Interoperability as a driver or barrier of smart building technologies?

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Abstract. Smart building solutions are a strong leverage for increased energy efficiency in buildings, improved quality of life for occupants and added value for work performance. However, the degree of interoperability of technical building systems (and analysis / software tools that use data from these systems) can be a limiting factor affecting the smart services and impacts that can be delivered within a building since several ways of representing components and systems exist and inherently means a comprehensive knowledge not easily reachable. Interoperability is essential for allowing technical building systems to interact with the energy grids, can avoid duplication of efforts and is desirable in the light of future upgrades of the building. On the downside, it can increase the risk for malfunctioning and introduce cybersecurity and liability risks. This paper presents an overview of the various layers of interoperability in smart buildings and related standards and ontologies. Experts from industry and academia were surveyed and mapped the barriers and drivers related to interoperability of smart building systems, followed by further prioritisation of key actions to strengthen the market uptake of smart building technologies.

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1. Introduction

Smart building solutions are a strong leverage for increased energy efficiency in buildings, improved quality of life for occupants and added value for work performance. Smart digital technologies in buildings are an important infrastructure requirement to explore flexible assets in the provision of energy and non-energy services.

The degree of interoperability of technical building systems (and analysis / software tools that use data from these systems) can be a limiting factor affecting the smart services and impacts that can be delivered within a building. Interoperability of systems can avoid duplication of efforts (e.g. investment for occupancy detection systems and monitoring displays for lighting, for space heating and cooling and ventilation systems) and optimise the control and maintenance of technical building systems (e.g. single interface for controlling heating and cooling facilitates the operation of the building and prevents spilling energy through uncoordinated simultaneous heating and cooling in building zones). Furthermore, interoperability is essential for allowing technical building systems to interact with the energy grids. Finally, interoperable systems are desirable in the light of future upgrades of the building as they can avoid proprietary lock-in and facilitate innovative solutions.

There can, however, also be a downside to interoperability. Exploiting interoperability through connecting various systems – potentially stemming from multiple manufacturers – can increase the risk for malfunctioning compared to proprietary systems and protocols. Fault diagnosis in a system of interconnected technical building systems can also be more intricate compared to a set of stand-alone systems. Finally, the delineation of responsibility for the provision of the service can become blurred in case of interoperable and interconnected systems. This can introduce cybersecurity risks and the risk that an end user is unable to establish who is responsible for the service and hence cannot legally seek recourse if a service they have paid for is not functioning as intended.

The topic of interoperability has been identified as one of the key topics to be investigated by the "SmartBuilt4EU" project, a Coordination and Support Action funded by the European Commission to bring together the research and innovation community on smart buildings.

2. Research Methods

2.1 Set up of Task Forces

The SmartBuilt4EU project has set up four task forces investigating issues related to smart buildings: their objective is to identify the remaining challenges and barriers to smart building deployment, and the associated research and innovation activities that should be carried out in the near future to address those.

The participation to Task Forces is open and on a voluntary basis: members are welcomed to join by applying to SmartBuilt4EU Smart Building Innovation Community (SBIC). Most members are currently involved in Smart Building projects funded by the European Commission., while others are involved in European sector organisations, standardisation bodies, academia, or private companies.

The Task force No 2 of SmartBuilt4EU focuses on the optimal integration and use of smart solutions to allow an efficient building operation. The Task Force investigates what are the interoperability requirements to ensure a seamless operation, as well as the optimisation in terms of building costs and reduction of environmental impacts, over the full life cycle. The first topic addressed by this task force and presented in this paper was on interoperability of smart building systems and services.

2.2 Process to collect inputs, package results and validate through consultation

The process developed by SmartBuilt4EU started at the end of February 2021 with a workshop officially launching all Task Forces and attended by close to 50 participants. Preliminary feedback on the scope of the topics to be investigated from March to September 2021 was gathered through the online interactive tool Conceptboard. Three online meetings were then organised on a monthly basis with the members of Task Force 2 to collect inputs on the State of the Art (SoA) related to the interoperability topic, to identify barriers to the market uptake of smart buildings related to interoperability of building components and systems (as well as drivers); and finally propose activities to overcome the barriers and leverage the drivers. All the inputs provided through Conceptboard were then consolidated in a White Paper, which went through an internal quality review followed by a peer-review open to all members of SmartBuiltEU SBIC. The final White Paper was officially released during the Sustainable Places Conference in Rome, in September 2021, and published on SmartBuit4EU website [1].

3. Results of the screening and surveying tasks

3.1 Definition of interoperability

Various definitions of interoperability are being used in practice, e.g. proposed by the **European Interoperability Framework** (EIF) and **ISO/IEC 2382-017** [2]**.** In the work carried out by the task force members, it was opted for using the definition proposed by ETSI: "*Interoperability can be considered to be the ability of two or more systems or components to exchange data and use information'* [3]. ETSI also defined different levels of interoperability:

- technical interoperability (Systems and components that should work seamlessly together: sensors, actuators, central controllers and displays, etc.): addresses the aspects related with connectivity, network, and device representation;
- syntactical interoperability: addresses packing and transmission of data;
- semantic interoperability: addresses the representation and knowledge description;
- organisational Interoperability: addresses the aspects related to business objectives and regulatory frameworks

Other organisations or authors have proposed slightly different taxonomies, e.g. the interoperability stack by GridWise Architecture Council (GWAC) [4].

The semantic interoperability is an important research challenge tightly related with the purpose of allowing computer-based systems to exchange data and more importantly to infer on that data and allows the exchange of knowledge [5]. Ontologies, such as SAREF [6], are being developed based on graph patterns to set understandable and interpretable definitions of components related to devices, systems and buildings.

3.2 Landscape of standards, protocols and taxonomies

Interoperability can be relevant in multiple stages of the life cycle of a building; e.g. exchanging information between various building professions during the planning stage benefits greatly from interoperable models such as BIM (Building Information Models) data based on Industry Foundation Classes (IFC) standards [7]. Following this standard, various participants in a building construction or facility management project can collaborate on a same data model; irrespective of the specific software tools they need for their activities. The desired IFC data can be encoded in various formats, such as XML, JSON, and STEP.

For smart buildings, interoperability during the operational phase becomes specifically important. Building management systems (BMSs) have evolved in recent years to support and efficiently operate diverse systems and appliances through technologies and ICT solutions; however, comprehensive multi-system management using one all-inclusive BMS and standardization of data flows, data analysis, and actuation remains an unattained goal [8]. A very broad range of IoT communication protocols is currently available. Besides proprietary protocols used by a single manufacturer, a large number of open protocols are being used including BACnet, LoraWan, ZigBee, KNX, DACI, EnOcean, Sigfox, Z-Wave, etc. [9,10]. Some of these are described in international standards, other are maintained by private initiatives supported by an ecosystem of multiple vendors. Given this multitude of protocols, using an 'open' protocol is not sufficient to guarantee interoperability. Furthermore, some of these protocols focus mainly on the communication layer, but do not extensively define the content and structure of the data exchange, thus still resulting in products of multiple vendors to not seamlessly integrate. One of the solutions to overcome this is making use of semantic taxonomies and standardised ontologies, which act as a common dictionary to map similar contents and data points across various protocols. This is especially relevant when the scope is widened from the single building to the interaction of the building and the connected energy grids. Irrespective of the building energy management system or smart appliances used at the building level, grid operators want to use a common approach to allow data exchange, e.g., when unlocking the flexibility offered by buildings to shift energy needs in time in response of fluctuating availability of renewable energy sources on the grid. Common ontologies such as SAREF allow to operate such an intricate system of buildings connected with an energy grid without forcibly imposing common hardware or communication protocols withing the buildings.

Two important initiatives in this regard are SMARTM2M and S2 interface. The SmartM2M initiative is supported by ETSI and focuses on creating the grounds for semantic interoperability in several sectors like the industry that led to IoT based ontology definitions [11]. SAREF is one of the related outputs concerning the smart appliances domain. The S2 Interface is initiated by a group of stakeholders and sponsored by IEC [12]. It aims developing a standardized way to exchange information to support energy flexibility services between for the grid side, making use of data representation of flexible assets within buildings under the resource manager designation.

One of the approaches being considered by several EU projects is the focus on the semantic interoperability and the ability to create decoupled representations of assets and entities that allow the development of new services for buildings. The InterConnect project has set an approach based on an interoperability framework (IF) to which adapters are used to ensure that different strategies or implementation approaches can be followed. The manufacturer, system integrator or service provider is responsible for developing software adapters to ensure the interaction with the IF based on graph patterns that exposes specific features based on SAREF extensions. The ability to ensure the interaction with other ontologies allows new generation of services to be exploited in the context of buildings, such as energy flexibility, energy forecasting, etc.

3.3 Main barriers identified by the Task force

Barriers to the market uptake of smart buildings related to interoperability of building components and systems were discussed by the Task Force.

Tab. 1 – Barriers related to interoperability.

Type	Barrier
Value Chain barriers	- **Vendor Lock-in (e.g. in the case of solutions sold with support & maintenance)** - Readiness of industrial players and complexity of value chain
Regulatory barriers	- Lack of industrial standards for homogenous interoperability - Data integration issues related to GDPR (General Data Protection Regulation) - Lack of regulation preventing or discouraging vendor lock-in
Social barriers	- **User acceptance / Final users' awareness and user friendliness** - Complex inclusiveness, lack of human-centric solutions for non-expert users
Economic barriers	- Reluctancy to adopt interoperability by manufacturers as it might affect market share / profit - Reluctancy to adopt interoperability by service providers / integrators who generate business on tailor made integrations - Cost related to IoT investment or semantic modelling (i.e. BIM)
Technical barriers	- **Cybersecurity of open systems** - Low "Smartness" of the building stock/ legacy equipment

Based on these extensive discussions, 12 main barriers were identified, which are displayed in Tab. 1. An attempt to further prioritise these barriers was undertaken by the Task Force, leading to highlighting the three top priority barriers – indicated in bold in Table 1. A first key barrier is related to vendor lock-in effects. A conventional example is a market offering of products of a specific vendor which are not interoperable with other products of different vendors. Many market actors are evolving into new business models relying on servitisation [13,14]. This might enhance lock-in effects, where not only products but also supporting services such as maintenance are closely tied to a specific vendor. While potentially beneficial for specific market actors, the proliferation of models relaying on vendor lock-in might hamper the overall market uptake of smart building solutions. A second key barrier to the uptake of smart building solutions is related to social aspects, namely the lack of user awareness and user-friendliness. Interoperability is a highly intricate field, even for experts working on this very topic. The complex technical concepts and terminology, e.g., related to various protocols used by smart building products, can cause confusion and lack of trust for many individuals. This barrier can become more crucial as the market is maturing and moving from frontrunners to a more general public uptake of smart building solutions. The third key barrier relates to cybersecurity of smart digital systems. Increased uptake of smart technologies and services relies on larger numbers of connected devices (sensors, actuators, controllers, etc.) which can mutually communicate and interact. Such intricate digital systems inherently raise the importance of cybersecurity aspects, especially compared to conventional buildings which rely on . In this regard, the role of interoperability can be ambiguous, as the possibility of connecting multiple systems of multiple vendors could also increase the risk for vulnerabilities. Typically, the risk for cybersecurity infringements will depend on the 'weakest' part of the system, and this harder to manage and maintain in an open system with multiple interoperable parts compared to a closed ecosystem for which roles and responsibilities are much more clear.

3.4 Main drivers identified by the Task Force

The Task Force also set out to define the main drivers for the uptake of smart building solutions related to interoperability. In total, 14 main drivers were defined, as listed in Table 2.

Two drivers were identified to be most critical. At first this is the market push, in which the market uptake of technologies clearly favours open standards and technologies. This is in clear contrast with the barrier of potential lock-in effects. Next, an important driver related to regulatory initiatives. Legislation such as the European Energy Performance of buildings directive and policy initiatives such as the Smart Readiness Indicator, Digital Logbooks for buildings and building renovation passports are perceived as important instruments to further drive the market towards interoperable smart building solutions.

Tab. 2 – Drivers for smart buildings related to interoperability.

Type	Drivers
Value Chain drivers	- **Market push** Initiatives from market actors providing energy and non-energy services - Democratisation of data assets/ strong push to make all the data available to all market players in the value chain
Regulatory drivers	- **EU Regulation: Energy Performance of Buildings Directive, Smart Readiness Indicator, Digital Logbooks and renovation passports** Renovation Wave - Development of (open) standards
Social drivers	- New trends in health care (tele-assistance - Customers requesting more plug-&-play solutions, democratisation of smart devices - Buildings becoming active in energy market: occupants require interoperability - Inclusiveness: a building should be as simple as a smart phone
Economic drivers	- Reduced development costs for new services thanks to interoperability
Technical drivers	- Cybersecurity: push to have a more interoperable system providing increased shared resistance to cyberattacks - Enhancement of potential synergies among devices - Crowd-evaluation of protocols

3.5 'Gaps'

Various activities required to overcome the barriers and leverage the drivers related to interoperability were suggested and prioritised by the Task Force members and are presented in Table 3. The priority ones according to the Task Force are indicated in bold.

Tab. 3 – Required R&I activities identified by the Task Force.

Type	Activities
R&I	- **Develop a unified and shared EU ontology & semantics for devices, equipment and assets (e.g. "Dictionary" bringing together all relevant semantics and ontologies, with shared definitions)** - Develop interoperable software tools allowing building operators to select their monitoring/actuation/analysis packages as a "kit of Parts" type approach - Develop Plug and Play hassle-free solutions specifically targeted at existing buildings.
Demo	- Build a marketplace for the manufacturing industry to respond to interoperability-related services - Set up exemplary projects showcasing the added value of interoperable equipment
Regulation & legal framework	- **Set up a central registry to give users a personal unique interface for filling, updating and sharing (give access to) information, in a just and safe way**. - Integrate interoperability into digital logbook / building passport - Develop regulations to demand open standards, create an imperative for strategic data flexibility - Set up minimum levels of interoperability/ smartness of buildings to maintain energy certificates validity - Define open and modular end-to-end interoperability and data management frameworks that enable open standards-based communication along the demand response value chain
Certification & standardisation	- Develop an interoperability label (with cybersecurity certification) at device scale - Standardization of semantic data tags for linked data in buildings - Set up exemplary projects showcasing the added value of smart building certification assessing the level of interoperability (e.g., Ready2Service certification, Smart Score, WiredScore)
Scaling up & industrialisation	- Develop approaches to facilitate the uptake of smart and interoperable solutions: start with the safety/security equipment - Develop data processing agreements with different stakeholders - Implement naming and tagging on devices
Upskilling & awareness raising	- Public acceptance/ awareness of interoperability: better educate or target the right market segment - Upskilling of practitioners in the field to fully take advantage of smart building and smart construction technologies

In next stages of the SmartBuilt4EU project, insights on identified gaps in knowledge, standards, industry uptake, etc. will feed into the development of a proposal for a strategic research and innovation agenda for European Commission services and the wider research and innovation community.

4. Discussion

The work carried out by the Task Force identified important barriers and drivers related to the interoperability of smart building products and services. Interestingly, some of these barriers and drivers can be in conflict. As an example, cybersecurity is definitively identified as an important issue, and like any digital technology, smart building solutions can bring about security risks, e.g. related to system hacking, fraud, data theft, etc. The role of interoperability is however ambiguous. Interoperable systems might be perceived as causing additional risks. Open systems can increase the risk for malfunctioning compared to proprietary systems and protocols and complicate fault diagnosis compared to stand-alone solutions. On the other hand, open protocols can often rely on a much larger user group and much more scrutiny in peer review of potential risks. An active community of multiple private companies, academics or individual software developers who review code and protocols and keep them up to date might result in lower overall risks compared to closed ecosystems.

Many of the other identified barriers and drivers relate to the complexity of interoperability: the large amount of stakeholders with divergent backgrounds, vested interests, competing protocols, etc. result in a highly intricate domain. While many demonstration projects have showcased the potential of fully interoperable solutions, a more seamless integration is needed to enhance a better uptake of such solutions.

One important aspect of interoperability in the building domain is the underlying goal of ensuring the necessary openness to allow the evolution of different representations devices, systems, services, among others. This is highly related with the barriers that have been addressed in several EU initiatives, including EU projects like SmartBuilt4EU, where contributions sought after by several groups of stakeholders are brought into standardization bodies where the discussion on contributions should be made to ensure that independent assessment is carried out, integration is made on existing standard and adoption is guaranteed. Aspects such as openness, modularity, and extensibility in interoperability strategies prevent lock-in strategies or closed innovation ecosystems thus ensuring an evolving and long-term lifecycle of interoperability standards and initiatives.

The use of open protocols may be a good starting point in the ability to provide ground for participatory engagement on creating solutions towards generalized adoption, whilst allows contributions to be made on several levels, the fact remains that currently that is not sufficient. The focus on modular and extensibility of standards supported by appropriate annotation schemes allows the creation of complex representation of graph-based information that intrinsically provide automated ways support knowledge-based information exchange.

Given the importance of interoperability in designing and operating smart buildings, providing trustworthy and up-to-date information on the interoperability of technical building systems could raise awareness and facilitate operational management. At present, assessment and certification programmes however rarely take into account these aspects. Technical interoperability can be already assessed in some certification schemes. The Ready2Service label of Smart Building Alliance in France includes a theme “Equipment and interfaces”, which deals with elements of interoperability such as the presence or absence of documented APIs (application programming interfaces), modalities for data access, etc. SmartScore by WiredScore evaluates some of the wired and wireless infrastructure implemented for building systems, and for example promotes the use of a single platform for analysing building performance data, irrespective of the underlying protocols or technology.

A similar approach is advocated by the Smart Readiness Indicator (SRI) for buildings, a scheme under the framework of the European Energy Performance of Buildings Directive that establish a common EU method for assessing smart buildings [15]. The SRI uses a twofold approach to include aspects of interoperability in the evaluation.

The implicit approach entails that interoperable systems are not explicitly assessed in the SRI method, but still will influence the scoring as some of the higher service levels and related impacts implicitly require interoperability. For example, the SRI score will improve for buildings with provisions to avoid simultaneous heating and cooling. Implicitly, this will require some level of interoperability of these systems (either directly or through other gateways).

Next to the inherent inclusion of some interoperability aspects in the scoring method of the SRI, there are also provisions to enhance the SRI label and supporting documents with additional information provisions, e.g. explicitly referencing the various technical systems and their corresponding protocols. This however is a voluntary add-on, and EU Member States implementing the SRI can further define this approach. There are significant challenges to overcome to make this an actionable feature of the SRI. Information on interoperability is usually not readily available to an assessor such as a certifier issuing Energy Performance Certificates and would require additional investigations. Especially in the case of legacy equipment it might be very hard or even impossible to retrieve sufficiently detailed information. Furthermore, such an assessment would need to be performed for many of the technical building systems present in a building (heating, cooling, lighting, ventilation, BMS…), requiring a large amount of time and effort which would have important repercussions on the cost of an SRI assessment. Furthermore, the SRI would in any case only provide a snapshot of the current status of the interoperability features of the technical building systems. This is a fast-moving field, and many software and hardware solutions emerge which allow interoperability despite using different technologies and protocols. Finally, this approach would require further efforts to generate a broad consensus on standards and protocols that would be included in this assessment. Open standards are not necessarily mutually interoperable. Nevertheless, their openness allows for developing gateways which can indeed facilitate communication between two distinct protocols; a practice which is very common in the current market. From this perspective, the use of open protocols does not guarantee interoperability, but it would indeed create a form of “readiness” to allow interoperability now or in the future.

Finally, a key lesson learned from the work of the Task Force is the importance of interoperability on a larger scale than just interaction within a building. In a context of intermittent renewable energy sources and smart grids, two-way communication between buildings and the grid (or peer-to-peer communication between buildings) becomes essential. Interoperability should not necessarily be attained through standardisation of all systems, components and protocols; rather ontologies and semantic models are proposed as the way forward to practically achieve interoperability in a context where various systems and protocols can still co-exist at the individual building level. Industry, policy actors and academia need to closely collaborate to further develop and implement such common ontologies and semantic models.

5. Conclusion

Interoperability is a key issue for smart building technologies. In an open collaboration process, a task force initiated by the SmartBuilt4EU coordination and support action has revied barriers, drivers and gaps related to interoperability of smart building technologies. Several demonstrations will take place to demonstrate the advantages of an interoperability approach to different technologies and digital platforms ecosystems to foster open and innovative services and solutions. In a next phase, draft for a European strategic research and innovation plan will be developed, highlighting the various actions needed for long-term and continuous support to enhancing interoperable implementations of smart building technologies, and the corresponding expected benefits, e.g. with regard to the active integration of smart buildings in a low carbon energy system.

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7. Data access statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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