revised	SRI score, vertical integration revised	SRI score, horizontal and vertical integration revised
Building A	46%	53%	71%	78%
Building B	58%	61%	69%	73%

4. Fieldbus integration and the technology programme Samba

The engineering practices of BMSs have primarily emerged from manufacturer documentation (Domingues et al., 2011). Many technology standards have also been originally developed and introduced by industrial companies, for example, LON by Echelon Corporation and KNX (originally EIB) by a consortium of German manufacturers (Merz et al., 2018). The field experience that is reflected on a standard does not necessarily equal the experience of other companies or market areas. The success of a standard is also influenced by the marketing power of the companies involved. In the field of industrial automation, similar conflicts of interest and lack of coordination even led to a period referred to as the fieldbus war (Felser & Sauter, 2002).

RAKLI, the Finnish Association of Building Owners and Construction Clients, had identified problems with building services; the most severe were unclear divisions of responsibilities among domains of technical building systems and the lack of proficiency in the field, leading to installed building technology that does not function as desired. Smart building technology was complicated, difficult to use and incompatible between vendors – often due to commercial reasons. This gave rise to the need to reform the culture of purchasing and implementing building technology. RAKLI organized a study to suggest solutions to these challenges and to designate a preferred communication protocol. The resulting study endorsed LON technology. The predecessor of KNX, the EIB, was merging with Batibus and EHS at that time and was considered immature. The study was funded by TEKES (Rakennustieto, 1995).

Inspired by these activities, TEKES launched the technology programme Samba, which was active from 1995 to 1999. Its objectives were to develop the operations of the national building automation industry and to promote its competitiveness in the export markets. TEKES funded the programme with a total of FIM 48.9 million (EUR 8.2 million), with the estimated total value of the programme being FIM 400 million (EUR 67 million). In 1997, the busiest year of the programme’s operation, 135 companies participated in projects receiving funding. Funding was provided for product development, personnel training and pilot projects (Eloranta, 1999; Sähkötieto, 2000; Tekes, 1998). However, after the completion of the programme, the commercial success of solutions based on LON technology began to decline, and these solutions are now virtually obsolete (Piikkilä, 2017).

In 2008, KNX Finland, a subsidiary of the international KNX Association, was established with the aim to promote awareness and the use of KNX technology in Finland. The promotional communication by KNX repeats the same arguments that were already in place during the implementation of Samba, particularly openness, manufacturer support and adaptability (Sähkötieto, 2019). KNX has neither received public support nor seems to have gained the popularity anticipated for fieldbus technology in smart buildings.

5. Professional interviews

5.1. Interview approach and process

What are the experiences, attitudes and expectations in the field regarding BMS integration and its future development? Obviously, such questions may be answered by conducting interviews with professionals. The qualitative methodology we used was adopted from Tuomi and Sarajärvi (2018). We searched for potential interviewees among experienced BMS professionals: consultants from planning organizations, system integrators from contractors and technical building managers by building owners. The interviews followed a semi-structured approach. Because of some ambiguity in terminology, we first presented the approaches of technical integration and then started the discussion with a set of open questions, as follows: What are the interviewees' experiences about each approach? What are these approaches' pros and cons? How do the interviewees expect them to be adopted in the future? Next, integration was discussed on a generic level, followed by the interviewees' views about the technology programme Samba. Later, we conducted a conceptual content analysis by reading the transcribed interviews and listing each argument where we interpreted each interviewee as expressing a position about each topic.

Following such a methodology may raise the question of whether the resulting outlook is universal or we have only seen the tip of the iceberg. To gain confidence that the results we collected comprehensively reflected the professionals' views, we counted the number of new arguments presented in each interview. As the number of interviews increases, the arguments presented by the interviewees should start to recur and the number of new arguments should decrease. This seems to have occurred with our interviews as well (Figure 2).

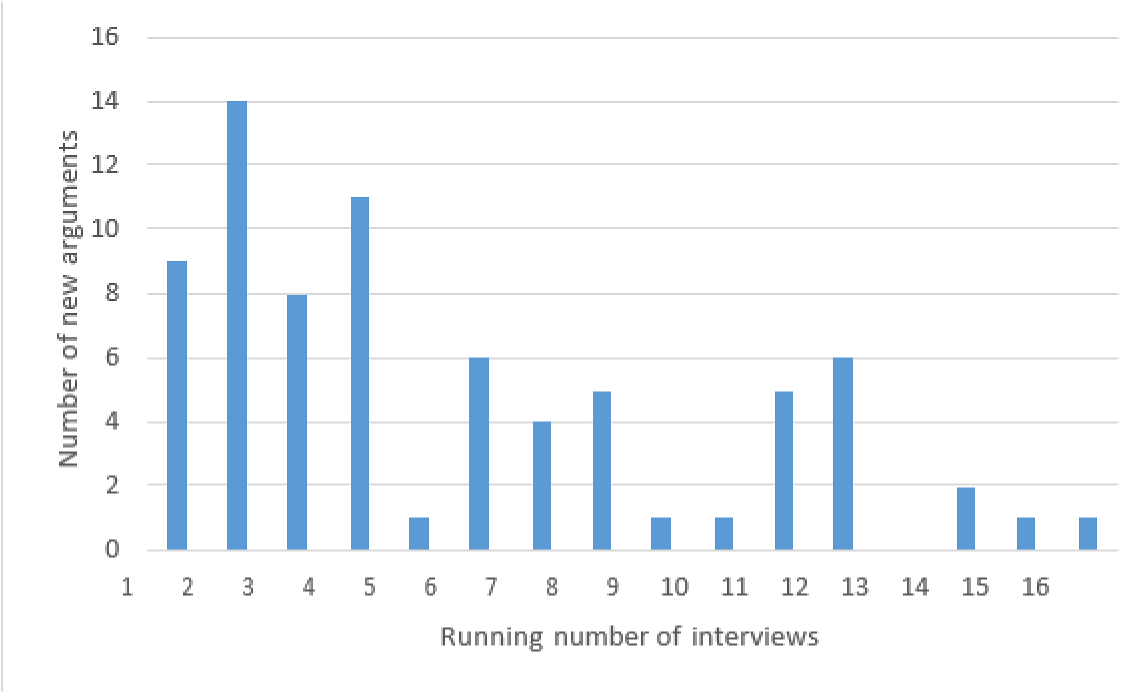

Figure 2. The number of new arguments per interview.

5.2. Professionals' views on integration approaches

Such arguments that were stated by more than one interviewee are presented in Table 2. In general, the interviewees emphasized the importance of standardized interfaces and integration, but there were more nuances in the views when this was discussed in detail. Many interviewees argued that there were significant differences in the amount of labour that different open standards would require for successful interoperation. Typically, the design specification of a BMS states that the adoption of open interfaces is a requirement. If the designer merely draws a plan with two boxes representing two systems and a line labelled 'Modbus' between them, he/she can claim that the design meets the specification. However, establishing a functional communication would require manually finding matches between registers, functionalities and data types with vendor-specific tools on both sides, and as the number of possible device combinations is virtually endless, there are limited possibilities to learn or copy-and-paste between projects.

Table 2. Arguments that were expressed by more than one interviewee.

Arguments per approach / subject	Number of interviewees who expressed the argument
Physical integration:	
Limited sharing of information between systems	7
Technically reliable	5
Trend towards more advanced integration	3
Requires intensive use of (physical) resources	3
Low cost to implement	3
Suitable for alarm signaling	2
Fieldbus integration:	
Allows collecting more information from sensors	4
Simplifies cabling	4
Increased maturity of fieldbus integration solutions	3
Lack of competence in the field	3
Easy commission, due to built-in functionality of devices	2
Multi-vendor systems are problematic to set up	2
Multi-vendor systems are considered risky due to shared/unclear responsibility	2
Software-level integration:	
Unclear share of responsibilities and division of tasks among contractors/vendors	5
Communication problems between devices from different vendors	3
Configuration updates in one system may force updating the other(s)	3
Missing *de facto* solution on this level	2
Information security challenges	2
Cloud-level integration:	
Lack of standards	5
Ease of adding sensors	4
Information security challenges	4

Ease of combining data from different sources	2
Cloud-computing solutions have access to more computing power than on-site systems	2
Two-way communication difficult or not possible	2
Slow communication	2
IoT solutions developed by companies with no expertise in BMS systems	2
Communication from cloud software down to automation requires tailoring	2
Technology programme SAMBA:	
KNX and BACnet offer better interoperability than LON	3
Negative experiences from pilot installations	2
Overly optimistic promises about ease of integration	2

The same seems to be the case during the implementation of the technology programme Samba. There was a mismatch between the visions communicated by the programme and what the industry could deliver with the tools and the products available at that time. In some cases, experiences from pilot installations even led the customers to prohibit the specification of certain fieldbuses, which was the opposite of the programme's objective. Later, the industry introduced standards with more advanced semantic interoperability, but obviously, more effort could have been put into communication, emphasizing the importance of interoperability rather than mere integration.

It was generally agreed that the utilization of cloud services would become more common. Cloud computing improves BMS functionality and performance and may replace on-site, management-level devices. Risks related to information security, low communication reliability, data latency, lack of standards and inconsistency in labelling datapoints in BMS were considered issues needing further development. Often, IoT-based solutions are introduced by companies with no expertise in BMS, which raises concerns about their products' maturity and expected lifespans.

Although the interviewees were experienced professionals in the field of smart buildings, the hierarchical levels in building automation were not always concretely clear. Some interviewees considered the hierarchy outdated. The use of cloud-based management would seem to remove the management layer, or some devices may have built-in automation and field level functionality. However, it can be argued that the three-level model expanded with the cloud level is still a valid hierarchical description of the automation structure, but a device or a function may vertically overlap level boundaries.

6. Discussion and conclusions

Based on the literature and history reviews, the interviews and the SRI impact evaluation, we conclude that the following approaches should be used in system design specifications to enhance BMS smartness and interoperability:

- To endorse vertical integration, ensure that all BMS processes have access to two -way cloud communication.
- To endorse horizontal integration, require the use of open communication protocols, adopting standards with effective semantic interoperability.
- In case of a controversy, prioritize vertical integration.

The technology programme Samba was not perceived as having made a lasting impact on the development of smart buildings. Although the programme succeeded in attracting a substantial number of companies, their activities declined soon after the end of the programme funding. This was influenced by their unsatisfactory experiences from pilot installations. The implementation of open and integrated systems with the maturity of the technology available at that time proved to be much more demanding than what was communicated by the programme. If similar technology programmes were to be considered in the present time, it is suggested that they are not as specific about the standard(s) to be applied.

The SRI analysis indicated that it's scoring system rewards better vertical than horizontal integration improvements. The potentially achievable score was higher in the older building with fewer domains. When using the SRI tool to benchmark buildings, it should be noted, that the SRI score is an indicator of smartness of the existing domains of a building, rather than a sign of its general modernity.

In this work, we have sought clarity in the management of the structural implementation of BMSs. We have reviewed the literature, acquired a historical perspective via the technology programme Samba, outlined the potential future impact of the implementation of SRI, and gained the consideration of professionals through interviews. Based on th is information, we have drafted the suggested guidelines for BMS implementation. These guidelines are valid for non - residential smart building markets with similar engineering practices.

The existing building stock is a major consumer of energy, which creates the demand to enhance its performance. The aspirations to improve smartness of buildings are hampered by the fragmented and inconsistent technology being used. This persistent problem slows down development in the industry because such a market scarcely offers economies of scale to innovators. By following this paper's guidelines in their policies, building owners may improve their systematicity and readiness to adapt new solutions, when such become available. Providers of IoT -based solutions are suggested to better consider technical readiness and system lifespan expectations of their smart building customers. Also, more education and training are suggested, to reduce the economic losses by performance gaps.

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