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RESEARCH ARTICLE

A conceptual use-cases mapping framework for IoT-based smart building management

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Abstract

Smart buildings aim to enhance user satisfaction and optimize operations through efficient facility management, employing IoT technology as a key enabler. IoT relies on sensors to collect building data, process information, and trigger actions via actuators. Despite the proliferation of IoT devices, there's a notable absence of a comprehensive framework for smart building management (SBM) in existing literature. While previous SBM frameworks focused on software, network, or data collection aspects, none address the classification of use cases for IoT devices, which form the backbone of these frameworks. The absence of a framework leads to a lack of standardized descriptions and contextual awareness of use cases, hindering research on SBM and its goal of maximizing beneficial outputs. This study addresses this gap by introducing a multi-dimensional conceptual framework for mapping potential IoT device use cases within the context of academic buildings. The proposed framework consists of four dimensions: (1) IoT device name and categorization, (2) building components, (3) building smartness dimensions, and (4) smart building management objectives. The study provides a detailed visual and textual representation of the framework, which is validated through four use cases, demonstrating its promising applicability in SBM. Initial observations from the framework implementation indicate its effectiveness in mapping existing sensors and identifying new potential use-cases and providing a tool for understanding and advancing the integration of IoT devices in smart buildings. This framework has the potential to serve as a communication tool for fostering collaboration among different research institutes and universities, contributing to the development of strategic SBM research programs.

1. Introduction

Smart buildings are those buildings characterized by their use of integrated systems of the Internet of Things (IoT), where IoT technology is "an ecosystem that contains smart objects equipped with devices (e.g., sensors and actuators), networking and processing technologies integrating and working together to provide an environment in

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which smart services are taken to the end-users" [1]. Given that many people in developed countries may spend 80-90% of their lives inside buildings, research is needed that focuses on "smart" (i.e., technological, adaptable, and automated) solutions to ensure user comfort and quality of life in these buildings [2].

IoT technology uses connected networks of sensors to acquire data in digital format, distil information and decisions, and automate actions via actuators. Accordingly, Smart Building Management (SBM) is defined as the utilization of various modern technologies and systems to achieve optimized building operations and costs while considering the user needs and sustainability aspects [3]. By extension, SBM can leverage the IoT as data collection platforms as well as to make automated decisions based on the data it collects. In the context of SBM objectives, these systems should improve the users' quality of life (safety, security, health, comfort, and satisfaction) without compromising the buildings operations, services, energy consumption, and maintenance cost from an environmental point of view [4]. For instance, one could minimize the energy use and operation cost while maximizing users' comfort and their productivity through the automation of building temperatures control on a room-to-room bases based on the occupants, activity levels, and hours. Such an optimization could be programed based on automatic processing of the data collected from various IoT sensors.

The challenge is that the proliferation of connected technologies can lead to situations of "solutions looking for a problem", where the capabilities of the technology are well understood, but it may not be clear how the capabilities can be leveraged to solve real world problems. There are two typical approaches to doing this: "use cases", which outlines an application of a technology to a specific scenario; and "frameworks", which can be used to help structure how new "use cases" could be developed. Hanes et al. [5], for example, focused on IoT use cases within domains such as manufacturing oil and gas, transportation, utilities, smart cities, and public safety without mapping them in frameworks. There are also use case taxonomies that are focused specific domains such as health [6], security and privacy [7, 8, 9], and sensor measurement [10]. The lack standardized descriptions of use cases and the context awareness of the uses of IoT devices was noted by Uviase and Kotonya [11] as one of the critical challenges in the research context of IoT architectural and integration frameworks design. Researchers offered many ways to perceive, integrate, and use the data collected by IoT devices, however, they did not address the need for a comprehensive mapping framework for IoT use cases that considers multiple dimensions in the context of SBM. These dimensions can include smartness drivers, building systems, and management objectives. For smart building research, the lack of such a use-cases mapping framework will limit the extent that IoT devices can be incorporated into SBM systems, by extension, limiting any benefits that would accrue from such incorporation. Up to the authors' knowledge, there does not appear to be any framework that specifically addresses the IoT-based use cases classification/mapping in the domain of smart buildings, yet such a framework could help organize research efforts and develop relevant use cases. One reason for this literature gap could be attributed to the lack of standardized descriptions of IoT use cases in that domain.

The overarching goal of this paper is to develop a multi-dimensional classification framework of IoT devices that maps the IoT sensors and their possible use-cases along with the targeted dimensions of building smartness and management objectives. In relation to this goal, the corresponding objectives are: (1) to identify, breakdown, and analyze the SBM keywords in this study, (2) to identify the key mapping dimensions of the IoT-based use cases framework, and (3) to assemble the identified dimensions in a solid mapping framework for IoT-based use-cases classification in the context of SBM. Due to the limitation in time and funding, the scope of the current study is limited to academic buildings within a university setting.

The contribution of this study includes a new understanding and perception of the SBM key dimensions that are integrated in a novel conceptual framework for mapping the potential use cases of IoT devices. This framework is intended to be straightforward in mapping and documenting existing IoT-based use cases after setting a scope by identifying the target smartness dimension and the management objectives in the context of SBM. Additionally, the framework is intended to aid in identifying potential and new use cases for IoT sensors as well as account for future additions of new IoT sensors or actuators. Theoretically, such a framework has the potential to provide additional functions including: (1) helps in identifying the needs for additional devices (sensors and actuators) for smarter building management, (2) serves as a communication tool for collaborations on IoT-related projects with different parties, and (3) supports setting strategic visions in SBM research programs.

The organization of the remainder of this paper is distributed over four sections. Section 2 presents a literature review to demonstrate the previous work done in the classification of IoT sensors, the smart building systems, and the smartness dimensions of the buildings and their relation to building management. Section 3 will go through the development of the proposed conceptual framework. Section 4 will cover the applicability of the framework developed, the approach of implementation, along with four case studies to verify and demonstrate the use of the framework followed with some discussions. Finally, Section 5, will end the paper with a set of conclusions and recommendations drawn based on the research outcome.

2. Previous Work

SBM aims at improving the smartness aspects (S) of the building systems (B) via the use of modern technologies (e.g., IoT devices) to achieve efficiently the management objectives (M). The identified key words in this domain are Smartness, S; Building systems, B; and Management, M which represent the key dimensions of SBM. Therefore, the literature reviewed in this section is organized in three subsections. First, the classification systems of the IoT devices are reviewed, then, the common and smart building systems. The last section covers the drivers of building smartness and the objectives of building management.

2.1. Classification systems of IoT sensors

A sensor is a device that generates an electronic signal from a physical condition or event while an actuator converts digital electronic signals from the information networks into operations [12]. In terms of classifying IoT devices, there does not appear to be a common categorization system. Armando et al. [13], introduced a taxonomy for sensors and actuators that is based on their built-in nature. They classified sensors accordingly into three classes: electronic-based, software-based, or human-based sensors. In contrast, Dorsemaine et al. [14] proposed a classification system that is focused on the connected objects. They identified five categories as: energy, communication, functional attributes, local user interface, hardware resources and software resources. In terms of IoT components, Gubbi et al. [15] suggested three categories: hardware (sensors, actuators, and embedded communications), middleware (on demand storage and computing tools for data analytics), and presentation (virtualization and interpretation tools). Sinche et al. [16] surveyed the frameworks of IoT devices and their classification from the perspective of their taxonomy and management. They were able to summarize the classification aspects of IoT devices into seven aspects: functionality, sensor type, criticality, resource constraint, communication nature, mobility, and heterogeneity. This multi classification system did not consider the uses/application dimension of these devices.

In contrast to these taxonomies, Rozsa et al. [17] introduced a practical system that is more oriented to the application domains of the IoT sensors. Based on the detected/measured signals from the physical conditions, they suggested five categories of IoT sensors which are motion, position, environment, mass measurement (i.e., related to a body or a physical interaction force with a body; (in)animate solid, liquid, or gaseous mass), and biosensors (related to organisms). This taxonomy is likely more relevant to the use cases for IoT sensors; however, the taxonomy does not cover building assets, occupants, and their behaviors. It appears that most of the classification attempts in the literature are based on either a single classification dimension system or a single use case. Therefore, they mostly miss the connection between the IoT devices' classifications and their corresponding possible use cases in a specific context. This connection is of high importance for both the IoT sensors' implementations and their research guidance in specific contexts.

2.2. Smart building systems

Buildings can be grouped in eight types, as reported by Joustra and Yeh [18], into residential, commercial, education, healthcare, hospitality, recreational, government, industrial, and utility buildings (e.g., treatment plants). However, the term "common buildings" refers to those which have the primary systems that make together a functional building. These systems fall under the categories of structural, architectural, electrical, and mechanical systems. Joustra and Yeh [18] expanded this list into seven systems as structural, heating, ventilation, and air conditioning (HVAC), lighting, electrical, water, sewage, security, and fire suppression.

Smart buildings, on the other hand, have evolved based on the integration of new technologies to achieve expanded building capacity and efficient operation and have additional systems, on top of the primary ones. Wong et al. [19] referred to these additional systems as "control systems". They proposed eight control systems including HVAC, telecom, security, smart/energy lift system, lighting, computerized maintenance management control systems, and integrated building management system. Sinopoli [3] described ten control systems, instead, as HVAC, lighting, audio/visual, video distribution, access control, data network, voice network, power management, video surveillance, and fire alarm control systems. These differing systems are in place to control and accomplish the occupants needs in smart buildings [2]. For example, user comfort is achieved by an HVAC control system, security needs are met through both video surveillance and fire alarm systems, and so on. In contrast to this categorization, Froufe et al. [20] suggested a more practical and comprehensive categorization of eight control systems. They grouped the smart systems as (1) HVAC for managing the air characteristics in enclosed environments, (2) light for managing artificial light, (3) energy for managing consumption, demand and quality of energy, (4) security for managing surveillance and access of building occupants and assets, (5) telecommunication for managing telephony, data, and image services, (6) fire fighting for managing detection, alarm, and fire extinction services, (7) vertical transportation for optimizing the occupants well-being without harming the environment, and (8) hydraulic systems for managing services of personal hygiene, water and gas supply, and rainwater and sewage collection.

In general, smart buildings have many interconnected technology systems that integrate, cooperate, and adjust to the needs and deliver advantages to the occupants, the owner, and the environment. Despite the wide similarity on the different grouping viewpoints of the smart building systems, there is not full agreement on the groupings in the literature. This is mainly due to the continues evolution of the new technologies (IoT, artificial intelligence, etc.), new management objectives or restrictions (e.g., sustainability, resiliency, etc.), and consequently the concept of smart buildings.

2.3. Aspects of building smartness

Buildings are expected to operate at more sophisticated levels because building owners' and occupants' expectations are evolving. While the owners require the building to operate well in terms of cost, the occupants require more life quality [21]. Smart buildings are intended to address efficiency issues, while enhancing the quality of life [22] making the objectives of smart buildings consistent with typical facility management objectives. Smart buildings are expected to consider users' needs (comfort, mobility, security, satisfaction), the system's needs (maintenance, operations stability, energy consumption) while also looking to future needs [2]. Building management aims are basically minimizing operation and maintenance cost, and energy consumption, while maximizing the positive impact on the occupants' comfort, security, and satisfaction.

In alignment with SBM, smart buildings have different smartness aspects/dimensions that represent directions or drivers for the buildings to be smarter. For instance, Cole and Brown [23] suggested smart buildings aspects such as automation, digital information and communication, and intelligent organization and space management. From a different perspective, Froufe et al. [20] conducted a comprehensive and interpretative literature search on the drivers that make buildings' smarter with their relation to the main beneficiaries. They identified eleven drivers distributed over three groups: users, owners, and the environment. Owners' related drivers are those aiming at maximizing the operation performance/automation, flexibility, and the longevity of the building systems. In contrast, environment drivers aim at minimizing the buildings' impact on nature and the consumption of the energy and resources. Users' drivers are those aiming at improving the user's health, security, satisfaction, and comfort.

In summary, building smartness is an evolving concept and can be viewed from different perspectives, however, the smartness directions/aspects all converge to the objectives of building management. Both the smartness directions and management objectives aim at enhancing the systems' performance and occupants' satisfaction. While the smartness aspects represent the drivers/directions of the building advancements, building management objectives represent the control directions or purposes of these advancements towards addressing sustainability considerations.

In relation to this study research, few conclusions have been drawn based on the reviewed literature. Firstly, the concept of smart buildings is still evolving, and the operation of their various systems should be controlled by management objectives to ensure holistic optimization of their performance and maximization of the users' satisfaction. Secondly, a universally accepted categorization or classification system for IoT devices has not arrived yet. Additionally, in the context of SBM, there is a lack of standardized descriptions of IoT use cases. These limitations explain the absence of a classification/mapping framework of the IoT-based use cases in the domain of SBM, despite its urgent need.

3. Conceptual Framework Development

In reference to the identified objectives in this study, the framework development includes identifying the key mapping dimensions of SBM and IoT sensors to be all integrated in a solid mapping framework of IoT-based use cases in the context of SBM. The first part of this section describes the relevant concepts and mapping dimensions, while the second part describes the integration of these dimensions in one conceptual framework. The development presents a multi-dimensional framework, that includes the dimensions of building components, building smartness directions, management objectives, and classification for the IoT sensors. In the following subsections these dimensions are further described.

3.1. SBM concepts breakdown

The structured breakdown for the term is based on the key words: Smart, S; Building, B; Management, M. Therefore, the concept breakdown starts by (1) analyzing the building components (systems and occupants), (2) identifying the building smartness drivers or dimesions, and (3) identifying the relevant management objectives. The following subsections provide more explanations.

3.1.1. Building components

Buildings are sets of integrated systems that provide services to the building occupants. Accordingly, buildings can be broken down in general into systems and occupants. While building systems include primary and control/technology systems, building occupants include the enclosed human users and assets/objects. This breakdown is illustrated visually in Fig. 1.

The literature broadly categorizes building systems into primary systems and control/technology systems. There is generally consensus on the breakdown of the primary systems and on the categorization of the control/technology building systems, though in some cases not all possible systems are represented. Most notable is that there is not an existing framework that unites and relates the systems and smart building control systems. Based on the literature review, this study proposes using the building primary systems as defined by Joustra and Yeh [18], and the control/technology building systems as defined by Froufe et al. [20], with some minor adaptations.

The building primary systems listed by Joustra and Yeh [18] includes Structural, HVAC, Lighting, Electrical, Water, Sewage, Security, and Fire Suppression. However, it was noticed that this list misses some typical systems that are present in definition by other studies such as Sinopoli [3] such as the telecom system. Furthermore, the architectural system, such as roofing and sidings, was not included. Hence, to be comprehensive, the adopted list in our study is as follows: (1) architectural systems, (2) structural systems, (3) electrical systems, (4) lighting systems, (5) HVAC systems, (6) water systems, (7) Plumbing/sewage systems, and (8) Telecom systems, (9) security systems, and (10) fire suppression systems. This list covers all primary systems defined in the reviewed literature.

Regarding the control/technology building systems, the breakdown introduced by Froufe et al. [20] is adopted because it appears to be a straightforward, practical, and comprehensive categorization as concluded from the surveyed literature. This classification includes eight systems which are (1) HVAC control, (2) light, (3) energy, (4) telecom, (5) security, (6) fire control, (7) vertical transportation, and (8) hydraulic and garbage collection systems.

The reviewed literature on building management did not consider the outdoor environments. There is value in considering certain aspects of outdoor environments that immediately surround the building given that these environments may be supported by internal building systems (e.g., winter maintenance of paths dispatched from the building). There may be a strong connection between internal and external building systems that could be facilitated through IoT technology. If we consider the buildings surroundings in this classification, an expansion should be made to include outdoor environment and systems, that belong to the building, such as (1) roads/paths, (2) sidewalk and bike racks, (3) landscape, (4) weather, and (5) outdoor garbage. Table 1 lists both building primary and control/technology systems proposed in this study.

Both groups of the systems (primary and control) are physical components that provide services and functions. In terms of characteristics, these two system types could be viewed from two perspectives: physical characteristics and functional/service characteristics.

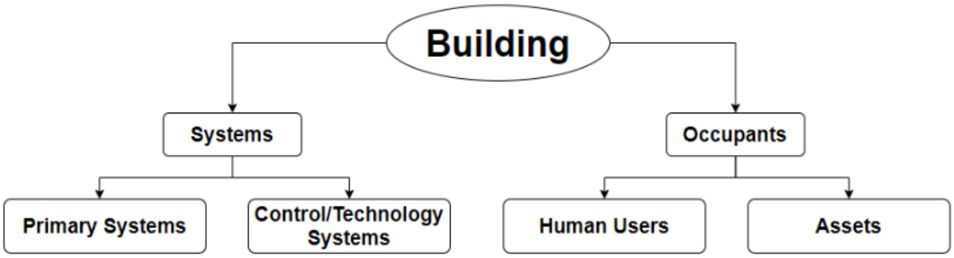


Fig. 1. Building breakdown into systems and occupants

Table 1. The building primary and control/technology systems proposed in this study

Primary building systems	*Architectural Systems, Structural systems,* *Electrical systems, Lighting systems,* *Mechanical: HVAC systems, Water systems, Plumbing/Sewage systems,* *Telecom systems, Security systems, Fire suppression systems*
Control/technology building systems [18]	*HVAC control system*: Equipment, and systems for managing temperature, humidity, flow, and quality of air in closed environments. *Energy control system*: Equipment, and systems regarding energy transmission, and management of the consumption of all systems, of the demand, and the energy quality. *Light control system*: Equipment, and systems for managing sources of artificial light, mainly through the presence of sensors and dimming, according to the incidence of natural light. *Vertical transportation control system*: Equipment, and systems for managing services related to enhancing the well-being of users, without harming the environment. *Telecom control system*: Equipment, and systems for managing telecom services, mainly those related to telephony, data, and image. *Hydraulic control system*: Equipment, and systems for managing services related to personal hygiene, water and gas supply, and rainwater and sewage and garbage collection. *Security control system*: Equipment, and systems for managing services related to personal and asset security, mainly through mechanisms of surveillance and control of access. *Fire prevention/fighting control system*: Equipment, and systems for managing mechanisms of detection, alarm, and fire extinction.

For instance, plumbing systems consist of pipes and connections that have physical characteristics such as materials and geometries. Leakage detection sensors are considered physical characteristics monitoring devices. In contrast, clog detection sensors are viewed as monitoring devices for the functional/service characteristics of the plumbing systems. Fig. 2 illustrates the systems breakdown described.

Building occupants are the second breakdown component of the buildings in this study as shown in Fig. 1. This component includes mainly the human users of the building systems. Building occupants can also include the objects or assets that are enclosed by the building environment. Any further breakdown is relevant to the building type. As indicated in the first section, the scope of the framework development in this study is limited to the education/academic buildings in the university settings. In an academic building, the users could be classified into students, faculty members, staff, technicians, visitors, and researchers. However, the privacy of these subclasses could be an issue so we must look at an aggregated level. Hence, in this research, it is suggested to classify the human users into public spaces users and research volunteers. In other words, the first subclass is (1) Aggregate measures from observations in public spaces and the second is (2) Volunteers in a research environment. Their activities and behaviors include occupying, accessing, teaching, learning, researching, services, and others (e.g., eating). Building assets, in this study, are categorized into space/room-related assets and system-related assets. While space/room-related assets are such as equipment (needs power) and furniture (do not need power), system related assets such as air conditioning (A/C) units and water pumps that are easily replaceable for a system. As indicated before, both human users and building assets could be viewed from two perspectives: physical characteristics and activity/behavioral characteristics. This description is visualized in Fig. 3 that shows the breakdown of the building occupants adopted for the framework with some examples.

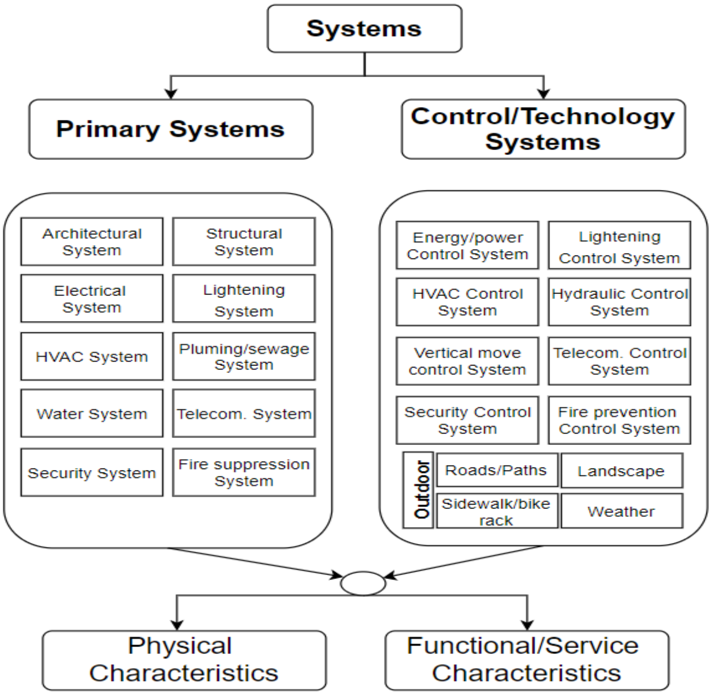


Fig. 2. The detailed breakdown of building systems

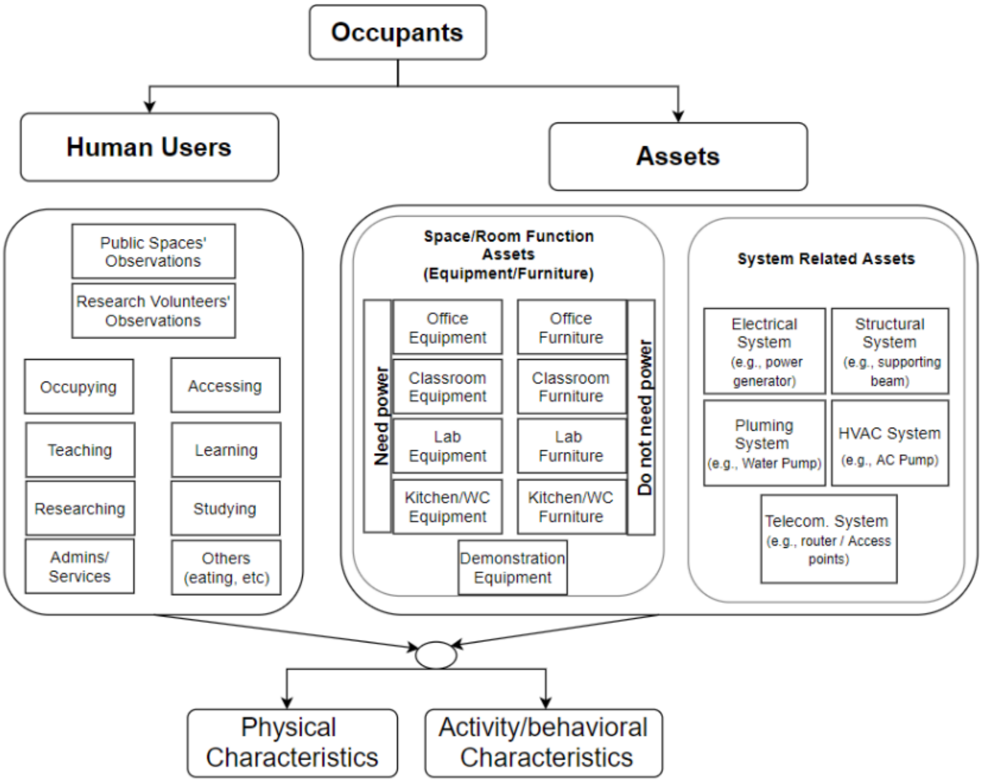


Fig. 3. A detailed breakdown of the described building occupants

To make the breakdown more comprehensive and to add more flexibility to it, the physical location of the IoT devices needs to be included in the breakdown. This location is classified in relation to the building itself, into building indoor and building outdoor. For example, an asset related to the electrical system, such as a power generator, could be located outside the building and still considered as an asset under the building occupants' category. Fig. 4 illustrates the building breakdown described earlier.

3.1.2. Building smartness model

The concept of smartness is always associated in the literature with the utilization and exploitation of the information and communication technologies (ICT) to achieve better systems' performance. In the context of SBM, the smartness aspects are expanded to cover both building systems and building occupants.

Based on a recent comprehensive literature search, by Froufe et al [20], 11 drivers have been identified for smart buildings. These drivers are distributed over three beneficiary groups: users, owners, and the environment. In our study, we have broken down the building concept into two components: systems and occupants. In order to identify and develop the smartness model of buildings based on these smartness drivers, we need to aggregate these drivers according to these two viewpoints of buildings in our study: systems and occupants.

For building systems, Latifah et al [20] summarized their needs under three categories: operations stability, maintenance, energy consumption. In relation to the building smartness drivers, Froufe et al [20] identified set of drivers that fall under owners' and environment related drivers. While owners' drivers aim at maximizing the operation performance/automation, flexibility, and the longevity of the building systems, environment drivers aim at minimizing the buildings' impact on the nature and the consumption of the energy and resources. Hence, from the perspective of building systems, these two groups can be combined under the smartness aspects of the systems and aggregated under the identified three needs of the building systems. Hence, from the perspective of building systems, these drivers can be distributed over three smartness' aspects of building systems: smart operation, smart maintenance, and smart energy based on this perspective, the identified drivers are aggregated judgmentally according to their definitions in Table 2.

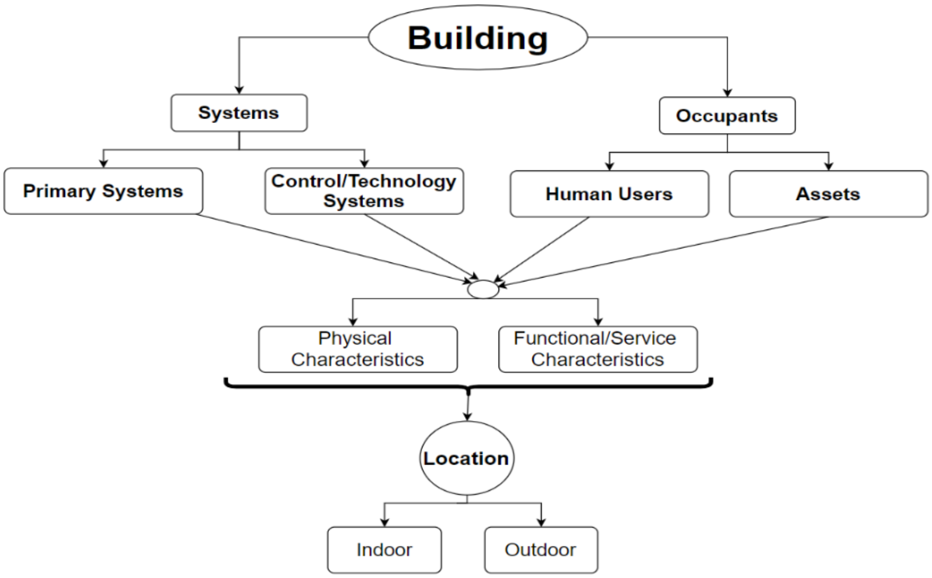


Fig. 4. The breakdown of the building elements; systems and occupants

Table 2. The aggregation and identification of the building smartness aspects

The suggested drivers based on a previous survey. [20]	Building smartness aspects aggregation in this study	Building Component
Technology: Enhances the use of existing techniques and knowledge to improve or facilitate the operations demanded by building systems.	Smart Operation	Building Systems
Ecology: Enhances building's integration with the environment, and reducing the use of natural resources, emissions, and waste, aiming to minimize the impacts on nature.		
Efficiency: Reduces the consumption of natural resources of the building's systems		
Flexibility: Enhances the possibility of systems to accepts changes over time, in response to future challenges regarding users' needs.		
Longevity: Enhances the extension of the building's useful life and keeps its value, through maintenance, and preventing the property from becoming outdated.	Smart Maintenance	
Energy: Enhances the use of architectural and technological solutions that contribute to the adoption of alternative energies and the rational use of energy in the building.	Smart Energy	
Comfort: Enhances the use of architectural and technological solutions that contribute to environmental comfort, aiming to improve users' quality of life and welfare, without harming the environment.	Smart Mobility	Building Occupants
Health: Enhances the use of architectural and technological solutions that contribute to the improvement or conservation of users' health and well-being.	Smart Environment Comfort and Human Health	
Satisfaction: Enhances the feeling of pleasure or disappointment, by comparing the expected performance of the building with users' expectations.		
Security: Enhances the mechanisms for the protection of the building and users, to prevent risks and limit their consequences.	Smart Safety and Security	
Integration: Enhances the aggregation and compatibility of systems to improve their capacity of interaction, to increase the interoperability between products, and people.	Smart Connectivity	Both

For building occupants, the term includes in this study both building users and assets. For the users, the general needs include comfort, mobility, security [20, 24]. In relation to the building smartness drivers, Froufe et al. [20] identified users' drivers are those aiming at improving the user's health, security, satisfaction, and comfort. Hence, from the perspective of building occupants, the smartness' drivers can be redistributed under three groups: environmental comfort and human health, occupants' mobility (including accessibility and tracking), occupant safety and security. Based on this perspective, the identified drivers are aggregated judgmentally in Table 2.

A critical component in this building smartness modelling is the connection, integration, and interoperability among building systems and occupants. This connectivity allows for interactions between the two components too. Froufe et al. [20] indicated this important driver as "Integration". As indicated above, ICT is associated with the smartness concept of systems that support connection, integration, and interoperability. Hence, ICT technology including the IoT devices (sensors and actuators) provide the required connection among and between the two building components. The seventh smartness aspect of SBM is the smart connectivity which is based on data and information sharing and communication (i.e., ICT).

In conclusion, for the building systems, the smartness aims at optimizing both the service cost (operation & energy) and condition of a building system (Maintenance). The corresponding smartness aspects include (1) smart operation, (2) smart maintenance, and (3) smart energy consumption of building systems. In contrast, for building occupants, the smartness aims at improving the user satisfaction and building assets management. Hence, the corresponding smartness aspects include (1) smart safety and security, (2) smart health and environmental comfort of human occupants, and (3) smart mobility (including accessibility and tracking) of both building occupants: human users and assets. Smart connectivity is the last aspect as it is the core of the connection and communication among the building systems and occupants. Fig. 5 illustrates the seven identified smartness aspects in the context of SBM in relation to the building systems and occupants.

3.1.3. Building management objectives

As indicated earlier, smart buildings use technologies and equipment to enhance building performance. This enhancement aims at enhancing the users' quality of life and optimizing the building operation and condition. This aim is shared with the purpose of facility management [25]. Hence, identifying the facility management objectives in the context of SBM helps in shaping the framework scope and adding precision to it.

Each smartness dimension in the smart building uses technologies and equipment to aim at a purpose. These purposes represent the management objectives of SBM in this study. For instance, smart operation aims at maximizing the systems' performance, while minimizing the associated costs. Similarly, smart maintenance aims at maximizing the longevity or the useful life of the building systems, while minimizing the maintenance costs. In the same manner, the smart energy aims at minimizing the energy consumption from the power networks, while maximizing the consumption from alternative renewable energy sources. This objective is referred to as zero-net energy buildings [26]. The building management objectives also include the building occupants. For instance, the dimension of smart safety and security aims at maximizing the security/safety for the users, belongings, and the building assets. The other two dimensions of smart comfort and smart mobility aim at increasing the users' productivity and satisfaction that include better management (mobility, tracking) of the users' belonging and building assets.

Based on the above description, the management objectives identified in this study for the SBM context includes both building systems and occupants. For building systems, the management objectives include (1) performance maximization, (2) useful life elongation, (3) cost minimization, (4) energy consumption reduction, and (5) renewable energy increase.

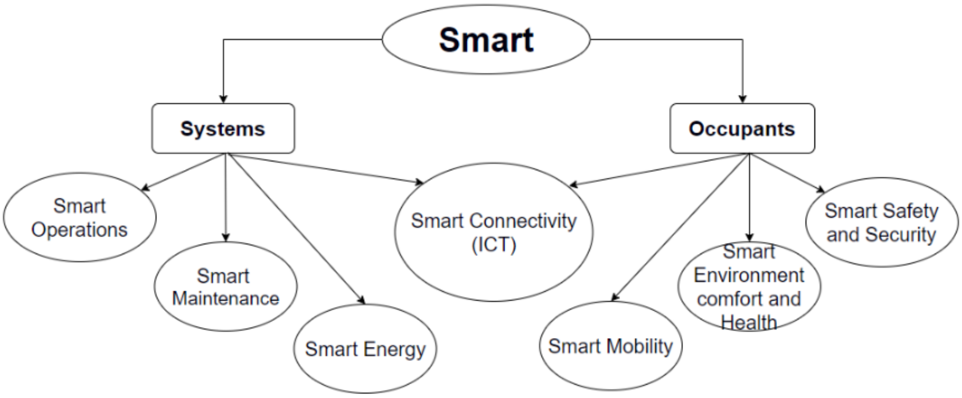


Fig. 5. The dimensions of the building smartness model

In contrast, for building occupants, the management objectives include occupant (1) security increase, (2) safety increase, (3) productivity and satisfaction increase, (4) improving asset mobility, and (5) improving asset tracking. Fig. 6 illustrates the identified ten management objectives for the building components (systems and occupants) in the context of SBM. In general, the operations of the identified objectives can be focused in four operations: maximization, minimization/decrease, optimization, and management that include all the operations. This focus allows an integration with the building smartness model.

3.2. Use-cases classification framework

While the SBM breakdown in the previous section provides a way to organize and contextualize smart building objectives, there is a need to be able to connect these objectives to a framework that will allow the creation of practical use-cases to address real-world problems. The use-cases classification framework itself includes three dimensions: (1) building components, (2) smartness dimensions, and (3) management objectives; however, there is also the need to connect this to the capabilities of IoT sensors. This introduces a dimension for the framework: the IoT sensors which can be classified based on any classification system, resulting in a total of four dimensions for the framework. The following section describes the four-dimension (4D) framework assembly and the developed visualization/symbol (i.e., the legend) based on these four mapping dimensions followed by a hypothetical example.

3.2.1. Classification dimensions

The first dimension in this framework is the IoT device. The rationale for including this as the first dimension is to address a typical situation where IoT devices and their capabilities are known and there is a need to determine the types of problems they can solve. The important part is to map the use cases corresponding to the IoT sensors. So, the IoT sensors classification system itself is not critical in this regard. Rozsa et al. [17] covered IoT sensors under five categories based on the detected/measured signals from the physical conditions. These categories are as: motion, position, environment, mass measurement (i.e., related to a body or a physical interaction force with a body; (in) animate solid, liquid, or gaseous mass), and biosensors (related to organisms). This taxonomy is a straightforward and more relevant to the use cases for IoT sensors. However, the biosensors class could be omitted as it is not relevant to the concept of SBM. Table 3 includes examples/subtypes of IoT sensor functions under each category as adopted in reference to Rozsa et al. [17]. To account for other sensors that does not fall under any of these categories, we should add a class with name “Others”. Any modifications can be adopted without affecting the use case classification framework.

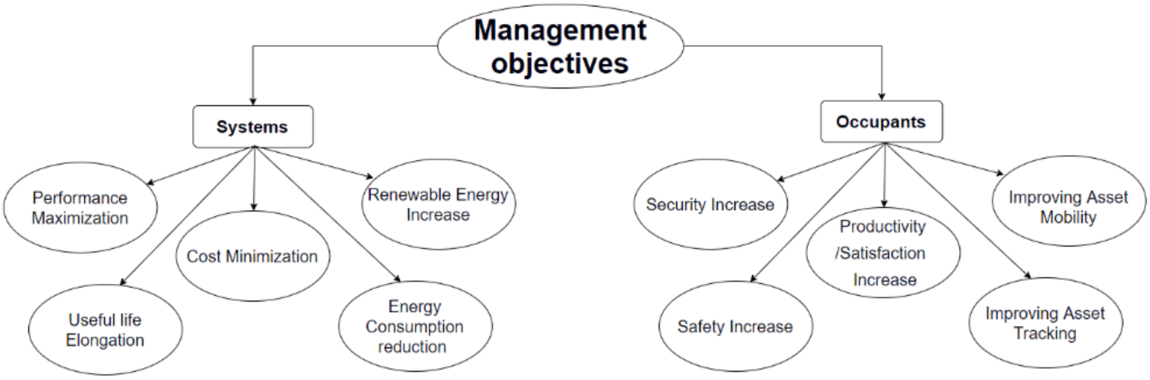


Fig. 6. The identified management objectives in the context of SBM

Table 3. IoT sensor types and subtypes

*Sensors' group	Definition	Subtypes
Motion	A group for the measures related to the movement of a body (Solid, liquid, or gaseous)	Movement, Velocity, Inertia, Vibration, Acceleration, Vibration, Rotation
Position	A group for the measures related to the positioning of a body	Orientation, Inclination, Proximity, Presence, Location
Environment	A group for the measures obtained from an environment	Temperature, Humidity, Luminance, Acoustic, Radiation, Gas, Magnetic Field, Weather, Chemical, Electrical, Color, Electromagnetic Field
Mass Measurements	A group for the measures obtained from the measurement of a body or a physical interaction force with a body	Volume, Pressure, Density, Deformation, Viscosity, Flow, Load, Moisture, Shock, Contact, Strain, Corrosion, Electrical Conductivity, Oxygen
Others	A group for different measures other than the four groups or using any of them for different purpose	Counting sensors using any measurements obtained by any of the listed sensors above

*Adopted from Rozsa et al. [17]

However, for the purpose of assembling the framework, we should note that the list of the IoT devices is almost endless, consequently this dimension is mapped on the vertical dimension (i.e., Y-axis) to allow for extended number of devices. This dimension identifies the device's name, type, and location (i.e., building indoor or outdoor).

The second dimension is the building components which include the building systems and occupants that have both physical and functional/behavioral characteristics. However, this breakdown of the components leads to a limited list. Hence, this dimension should be mapped on the horizontal dimension (i.e., X-axis). The cell in the plane (i.e., XY-location) identifies the building component targeted by the IoT sensor under consideration. The enclosed area (XY location) is the location of the cell that includes information about both the smartness dimension and the management object that is represented by complex symbols.

The third dimension is the smartness dimension. The building smartness model, developed in Section 3.1.2, has seven dimensions that cover the building systems and occupants. These dimensions are (1) smart operation, (2) smart maintenance, and (3) smart energy consumption, (4) smart safety and security, (5) smart health and environmental comfort of human occupants, and (6) smart mobility, and (7) smart connectivity. To be integrated in a 2D framework visualization, these smartness dimensions can be represented by their numbers (1, 2, 3…7).

The fourth dimension in this framework is the management objectives, identified above (in Section 3.1.3) and illustrated in Fig. 6. By looking to this Figure, one can notice that the operations of these objectives can be focused in four operations: maximizations/increase, minimization/decrease, optimization, and management that include all the operations. When these operations are integrated with the dimensions of the building smartness model (the third dimension), more details can be visualized in a 2D (XY) page plane. Hence, for the purpose of assembling the 2D framework, the focused management operations can be represented by shapes such an up/down triangle for increase/decrease, circle for optimization, and square for all. These shapes can include the smartness dimensions represented by their numbers.

In reference to the above description, therefore, the 2D use-cases classification framework can be assembled. While the horizontal access lists the building components and their characteristics, the vertical dimension lists the IoT sensors by their categories and location. The cells under these two dimensions (XY location) represents the potential use case of any IoT sensors. Once a use case is identified, both the smartness dimension and the management objectives are inserted at that cell using a combination of shaped symbols that represent the management operations (△,▽, ○, □) and numbers enclosed to represent the smartness dimension (1, 2, 3…7). Fig. 7 shows the structure of the assembled 4D framework (denoted as D1, D2, D3, and D4) along with the legend.

The building components dimension (D2, the horizontal dimension; X-axis) has more details than what is presented in Fig. 7. For example, it does not show the building primary and control systems. The following two figures provide a more detailed illustration of the building components, both systems and occupants. While Fig. 8 shows the detailed breakdown of the building systems, Fig. 9 shows the detailed breakdown of the building occupants of academic buildings because it is the scope of this framework as stated earlier.

By having a look at this building breakdown, one can see that any IoT sensor has the possibility to target any of the framework cells where each corresponds to a potential use case relevant to its location in this building breakdown. For any sensor, potential use cases can be identified as the number of possible use cases is scoped in this breakdown. This does not mean that the ultimate state of IoT sensors inclusion in this framework will be filling all the cells.

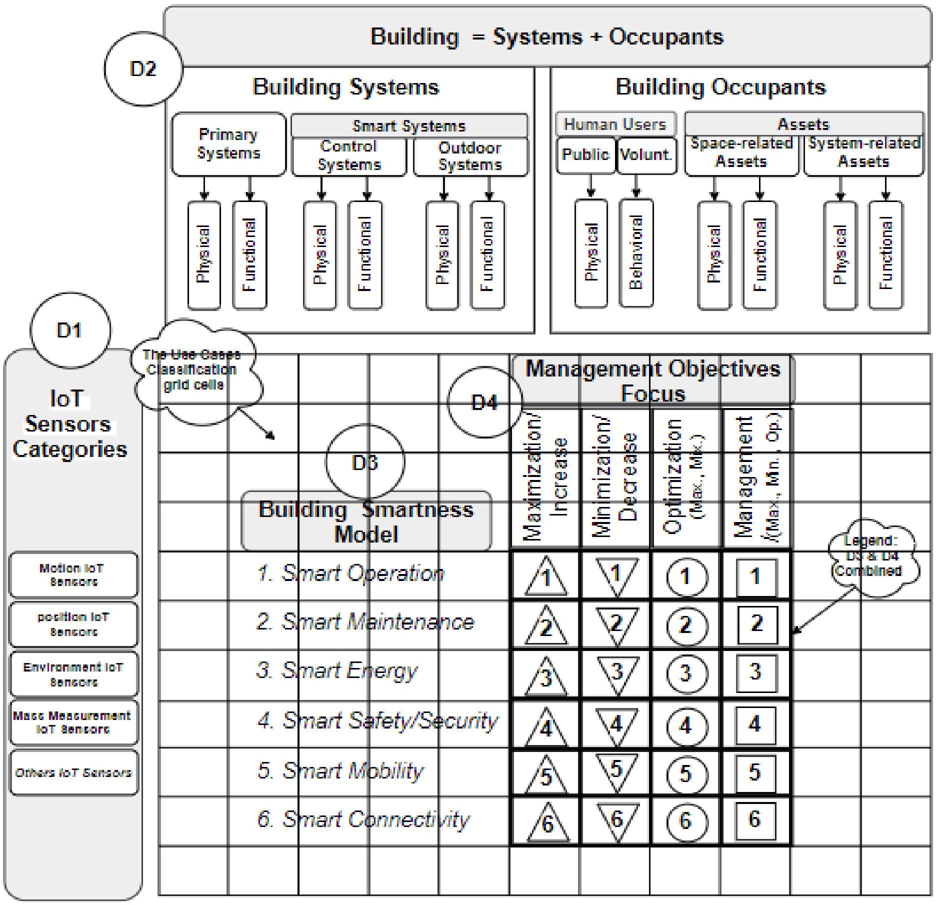
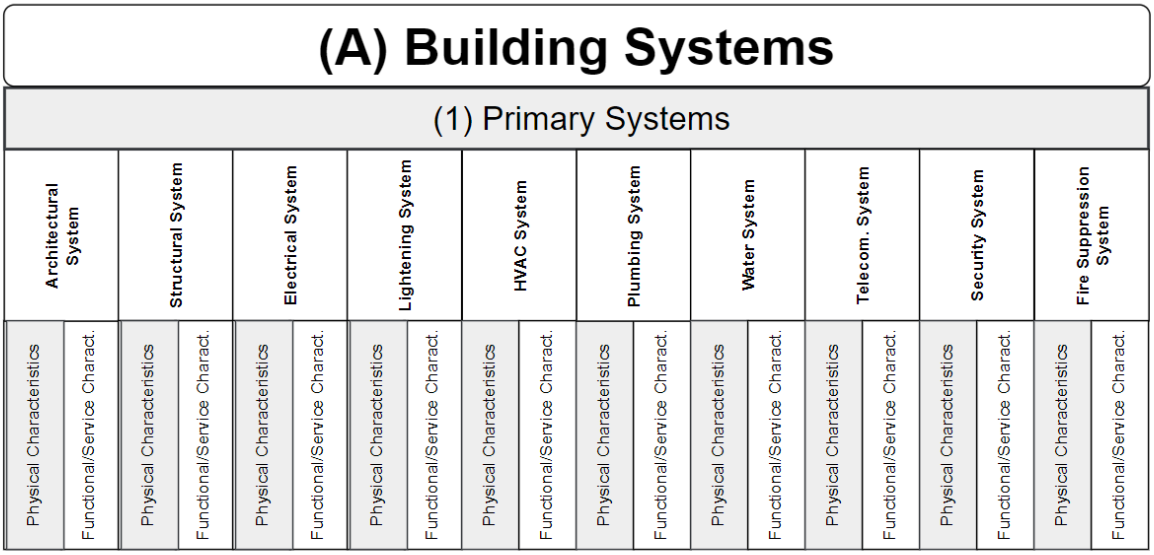
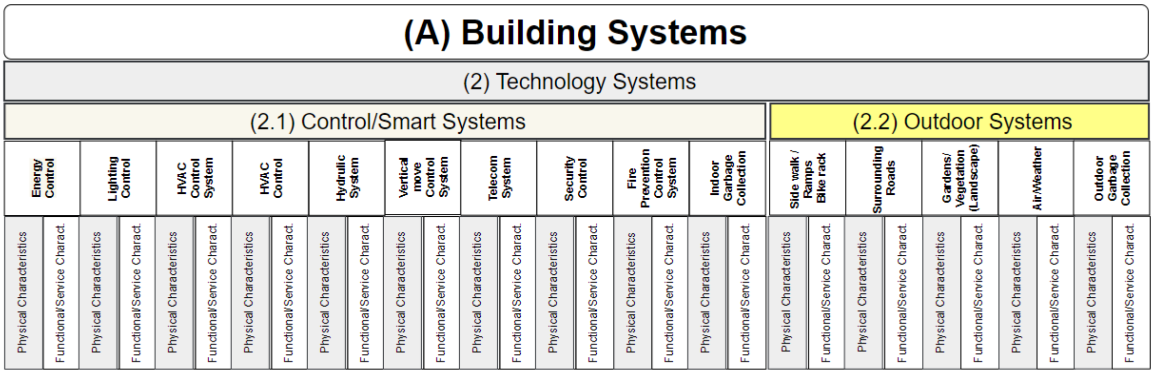


Fig. 7. A simplified version of the 4D use cases framework showing the developed models and legend



(a) The breakdown of the Primary Systems



(b) The breakdown of the smart systems

Fig. 8. A detailed breakdown of the building systems

However, it helps in identifying use cases very easily by answering the question "What would be the use case under this cell?" for each building component cell. The full detailed version of the developed 4D framework is provided in the Appendix.

3.2.2. Hypothetical example

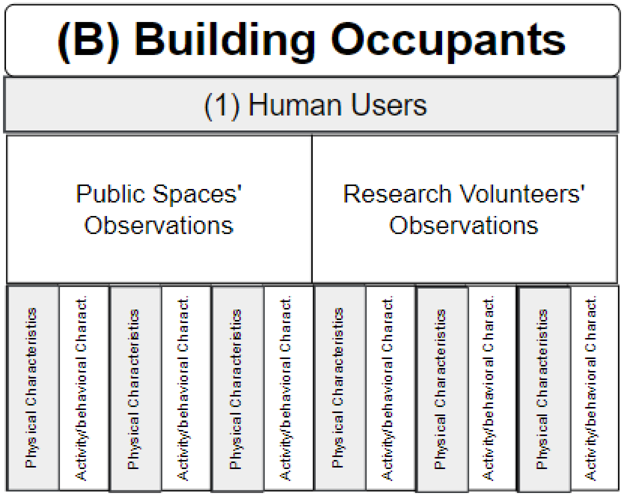
Imagine that we have a hypothetical sensor named (PowerSensor) that is monitoring a building's energy consumption. This sensor targets the function of the electrical system which is a primary building system. The following steps will be followed.

1) The sensor name (PowerSensor) should be included in the first mapping dimension (IoT sensor) under the relevant device category based on the adopted IoT devices classification. In our case, the IoT category is Mass measurement/Electrical Conductivity.

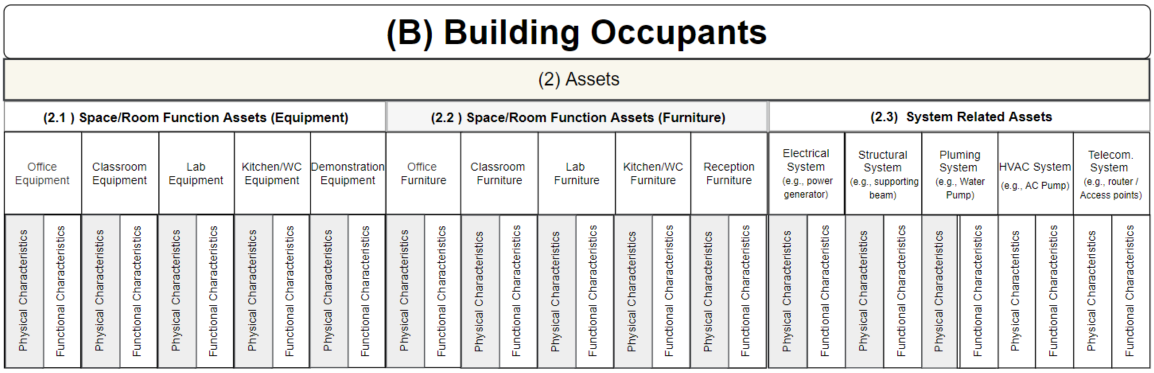
2) The framework cell should be under the building systems, primary systems, Electrical System, Functional characteristics. This is because the sensor monitors the service/function of the system not the physical component of the electric system.

3) The smartness dimension targeted by this sensor is the smart energy (#3).

4) The management objective of this use-case is to minimize the energy consumption (▽).



a) The breakdown of the human users of academic buildings



(b) The breakdown of the building assets of academic buildings

Fig. 9. A detailed breakdown of the building occupants of academic buildings

Fig. 10 illustrates the resulting documentation of this use case. The cell under the functional aspect of the electrical primary systems has the number (3) which indicates the third smartness dimension "Smart Energy = 3" and a triangle pointing down to indicating that the focus is to decrease in energy consumption.

4. Applicability Demonstration

Recently, there was an effort at the University of New Brunswick to develop use cases for smart building research, which including hiring a summer research assistant (Pritish Sookar) to do background research. Sookar's [27] unpublished report, supervised by Trevor Hanson, presented four potential use cases: (1) active transportation use, (2) emergency evacuation, (3) pandemic resilience, and (4) universal design. These use cases were developed prior to having a framework, therefore the application of the framework serves to organize the use cases, while also helping to identify any areas that may be missing from the use cases.

These use cases were summarized in Table 4 below. The following subsections present the four cases identified with more detail.

4.1. Sidewalk use monitoring (Active transportation)

The first case is about outdoor mobility where the focus is on the sidewalks. Different buildings are dedicated for different functions on university campuses.

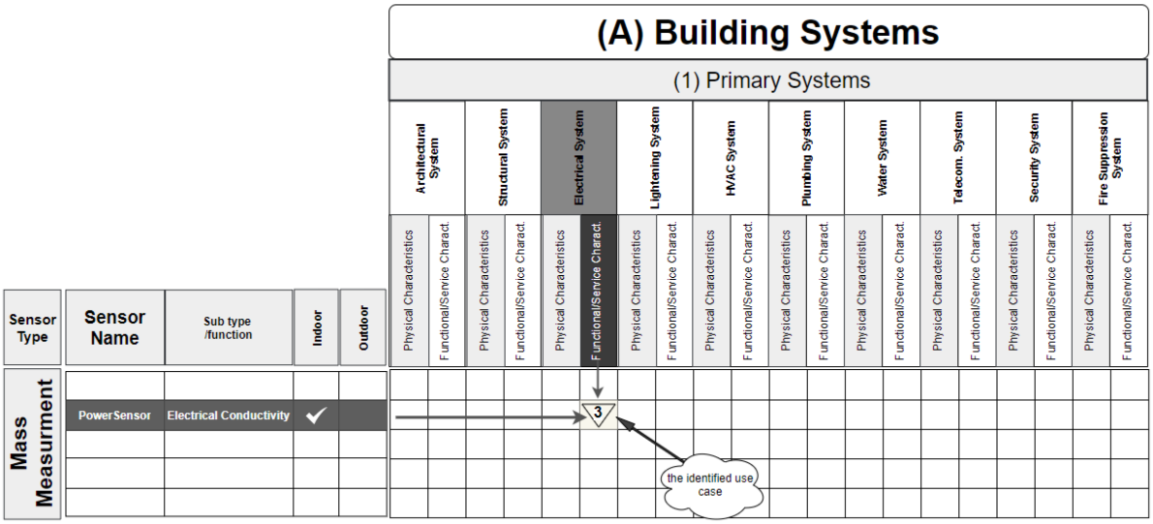


Fig. 10. The use case documentation in the developed 4D use case classification framework

Table 4. A summary of the proposed use cases in a previous study*

Use case Focus/ Name	Summarized Description	Suggested Sensors
Sidewalk use monitoring	Counting the pedestrians and bikers who are using the sidewalks surrounding the academic buildings with the university settings. The aim is to collect data that helps in understanding the mobility behaviors of the sidewalk users and managing the maintenance of the sidewalks (e.g., snow removal).	Inductive loops, magnetometers, piezoelectric strips, radar sensors, & thermal imaging
Outdoor bike racks monitoring	Measuring the usage of bike racks by detecting bikes and counting them on the bike racks within academic buildings. The aim is to collect data that helps in understanding the users' behavior, identifying the influencing factors, and managing the bikers needs (e.g., numbers and locations of bike racks).	Pressure sensors, Infrared beam sensor, Single/stereo cameras
Indoor localization and building occupancy	Counting and locating the users who are moving via different indoor routes. The aim is to collect data that helps in providing indoor wayfinding service and understanding the users' navigational/mobility behaviors within academic buildings.	Wi-Fi-based loc., RFID, Bluetooth, dead reckoning, & acoustic technology
Indoor people's mobility tracking	Counting academic users (students, faculty, staff, etc.) entering to and leaving from ana academic buildings via different access points. The aim is to collect data that help in managing the building accessibility and analyzing their users' mobility behaviors (e.g., mobility trends and the influence factors)	Infrared beam, Thermal camera, & Video-based counters

*Adopted from a prior unpublished work relevant to this study by Pritish Sooker [27] and supervised by Trevor Hanson

For example, some buildings are designed for students' accommodation and others for administrative purposes. For this reason, students often must walk from one building to another using the network of sidewalks. There is value in knowing which sidewalks are the most or least used, what factors affect their popularity among students, and how their popularity varies across a particular day or year to inform snow clearing activities during the winter or other recurring maintenance activities. Pedestrian or bike count data can also serve as basis for decisions regarding where investment in walking infrastructure is most needed and whether those investments are having positive benefits. Along with tracking or counting the number of pedestrians using a particular sidewalk, the sensors can also be used to identify the desired paths.

The potential technologies, suggested for this case, is counting sensors for both pedestrians and bikes. For counting pedestrians, active infrared beam devices and passive infrared devices could be used. This technology cannot be relied on for bike counting as they are not equipped to distinguish between a pedestrian and a bike. For counting bikes, inductive loops, magnetometers, piezoelectric strips, radar sensors, and thermal imaging can be more apt for long durations of bike data collection [28]. In this case, a building could be equipped with these technologies to monitor active transportation use to and from the building.

As described above, the first case is relevant to mobility analysis. It is about measuring the usage of sidewalks, surrounding buildings, by people and bikes within university campuses. The technologies suggested for this case are counting sensors including active/passive infrared beam for people counting and inductive loops, magnetometers, piezoelectric strips, radar sensors, and thermal imaging for bike counting on sidewalks. The case aims at collecting mobility data for sidewalks, identifying trends of most used routes, and investing the behavior of pedestrian and bikers.

The component targeted by this case is the “function” of the “outdoor” building system (sidewalk). In the context of SBM, the data to be collected will help in improving the users’ quality of life via “managing” their “mobility and accessibility”. Therefore, in reference to the developed use cases framework in this study, this case should be documented as follows: horizontally, (D2) under the “functional characteristics” of the outdoor building system (sidewalk), (D3) the smart mobility dimension (No. 5), and (D4) the managing objective focus (☐). Vertically, for the first dimension (D1), the symbol should be inserted at the row relevant to the motion sensors’ type (counting). Fig. 11 illustrates the documentation of this case.

4.2. Outdoor bike racks monitoring

The second case is relevant to outdoor mobility where focus is on quantifying demand for active transportation infrastructure such as bike racks. The aim is to determine bike rack demand and to determine the relationship of this demand with respect to weather, time of the day or time of the year. The data which could be collected can also be used to determine whether the existing bike racks on campus are appropriately located, whether new bike racks should be installed at new locations or whether existing bike racks should be altered to increase capacity. A use-case to collect data on bike detection on bike racks could help with this infrastructure planning.

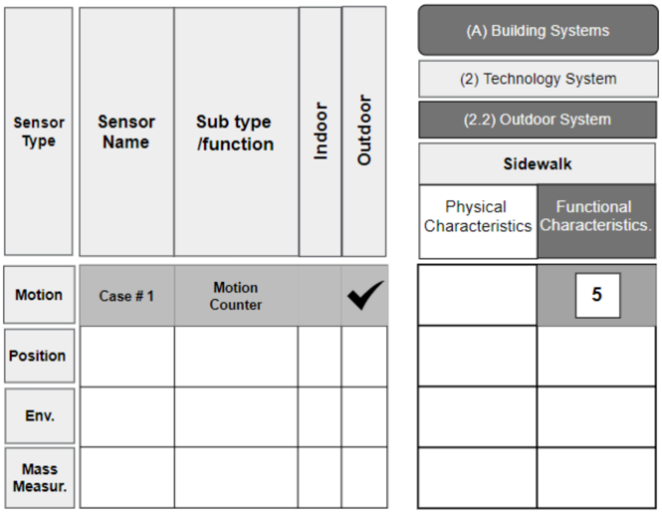


Fig. 11. The 1st use-case (sidewalk use monitoring) insertion in the 4D framework developed

The potential technology, as suggested for this case, is the detection systems for collecting bicycle rack occupancy data. There are two broad categories of these systems. The first category are physical sensors which include pressure sensors and infrared beam sensors. A pressure sensor is activated whenever a bicycle is placed on it while and infrared beam sensor is activated whenever the wheel of a bicycle cuts the infrared beam which spans the width of a bicycle parking spot. Optical sensors are essentially a pair of wireless cameras which when operated conjointly are capable of processing images in three-dimensions (3D). A computer is responsible for conducting the image analysis to determine occupancy of the bike rack at regular time intervals. Once the occupancy is determined, the analyzed images are discarded, and the pair of cameras captures another series of images to be analyzed by the computer. Wireless cameras connected to a building can communicate via Wi-Fi with a router and can either be powered by a power cord or can run on batteries. The video footages are automatically sent via Wi-Fi to a cloud-based storage system where the footages can be accessed for analysis. This wireless system warrants a strong Wi-Fi network for efficient operation. The use of stereo cameras allows the camera to simulate human binocular vision. With the help of a Computer Vision algorithm, a 3D model of each parking space can be constructed, and the occupancy of the bike rack can be assessed.

As described above, the second case is relevant to mobility analysis. It is about measuring the usage of bike racks close to an academic building. The technologies suggested for this case are bike detection sensors including pressure, infrared beam, and optical single/stereo camera sensors. The case aims at measuring bike racks usage data, identifying trends of usage, and understanding the travel demand for biking infrastructure.

The component targeted by this case is the "function" of the "outdoor" building system (bike racks). In the context of SBM, the data to be collected could help in improving the bikers' experience via "managing" the needs (e.g., numbers, distributions) for bike racks. Therefore, in reference to the developed use cases framework in this study, this case should be documented as follows: horizontally, (D2) under the "functional characteristics" of the outdoor building system (bike racks), (D3) the smart mobility dimension (No. 5), and (D4) the managing objective focus (☐). Vertically, for the first dimension (D1), the symbol should be inserted at the row relevant to the motion sensors' type (Counting). Fig. 12 illustrates the documentation of this case.

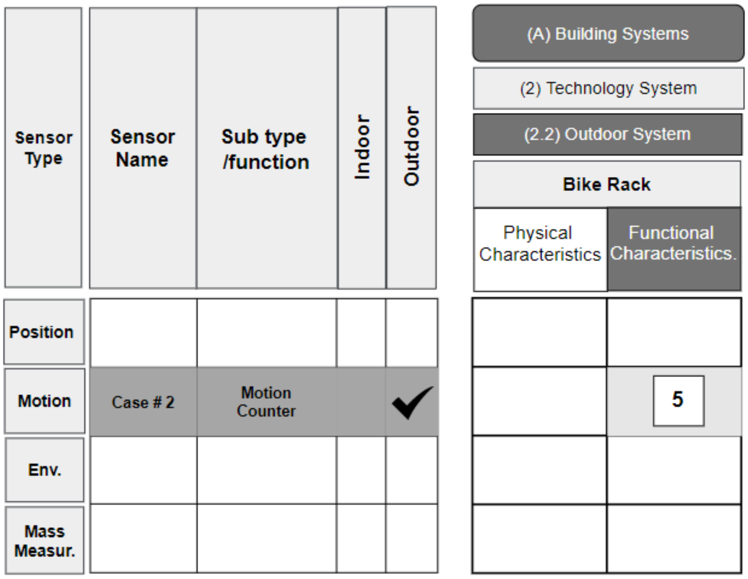


Fig. 12. The 2nd use-case (outdoor bike racks monitoring) insertion in the 4D framework developed

4.3. Indoor localization

The third case is about indoor mobility where the focus is on building users' localization and occupancy monitoring. In regarding to building users, it is important to their satisfaction to provide an indoor navigation (wayfinding) service, which is based on indoor localization systems. Also, collecting data about the users' navigation and the most used routes is essential to identify the factors influencing the users' route choices. The correlation between most used routes and factors such as time of the day or time of the year helps in understanding the building users' behaviors and opens doors for new avenues in active transportation research. However, without the right technology, no data regarding building indoor locations and occupancy will be available to support services like wayfinding. Hence, a use case to collect data on indoor localization and occupancy should be collected.

The potential technologies, as suggested for this case, is indoor localization systems. These systems can be classified in two broad categories: active and passive localization techniques. While the active localization technique requires tags or other electronic devices that need to be carried by the building user, passive localization techniques does not require any additional equipment. For an indoor setting, it is more apt to use technologies such as Bluetooth, RFID (radio-frequency identification), dead reckoning, and acoustic technologies. In addition to these, Wi-Fi signals are being exploited. Although the primary function of Wi-Fi is to enable access to high-speed internet, the time of arrival or direction of arrival of Wi-Fi signals from smartphones can also be used for indoor positioning. It is, however, the proximity-based Wi-Fi positioning system that has an edge over the two previously mentioned methods for indoor navigation. The received signal strength (RSS) by the access points in the network is used to indicate the approximate location of a device. The advantage of using this method for determining location of building occupants is that no additional infrastructure is required. There are, nonetheless, some drawbacks with this technology, one being large range Wi-Fi transmission. Ideally, the stronger the RSS the closer is the device to the access point. However, owing to attenuation caused by physical obstructions, a device may appear to be further than it actually is. It is important to indicate that the choice of an indoor localization technique is to be guided by the environment where localization technologies will be deployed, and the accuracy warranted.

As described above, the third case is relevant to mobility analysis. It is simply about indoor mobility and the behavior of the building users in a public space. The technologies suggested for this case are indoor localization technologies including Wi-Fi, Bluetooth, RFID. The case aims at collecting data about the navigational behaviors of the building users in the indoor environment.

Hence, the component targeted by this case is the navigational "behavior" of the building "human users". In the context of SBM, the data to be collected will help in improving the mobility experience via "optimizing" the influencing factors and navigation guidance (wayfinding service) for the building users. Therefore, in reference to the developed use cases framework in this study, this case should be documented as follows: horizontally, (D2) under the "behavioral characteristics" of the human building users in the public spaces, (D3) the smart mobility dimension (No. 5), and (D4) the optimization objective focus (○). Vertically, for the first dimension (D1), the symbol should be inserted at the row relevant to the position sensors' type (Navigation). Fig. 13 illustrates the documentation of this case.

4.4. Building access mobility tracking

The fourth case is about the interface between indoor and outdoor building access where the focus is on how people access the entrance/exits, including accessibility for persons with a disability. Many buildings are equipped with powered accessible entrances which are opened by a push button.

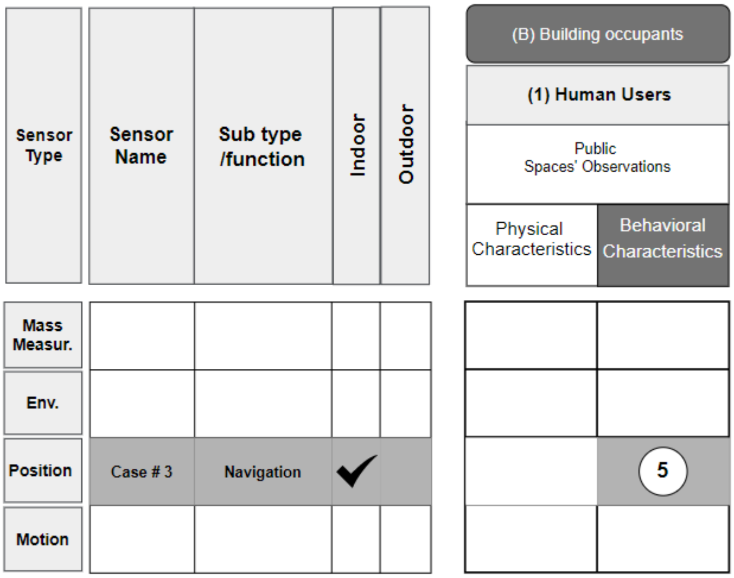


Fig. 13. The 3rd use-case (Indoor localization) insertion in the 4D framework developed

Depending on the type of disability, someone may not be able to open a door without power controls, therefore rely on the reliability of a push button to enter the building. It can be expected that such buttons may become less reliable over time and with use, but there is typically no measure field of this use, and someone may only be aware of the failure when trying to use the door and button does not work. With this information, it may be possible to identify the reliability of the door and dispatch a maintenance person automatically.

The potential technologies, as suggested for this case, is counting sensors. Sensors for people counting can be classified into three broad categories. This categorization is based on the prevalence of the underlying technologies employed by the sensor in time. Initially infrared beam counters were used for counting people. There are two components to the infrared beam counter: the infrared beam emitter which emits a beam that spans the width of the pedestrian path and a receiver which is placed directly opposite to the emitter on the other side of the path. Whenever the infrared beam is cut by a pedestrian, the sensor is triggered, and a count is registered. This means of counting people is prone to errors as the sensor does not perform well when several pedestrians pass the counting point simultaneously. Another people counting technology is the thermal camera which detects presence of pedestrians owing to the heat emitted by the pedestrians. Although the thermal camera outperforms the infrared beam counter in terms of accuracy, it falls short when compared to video-based and Wi-Fi counting technologies. Depending on the type of accessible door opener, sensors can also be installed to measure the use of electronic door openers.

As described above, the fourth case is relevant to accessibility analysis. It is about counting people “in a public space” entering to and leaving from an academic building via different access points. The technologies suggested for this case are counting sensors including infrared beam, thermal camera, and video-based counters. The case aims at collecting mobility and accessibility data, identifying trends of people’s movements, and investing the behavior of pedestrian.

Hence, the component targeted by this case is the “behavior” of the building “human users”. In the context of SBM, the data to be collected will help in improving the users’ quality of life via “increasing” their “mobility and accessibility”.

Therefore, in reference to the developed use cases framework in this study, this case should be documented as follows: horizontally, (D2) under the "behavioral characteristics" of the human users (all categories), (D3) the smart mobility dimension (No. 5), and (D4) the increase management objective focus (△). Vertically, for the first dimension (D1), the symbol should be inserted at the row relevant to the motion sensors' type (Motion). Fig. 14 illustrates the documentation of this case.

4.5. Discussions

In the previous subsections, four use cases were described, based on a previous work, and broken down in accordance with the developed use cases classification framework. The analysis and insertion/documentation of these four cases demonstrates the applicability of the framework developed. In this section, further analysis to those case to identify some gaps (potential cases) that are missed in the previous work. Fig. 15 provides a side-by-side documentation of the four cases in the framework described earlier.

The first case was about the function of a sidewalk as it is classified as an outdoor building system component in our framework. For documenting this case, the smartness dimension (smart mobility), and the management objective focus, in the context of the SBM, were identified/inferred easily from the case definition. In terms of the framework practicality, it was straightforward to map the aspects of the use case and put it in scope after identifying its relevant smartness direction and management objective. The focus of the case was on monitoring the function of the sidewalk using motion sensors. However, as shown in Fig. 15, the case misses to consider the physical aspect of the sidewalk. To fill this gap, for example, the same motion sensors can be used to measure the usage (by humans) of the sidewalk and correlate this information with the physical condition of the component over different times and weather conditions. An opportunity could be monitoring the activities of "non-humans" such as the snow falling using mass measurement sensors. This information could be correlated to both the physical and functional characteristics of the sidewalk which are its condition maintenance and its users' behavior. The aim of these potential use cases could be towards smarter operations or maintenance dimensions (No. 1 or No. 2) of the sidewalk.

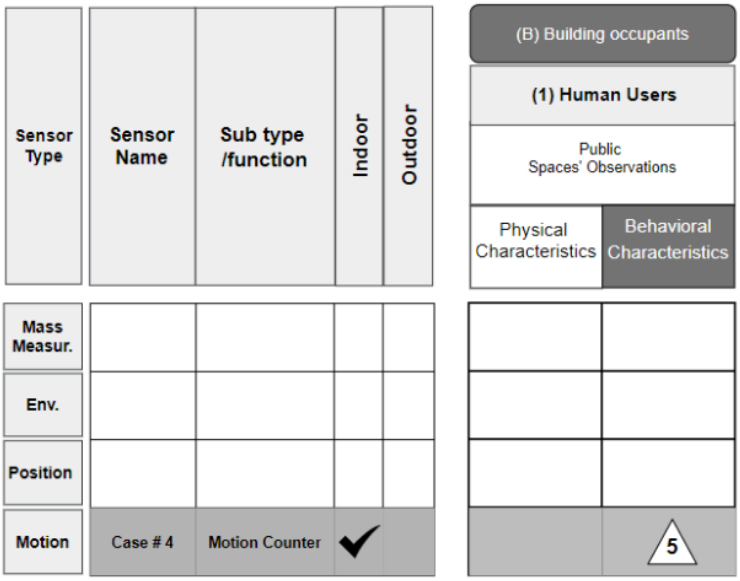
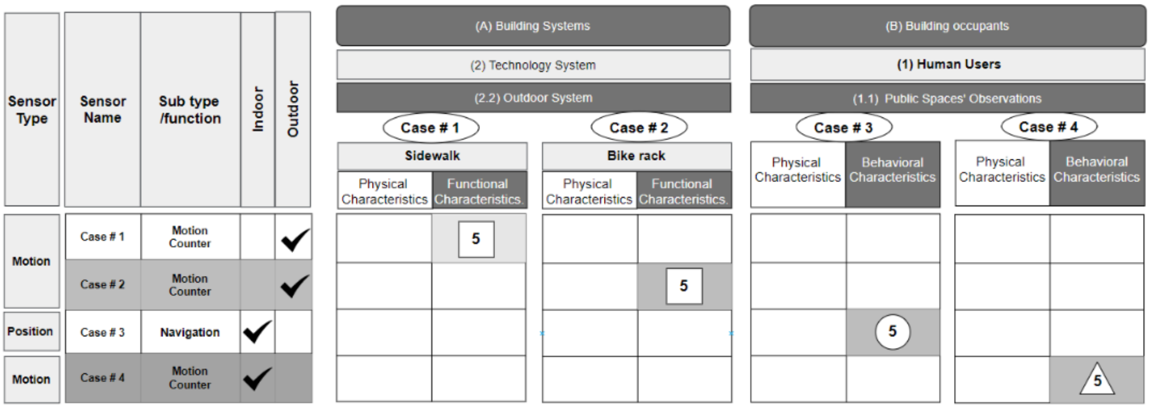


Fig. 14. The 4th use case (indoor people's mobility tracking) insertion in the 4D framework developed



					(A) Building Systems				(B) Building occupants			
					(2) Technology System				(1) Human Users			
					(2.2) Outdoor System				(1.1) Public Spaces' Observations			
					Case # 1		Case # 2		Case # 3		Case # 4	
					Sidewalk		Bike rack					
Sensor Type	Sensor Name	Sub type /function	Indoor	Outdoor	Physical Characteristics	Functional Characteristics	Physical Characteristics	Functional Characteristics	Physical Characteristics	Behavioral Characteristics	Physical Characteristics	Behavioral Characteristics
Motion	Case # 1	Motion Counter		✓		5						
	Case # 2	Motion Counter		✓				5				
Position	Case # 3	Navigation	✓							⑤		
Motion	Case # 4	Motion Counter	✓									△5

Fig. 15. The framework's documentation for the four cases presented side by side

The second case was about the function of a bike rack as it is classified as an outdoor building system component in our framework. For documenting this case, the mobility aspect of the smartness model, and the focus of management objective were identified/inferred straightforwardly from the case described. In terms of the framework practicality, it was easy to map the characteristics of the use case and scope it after identifying its relevant objective. The focus of the case was on monitoring the function of the bike rack using motion sensors. However, as shown in Fig. 15, the case misses to consider the physical aspect of the bike rack. To fill this gap, for example, the same motion sensors can be used to identify the non-functioning slots of the bike rack, by measuring the usage which should be zero, due to rust or break. This information is required for automatic alarming of facility management group to take the right actions. The aim of this potential use case is towards smarter maintenance dimension (No. 2) of bike racks.

In contrast to the second case, the third case was about the navigational behavior of human building users as they represent the first component of the building occupants in our framework. For documenting this case, the smartness dimension (smart mobility), and the management objective focus (optimization), in the context of the SBM, were identified/inferred easily from the case definition. In terms of the framework practicality, it was simple to map the aspects of the use case and put it in place after identifying the right smartness direction and management objective. The focus of the case was on monitoring a behavioral characteristic of building users using position sensors. However, as shown in Fig. 15, the case misses to consider the physical aspect of the building users. To fill this gap, for example, the same position sensors can be used to measure positions of the users (humans) within the building indoor locations. This positional information can provide data about the most crowded locations (many people close to each other) with people in the buildings that can be correlated with other parameters (e.g., events) or restrictions such as the social distances in pandemic situations, which is an important safety concern. An opportunity could be tracking the optional movements of building assets (e.g., furniture, A/C units, etc.) and users' belongings. This could help in improving the smart security dimension of the buildings. The aim of these potential use cases could be towards smarter safety and security dimension (No. 4) of buildings.

The fourth case was about the accessing behavior of human building users (in academic environments). For documenting this case, the smartness dimension (smart mobility), and the management objective focus (increase), in the context of the SBM, were identified/inferred from the case definition. In terms of the framework practicality, it was easy to map the aspects of the use case and put it in scope after identifying the right smartness direction and management objective. The focus of the case was on monitoring the access of the building users, via different doors/entrances, using motion sensors. However, the case misses to consider the physical aspect of the building doors/entrances. To fill this gap, for example, the same motion sensors can be used to count the number of door usage (opening/closing) and associate this information with the physical condition and maintenance of the building architectural system (doors) and accessibility. The aim of this potential use case could be towards both smarter mobility and maintenance dimensions (No. 5 and No. 2) of buildings.

As shown via the hypothetical example and the four cases, the applicability and usefulness of the developed framework have been demonstrated. In the case of having some existing IoT-based use-cases (scenarios/ideas for smarter buildings), mapping and documenting such use cases were straightforward. The mapping process starts by setting a scope for the use case which is simply identifying the target smartness dimension and the management objective. It was clear from the presented discussions how the framework useful in setting scopes and directions for use case in the contexts of SBM. The framework assisted in identifying gaps and the potential use cases for the IoT sensors that are being considered for other uses. Further, the framework helped in highlighting opportunities for new use cases with different IoT sensors for smarter building management. Having the mapping dimension of the IoT sensors on the vertical (Y) axis is advantageous. That allows accommodating new IoT sensors, by stacking new use cases in rows, and accounts for future IoT sensors' changes, additions, and evolutions.

Mapping many use cases with a variety of IoT sensors in a single framework is very useful. It helps in visualizing all possible scenarios and hence supports better communication. So, this mapping framework has the potential to serve as a communication vehicle/tool for collaborations on IoT-related projects with different parties. Additionally, mapping the use cases visually in a framework allows comparisons, identifying gaps, and highlighting new uses in the context of SBM. Hence, it can be utilized for planning, visioning, and building roadmaps for strategic SBM research and development programs. However, these qualities are identified as potential uses that require further validation through performing expert panel investigation.

It is worth noting that this research introduces a conceptual framework. For full validation, it should be applied to real case studies of different buildings, as well as undergo in an expert panel review based on a focused group, and investigation based on industry practitioners to collect feedback on its soundness, applicability, practicality, and validity of its use. However, due to limitation in time and funding, the implementation part of the study was limited to framework verification and applicability demonstration.

5. Conclusions

In the context of SBM, this paper highlighted the literature gap of lacking a use-cases mapping framework for smart buildings despite its need. Accordingly, a four-dimensional framework was introduced in this paper for IoT-based use-cases mapping. The developed framework contributes/presents a new understanding and perception of the SBM key dimensions that were integrated into a conceptual framework.

From the SBM perspective, the four framework dimensions identified in this study were (1) IoT sensor name and categorization, (2) building components including both systems and occupants, (3) building smartness model with six dimensions, (4) smart building management objective focus. The applicability of the developed framework was demonstrated through a hypothetical example and four use cases in university settings as the study scope is limited to academic smart buildings.

Many functions were identified in the developed framework based on applying it in multiple use cases and discussing the observations. Based on these observations, the developed framework has the several potential functions such as (1) documenting all the available IoT sensors in a specific building and accounts for future additions, (2) mapping the current use cases of the available IoT sensors, (3) the possibility of identifying the potential use cases of the available IoT sensors, (4) highlighting gaps and opportunities for new use cases, and (5) helps in identifying the needs for additional devices for a smarter building management. Furthermore, the framework, theoretically, can serve as a communication tool for collaborations on IoT-related projects with different parties, and support planning, visioning, and building roadmaps for strategic SBM research and development programs. However, these functions were identified based on observations and hence require further testing and validation.

In this regard, some limitations could be highlighted in this study. The implementation part was restricted to verifying and demonstrating the applicability of the framework. Therefore, it is crucial for the developed framework to undergo thorough rigorous validation and more testing to assure its robustness. Accordingly, our future research attempts will target applying this framework in real case studies of different buildings, conduct an expert panel review based on a focused group, and investigation based on industry practitioners to collect feedback on its soundness, applicability, practicality, and validity of its use.

Declaration

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Author Contributions

A. Suliman: Conceptualization, Methodology, Writing- Original draft; T. Hanson: Supervision, Data Curation; M. Wachowicz: Supervision, Funding acquisition.

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Data Availability Statement

The use cases verification data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

Not applicable.

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Appendix A

A full version of the conceptual use-cases mapping framework for IoT-based smart building management.