Smart Building Conceptualization: A Comparative Analysis of Literature and Standards

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ABSTRACT

Smart building is an emerging concept in the contemporary built environment that aims to leverage new technologies and practices to improve building’s performance. Despite recent efforts to articulate the concept, there is still no commonly accepted definition for the term smart or intelligent building. Also, there are discrepancies in smart buildings’ components and evaluation criteria identified by academic literature and industry publications. This paper analyzes the concept of smart building in order to determine its context and applications. For this purpose, in this paper, we completed a comprehensive literature review of both academic articles and building certification standards to summarize the current interpretations and characteristics of smart buildings. Subsequently, we conducted a comparative ontological analysis on the selected publications and the relevant building certification standards to further identify smart building’s components in comparison with other relevant concepts including sustainable building. The results of this study will benefit future research in smart buildings as well as the development of certification standards for smart buildings’ evaluation.

INTRODUCTION

The market for smart buildings is rapidly evolving mainly because of emerging digital technologies, integrated project delivery approaches, and the data-driven management of the built environment that supports leveraging information through the entire project’s lifecycle. In recent years, academic scholars and industry practitioners have made efforts to provide insights to better understand the concept and develop best practices to achieve more intelligent buildings.

Despite recent progress, there are still gaps in defining the term and concept of *smart building* (De Groote et al. 2017, Kushal 2019) since interpretations of smart or sometimes called *intelligent building* vary from region to region (Wong et al. 2005). Also, key actors (e.g. real estate developers and technology vendors) in the building industry point out different characteristics and components for smart buildings based on their context-specific perceptions and priorities (De Groote et al. 2017). Ambiguity in knowing what makes a building smart and how to unpack the complex concept of building intelligence limits building stakeholders’ abilities to decide what technologies to implement in their buildings, prove its capabilities and advantages, and improve its performance. This echoes and extends from the problem the industry faced in articulating and measuring sustainable buildings as the concept was evolving during the past decades. Sustainability certificate systems (such as LEED, BREAM, and Green Globe) have addressed the issue by determining sustainability criteria and providing a standard method for sustainable buildings' evaluation and certification. However, only a few evaluation systems have been developed for smart buildings due to the lack of clarity and consistency on identifying smart buildings' components. This study contributes to the body of knowledge by identifying and categorizing components of smart buildings which is a prerequisite for smart buildings' evaluation. It also makes a distinction between the concepts of smart building and sustainable building in order to determine their applicability and examine the possibility of using the well-established sustainable building's criteria, processes and best practices for developing the domain of smart buildings.

BACKGROUND

The concept of smart building has emerged in the building industry since the 1980s.' The term "smart building" has been interchangeably used with other existing terms including smart building and integrated building (Kroner 1997) and has contently overlapped with the terms sustainable building and green building. Although there is no standard and commonly accepted definition for this terminology, it generally refers to the core capability of providing information to a building's owner and manager about its intelligence in terms of the building's physical assets, its systems' performance, and its spaces' conditions in order to facilitate a more informed decision-making during design and construction phases and a more efficient facility management during the operation phase.

The literature review indicated specific trends in defining the constantly evolving concept of smart building over time:

- Technology-based definitions: consider smart/intelligent building as one that leverages new (digital) technologies. The building intelligence is defined based on the functionalities of technological artifacts implemented in the building and specifically the use of data for better decision making.
- Performance-based definitions: articulate smart/intelligent building in relation with specific aspect(s) of building performance. Like "business intelligence", the building intelligence is defined in accordance with benefits of a high-performance building (compared to a conventional building) for its stakeholders (owner, facility manager, occupants, etc.).
- System-based definitions: identify smart/intelligent building by characteristics of its physical and digital systems. The building intelligence is defined as an integrated system or system of systems (SoS) that manages the building's technical systems and services.

The performance-based definitions and characterizations of smart building indicates a considerable resemblance with the sustainable building which is a well-established and long investigated term. The concept of sustainable/green building emerged as a response to the need of contextualizing "sustainable development" in the building industry by defining a building project that makes a balance between the priorities of economic prosperity, environmental quality, and social equity (Pitts et al. 2008). However, comparing the markets of smart building and sustainable building reveals tangible differences in the two concepts' interpretations, their best practices, and the involved key players. Overall, the current ambiguity in using smart/intelligent building concept (in relation to other existing terminologies) as well as the lack of a consistent approach towards smart building definition emphasize the need for a systematic approach to develop a standard taxonomy of smart building's components.

METHODOLOGY

The research team developed a three-steps process (as shown in figure 1) for this research. First, a comprehensive literature review was conducted to gain an understanding of existing smart/sustainable building's definitions. Subsequently, Actor-Network Theory (ANT) was used to create a framework for building intelligence by identifying relevant topics and their relationships. Finally, a comparative ontological analysis was performed 1. to develop a single taxonomy of components for each smart building and sustainable building concepts, 2. to make comparison between the developed taxonomies to find similarities and differences, and 3. to build a theory for building intelligence conceptualization in terms of its content, context, and application.

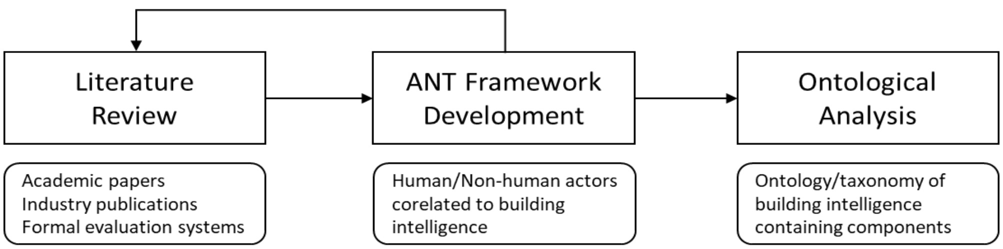

Figure 1. An overview of the research process.

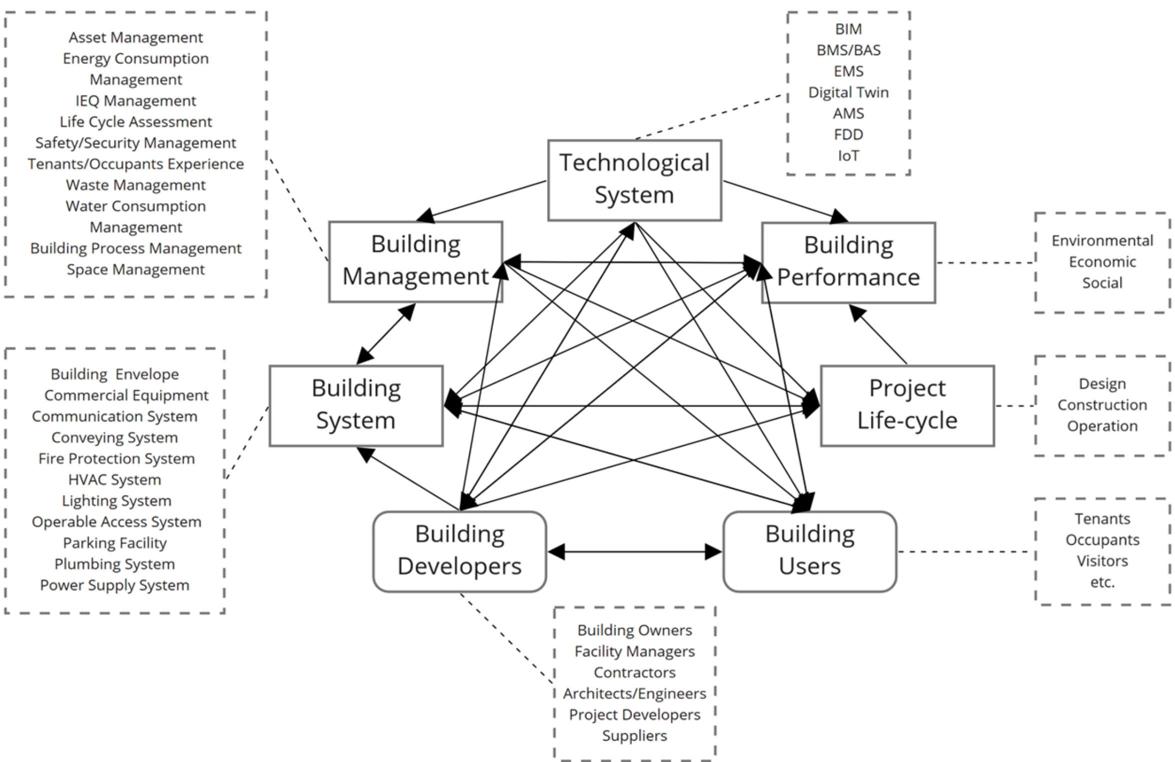

Figure 2. Schematic visualization of ANT for developing building intelligence framework.

For literature review, the research team analyzed 58 publications (containing academic papers and industry technical reports and best practices), and 29 formal smart/sustainable building evaluation systems. For sustainable building, the research team mainly analyzed formal evaluation systems to create a unified taxonomy. The selected evaluation systems for in-depth analysis include LEED, LBC, DGNB, BREAM, EDGE, and WELL to cover various approaches and evaluation criteria. For smart building, the research team focused on academic/industry literature (37 papers were used to extract smart building's components) along with the following three more formal evaluation systems: Intelligent Building Index (IBI) provided by the Asian Institute of Intelligent Buildings, Building Intelligence Quotient (BiQ) created by the Continental Automated Buildings Association (Katz et al. 2009), and the Smart Readiness Indicator (SRI) project supervised by the European Commission services (Verbeke et al. 2020).

In this research, actor-network theory (as shown in figure 2) was used for a preliminary conceptualization of building intelligence. This theory was selected since it considers both human and non-human actors (ideas, artifacts, know-how, etc.) and their relationships to holistically investigate a phenomenon (Latour 2005).

ANALYSIS: COMPONENTS OF BUILDING INTELLIGENCE

The main objective of this research was creating a building intelligence taxonomy that articulates key components of smart building. As the result of the analysis, the research team identified 87 components and categorized them into 18 clusters, which are defined in this section.

Safety, Security, and Reliability: this cluster highlights the need for a safety and security plan for the whole project lifecycle containing a workflow for risk identification and mitigation. Structural reliability is another aspect of the building intelligence focusing on earthquake and critical building structure monitoring through regular survey or automated systems. Also, control and monitoring of building's safety and security is a part of this component that includes utilizing a central safety/security management system for disaster response, airborne contamination detection, emergency voice communication, fire detection and protection, and alarming system (Kushal 2019).

Intelligent Design: refers to the building's responsiveness to technological and sociocultural changes as well as architectural and ecological considerations (Himanen 2003). Design for flexibility and long-term adaptability based on demands of building's occupants as well as a life-cycle approach to address owners' objectives for design intent (from constructability to operability) are among the specified requirements. In addition, this has an overlap with the concept of sustainability as it contains passive design and use of smart materials as indicators of building intelligence.

Economic Management: addresses economic repercussions in projects by adopting life cycle cost analysis (LCCA) approach. The cost/benefit analysis includes both initial cost with added marginal cost associated with smart building initiatives and best practices, and operation and maintenance cost with consideration of smart building initiatives' cost effectiveness and strategies for long-term cost savings (Ghaffarianhoseini et al. 2016). The second aspect of economic management is related to economic performance of a building that is mainly determined based on the elements of affordability for prospective building tenants and marketability for project developers to secure return on investment.

Occupants Experience/Management: promotes enhanced occupants experience in buildings through adopting an end-user need orientation. This includes building systems and architectural design, occupants' education programs, and managerial strategies that lead to better occupants' physical and mental comfort, health and wellbeing, productivity, and work satisfaction. Moreover, a part of occupants' demands management is improving building services and amenities such as building's web-based internal portal and in-building user interface devices to provide occupants with effective controllability and interactivity.

Environmental and Resource Protection: specifies deployment of new technologies, operation, maintenance and repair (OM&R) planning, and knowledge-based systems that result in reduction of the building's environmental impacts (e.g. greenhouse gas emissions) and conservation of natural resources. Also, this cluster concentrates on using innovative solutions for building's waste management including utilizing a waste management plan for efficient construction waste disposal during the construction phase and installing advanced refuse handling equipment in building for tenants' waste management and recycling during the occupancy phase.

Water Efficiency/Management: refers to monitoring and control of water consumption to improve water efficiency, leveraging intelligent systems for managing water supply based on various demands (potable water, water reuse for irrigation, etc.), and the building's hydraulic/drainage systems' technical specifications required for achieving the building's water efficiency goals (Chow et al. 2005).

Operation and Maintenance (O&M): highlights the importance of life-cycle asset management planning that contains establishing performance requirements, conducting commissioning, measurement, and verification for the facility's current condition analysis, and developing a proactive performance-based approach for facility management (Kushal 2019). Additionally, the component emphasizes the role of intelligent monitoring-based systems with analytics capabilities for enhancing O&M effectiveness.

Technology Deployment: articulates building's emerging digital technologies (e.g. IoT, digital twin, and robotics) and the relationship between the high-tech incorporation and building intelligence. There are multiple use cases for these technologies such as implementing IoT sensors and devices for real-time energy and water metering, occupancy detection, and building's system monitoring and condition assessment. In addition, technology deployment applies to use of artificial intelligence (AI) and machine learning (ML) for data analytics and pattern detection which is proven to be beneficial for building stakeholders. For example, it helps facility managers to understand their building's actual performance, predicts occupants' demands more accurately, and makes more informed decisions about the building O&M.

Building Systems and Equipment: identifies technical specifications for high-performance and intelligent building systems, devices, and commercial equipment. In this context, "high-performance" is determined in terms of utilities' cost effectiveness, while "intelligent" depends on interoperability, and integration with building management systems. The frequently discussed building systems include bathroom/kitchen fixtures (energy- and water-efficient appliances), building envelope (dynamic and interactive façade system), electrical system, lighting system (intelligent and controllable fixtures), conveying system (energy efficient and programmable elevators, escalators, and lifts).

HVAC System: provides specifications for high-performance and intelligent HVAC systems. It also emphasizes constant system monitoring and optimization based on the actual building usage and occupants' behaviors. Even though this cluster is similar to the previous one, it is presented as a separate component because of substantial amount of detailed discussions in the smart building standards and industry best practices (e.g. Froufe et al. 2020) about required HVAC system's features and configurations for flexible and efficient heating, cooling, and ventilation.

Parking and Transportation: associates building intelligence with a project's location similar to sustainable building evaluation systems, (e.g. Chow et al. 2005), namely ease of parking and accessibility to public transportation. However, the ontological analysis indicated two elements for this component. First, smart parking which is defined as a parking facility that provides users with sufficient information sharing, finding/booking parking spots conveniently, and planning commutes remotely. Second, availability of electric vehicle (EV) charging stations that promote environmental friendliness by reducing fossil fuels consumption.

Space Management: requires creating a building's interior layout system that allows for flexibility and adaptability based on changing space occupancy/functionality and space utilization's conditions. Another aspect of this component is intelligent space monitoring and optimization using performance analysis and post-occupancy evaluation (POE).

Power supply and Management: generally describes smart practices for acquisition, distribution, and stabilization of power as well as management and optimization of the power supply system in a building. Key elements of this component include leveraging distributed energy resources (DER), using uninterrupted power supply (UPS), and integrating to smart grid.

Access Control: promotes using a unified control system for safe and secure access to buildings. Examples of required functions are monitoring and managing rooms' signage and directory information, building's visitors, and access to restricted areas. Such a system consisted of technologies for identity check combined with a data analytics layer. So ideally, a cyber-physical system is used for automated access control and management. Additionally, the concept of access control applies to an organization's data protection and data environment's accessibility control, which is closely related to the concept of cybersecurity. In this case, the unified system is used to manage authentication and authorization of users (e.g. occupants and visitors who connect to the building's internet/intranet networks).

IT and Telecommunication: provides the specifications and best practices for an information technology (IT) infrastructure that is required for adoption and implementation of smart building's technologies and systems. The main elements include wired and wireless information networks (broadband internet, fiber-optic network, etc.), data governance system, and network coverage stabilization. Also, it identifies the requirements for an effective telecommunication system in buildings such as video-conferencing equipment and integrated audio/visual system.

Energy Efficiency/Management: refers to monitoring and control of energy consumption to achieve energy efficiency, using renewable energy sources (solar panels, geothermal, etc.) and limiting building's dependency on fossil fuels, and leveraging intelligent management systems for energy demand predictions and energy efficiency optimization.

Building Automation and Management: explains technical features and functions of building management systems (BMS) and building automation systems (BAS). The primary functions of these systems include controlling and management of building's physical systems and zones, system integration and interoperability (for interaction with the building systems), automated monitoring of building performance/condition, faults detection and diagnostics, and utility management (King et al. 2017).

Indoor Environmental Quality (IEQ): determines IEQ requirements in a building to ensure occupants' thermal, acoustic, and visual comfort. It also requires zone-based IEQ monitoring and control and making balance between natural and artificial/mechanical indoor air supply, lighting, and ventilation.

DISCUSSION AND CONCLUSION

The comparative ontological analysis confirms the overall conclusions of the literature review about the substantial overlap between the smart and sustainable building's components the specific areas of similarity and difference are now clearly identified. Also, this analysis indicated that several mutual components are different regarding content and evaluation metrics. According to the analysis, energy/water efficiency, indoor environmental quality, and occupants (health and wellbeing) are the clusters with higher similarities. On the other hand, topics like IT infrastructure and building automation/management systems are mostly addressed by smart building components while physical infrastructure and materials are mostly discussed as sustainable building components. These findings are visualized in figure 3.

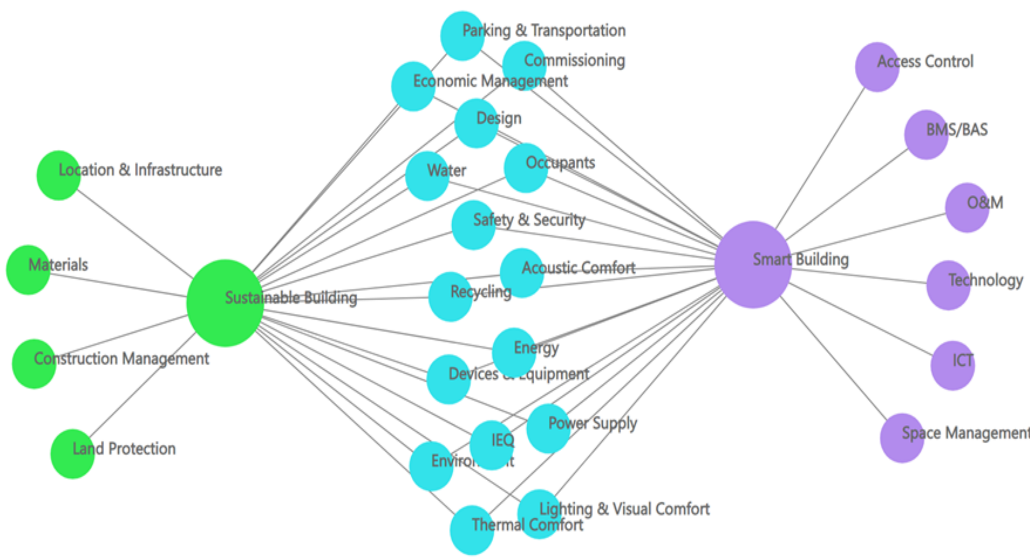

Figure 3. An overall comparative analysis of smart/sustainable building's components.

In addition, two themes are notable in the smart building's specific components that help to make a clearer distinction between the concepts of smart and sustainable buildings. First, emerging technologies and how they are implemented in smart buildings. Second, the use of data analytics during the entire project lifecycle for more effective monitoring, control, management, and decision making.

The ontological analysis revealed a contextual difference in the ways that components are defined in different articles or rating systems. While one type of components describes "outcomes", another type describes "actions" required for producing such outcomes. For example, one component may address the topic of thermal comfort as an indicator of building intelligence by defining a required level of comfort, while the other component determines the technical specification of the HVAC system that leads to that level of thermal comfort. Currently, most of smart/sustainable building literature include both types of components without distinguishing between them. This finding can serve as a basis for building intelligence conceptualization as going forward, we can distinguish between these types of component definitions and organize the components into categories by understanding both the outcomes and actions of these components.

To further develop this idea, it is important to understand how building intelligence is contently and structurally different from building sustainability. Theoretically, the concept of sustainability comprised of environment/ecology, society/culture, and economy/business pillars according to the triple bottom line methodology. In comparison, building intelligence can be conceptualized based on the process, product, people methodology. In this regard, the element of people refers to a building's occupants and their behaviors' effects on the building's performance; process is defined as overall design and construction process and procedures as well as organizational settings for facility and asset management; and finally, the element of product consists of building's physical and digital systems and adopted technological solutions (cf. ALwaer et al. 2010). Therefore, it is concluded that building sustainability specifies elements of building's economic, environmental, and social performance based on stakeholders' desired objectives and benchmarks set by the industry, while building intelligence focuses on articulating people, processes, and products in a building, their dynamic relationships, and their impacts on the building's performance.

This research aimed to explore smart building's definitions and create a taxonomy for its components in order to provide a basis for evaluating smart buildings' capabilities. For this purpose, a comparative ontological analysis was conducted to articulate building intelligence, its components, as compared with existing building sustainability rating systems. As the next steps, more research is required to validate the smart building's developed taxonomy and to further investigate the applications of building intelligence concept in different contexts including implementing smart building technologies and developing smart buildings' holistic and quantitative evaluation systems.

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