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Smart Buildings: Systems and Drivers

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Abstract: Since the 1980s, smart buildings have aroused the interest of researchers. However, there is still no consensus on what the intelligence of a building is, and what enhances that intelligence. The purpose of this paper is to identify and correlate the main drivers and systems of smart buildings, by associating them with the main beneficiaries: users, owners, and the environment. To identify the main drivers and systems of these buildings, we carried out a comprehensive, detailed, and interpretative literature search. From the selected articles, we sorted the information, extracted the main concepts and knowledge, and, finally, identified the set of potential drivers and systems. Results showed eleven drivers and eight systems, and these can be enhanced by more than one driver. By analyzing the main beneficiaries, we grouped the drivers into three categories: users, owners, and the environment. Given the lack of consensus on the key drivers that make buildings smarter, this article contributes to filling this gap by identifying them, together with the key systems. It is also relevant for detecting the relationships between drivers and systems, and pointing out which drivers have the greatest potential to affect a particular system, keeping in mind the main beneficiary.

Keywords: smart buildings; intelligent buildings; sustainable buildings; buildings' systems; building performance; drivers

1. Introduction

Smart buildings are a reality increasingly present in cities around the world. The concept of smart buildings is not new, but it has evolved mainly due to the development of new technologies, which, when incorporated, enable more intelligent resources and processes, which expand the building's capacity to operate in a more efficient, flexible, interactive and sustainable way.

The concept of smart buildings has received several definitions and interpretations. Several researchers [1–4] have emphasized the term intelligent building, while others [5–8] have emphasized the term smart building. In Ghaffarianhoseini et al. [9], this difference in point of view is very evident when the definition of Buckman et al. [10] is contrasted, which considers intelligence as one of the components of smart buildings, with Ghaffarianhoseini et al. [11], who considers smartness was only an indicator of intelligent buildings, but what is more important is that, in essence, they represent the same objectives.

This continuous evolution has led to the more frequent use of the expression "smart buildings". Although this term has evolved since the 1980s, there is still no consensus on how to define the intelligence of a building [10], mainly because of its several aspects and approaches.

Studies on smart buildings have mainly addressed the formulation of concepts from the dimensions that define them, and from the multidisciplinary character of the actions required [11,12]; on the identification, characterization, and development of technologies towards automation and improvement of the interaction with buildings' users and managers [13,14]; on the detection of drivers that can make buildings smarter, which are responsible for improving their systems' performance [10,15]. The detection of drivers has received fewer contributions over time; however, until now there is no consensus on the main drivers that should be considered for making buildings smarter.

This study addresses this gap by researching the main drivers that collaborate to increase the intelligence of building systems. It also collaborates by understanding the relationship between drivers and systems and which drivers have the greatest potential to affect a given system, under the perspective of users, owners, and the environment. By exploring concepts related to drivers, systems, and the relationship between them, this work also contributes to the decision-making process of the owner about the characteristics and functionalities of building systems to be adopted, according to their objectives, mainly those related to the return on investment (ROI) and improving market competitiveness.

2. Literature Review

Smart buildings are intricately related to smart cities and, therefore, although the main object of this work is smart buildings, this relationship must be addressed. The concepts "smart city" and "smart building" emerged in the 1980s [16] and evolved similarly. When analyzing the literature on smart cities, the approaches can be grouped in two phases [17]: the first, from the end of the 1980s, focused mainly on the role of information technology and innovation, with the prevailing studies aimed at making more digital, technological, and cyber cities and buildings; the second, from the end of the 1990s, with a comprehensive approach emphasizing more and more the role of user interactions and the social context, with a focus on improving the quality of life [4,17] and sustainability. The same behavior of the evolution of concepts can also be observed concerning buildings. Indicators used to assess smart cities, such as, for example, mobility, connectivity, health and safety, well-being, and reduction of resource consumption and emission of pollutants, are also used to evaluate smart buildings.

A significant range of studies on smart cities and buildings addresses the intensive use of information and communication technologies (ICT). With regard to cities, they mainly deal with ICTs connecting the physical infrastructure, aiming at the optimization of services, accessibility to information and public services, public participation, integration of aspects of intelligence and sustainability, and improvement in the quality of life [18–21], and with respect to buildings, they mainly address ICTs by connecting systems and stakeholders through the building automation system (BAS) [22–24].

Literature highlights two main fields of study on smart buildings: (a) as part of researches aimed at better understanding smart cities from the dimensions and factors that characterize them (vast literature), from the integration of the building's intelligence to the city (little literature), and from the integration between smart buildings (very little literature); (b) has focused on the concepts and characteristics of smart buildings (vast literature).

Concerning the first field of study, the concept of smart buildings has been approached as intrinsically related to that of the smart city, being normally considered as a factor that contributes to the increase in the intelligence of cities [9,25–27].

Buildings are part of complex ecosystems with many characteristics similar to those of living organisms, such as flows of energy and matter, flows of information, and interaction with the environment [28,29]. Considering that smarter ecosystems are the basis of smart cities, the integration of the building's intelligent systems with the city's intelligent systems provides a more intelligent urban system [17], enabling intelligent, real-time decisions at both levels, such as, for example, intelligent energy management considering the relationship between availability and demand of energy and times of higher and lower consumption at both levels.

However, in several cities, mainly those in developing countries, the increase in intelligence has occurred slowly, through the incorporation of new technologies over time. The focus has been mainly on the optimization of services, accessibility to information and public services, public participation, the integration of aspects of intelligence and sustainability, and improving the quality of life [21,30,31], but without strategically considering integration with smart buildings and among them. In this context, the intelligence of the building is limited, as they have services that manage the building or that help people manage it, but are built in areas without intelligent infrastructure.

Smart buildings are the key block of smart cities [32] and integrating them into the smart built environment also implies integrating them with each other. Bartolucci [33] establishes an analogy of smart buildings with Lego pieces, which although they have different dimensions and shapes, present the same basic characteristic: any piece can connect to any other piece. This characteristic is represented in smart buildings mainly by the interoperability provided by the BAS of each building.

In this context, the interaction between smart buildings is a fundamental element for the scalability of smart cities, according to a principle called by Beevor [32] as Domino Effect. From this perspective, intelligent buildings with common objectives, for example, improving security, when interacting create a small intelligent environment. The benefits generated by this intelligent environment enhance the association of other smart buildings, expanding the range of interconnection solutions and the awareness of the parties involved, creating an intelligent community that can expand and/or connect to other intelligent communities and, thus, successively. This type of interaction is highly dependent on the city's intelligent infrastructure, especially ICT and smart grids.

In addition to the interaction between "individual" buildings, another situation is that involving a collective of formally related buildings, such as condominiums or university campuses, in which internal networks connect the building systems to a single BAS, or connect the BAS of each building, to optimize the functioning of building systems in an integrated manner.

However, in both cases, the connection to the city's smart infrastructure is essential. For example, if we consider electricity consumption, smart buildings can individually manage their consumption based on information received from smart grids, while collectively, from the interaction between buildings, network stabilizing "micro-networks" can be created primary sources, compensating for fluctuations in supply and reducing overall energy demand [34].

In this context of integration, ICT has played a key role. Rawte [23] summarizes the enabling role of ICT (Figure 1), considering them as a key element for Smart Buildings and for having a sustainable built environment, by enabling the aggregation of these buildings in neighborhoods, campuses, districts, cities, and countries. In addition to ICT, Schuster [35] adds smart grids to create a more suitable environment for the smart user (Figure 2). Smart grids have received a lot of attention from researchers, mainly because the ability of cities to meet energy demand is a major problem for smart cities [36], which is intrinsically related to the energy performance of buildings.

The evolution of this integration environment has demanded the development and improvement of technologies, tools, and methods based on integrated, transparent, and comprehensive approaches [37], such as, for example, those that improve the ability to access and transfer information between city domains and buildings, mainly considering the availability, confidentiality, and data integrity. In addition, artificial intelligence technologies and the increased processing and storage capacity of computer systems contribute to the expansion of the systems' ability to interact and meet stakeholder expectations.

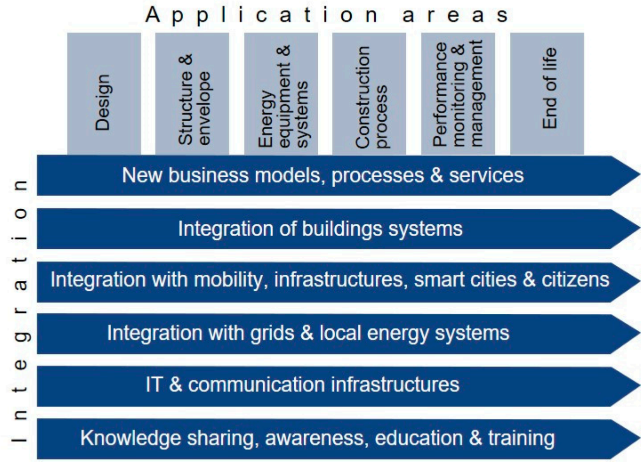

Figure 1. Summary of the enabling role of information communication technologies (ICT) [23].

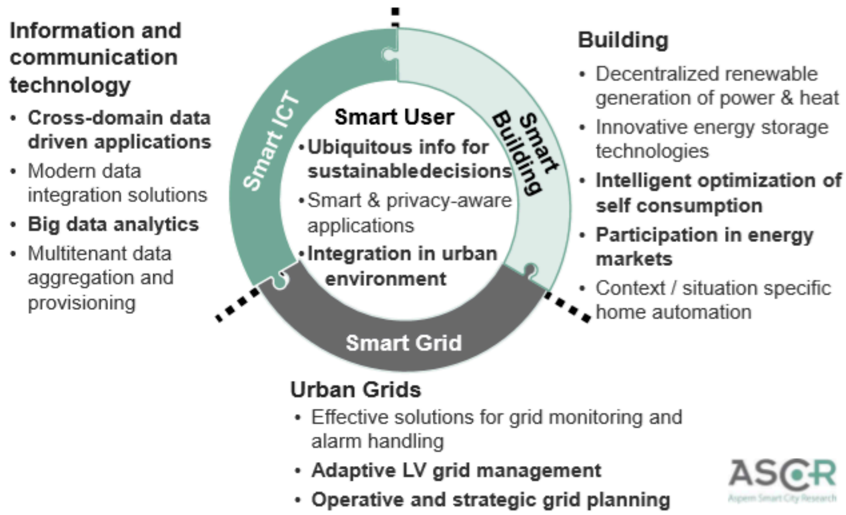

Figure 2. The fundamentals of future Smart Cities, [35].

Regarding the second field of study (focus on the concepts and characteristics of smart buildings), the literature highlights three main branches of study on smart buildings: one focuses on understanding and formulating concepts [10–12,15]; a second addresses technology and automation [14,38]; and a third branch deals with the identification and understanding of the drivers that can enhance building's intelligence [10].

As for the first branch, bibliographic research showed that the concept of the smart building has expanded in the last decades, mainly by incorporating resources that both the real estate market and the society wish. This evolution is noticeable and starts with the concern with the use of technology in buildings, then focuses on user satisfaction, and later adds responsibility for the environment [10]. When the first concepts about smart buildings appeared, around the 1980s, automation, light, and telecommunications were the main actors [11]. The integration of systems to manage resources and flexibility were inserted in the concept's formulation [12], together with the need for energy-saving [10].

The concept of the smart building has also evolved through the incorporation of sustainability aspects [3], mainly regarding the improvement of its performance and interaction with the environment. The smart building also embodies the concept of "sustainable" by interacting with the city in a balanced way, especially concerning infrastructure, information, and communication technologies (ICT), smart technologies, and energy saving.

Over time, other definitions emerged, as new features were incorporated into buildings. For Belani et al. [39], a smart building is the combination of design, materials, systems, and technologies that offer users an interactive, flexible, productive, economic, integrated, and dynamic environment. Batov [13] understands the term primarily through the benefits provided, such as comfort, energy and time saving, security, health, assistive domotics, and embedded systems. Howell et al. [40] emphasize intelligence parameters used to reduce impacts on the environment, and De Groote et al. [41] and Akadiri et al. [42] call attention to the need for a more efficient and decentralized system, based on renewable energy and focused on the consumer. Therefore, although there is not a widely accepted concept, smart buildings are generally understood by their purpose and the resources they offer.

Thus, the smart building has several interconnected technology systems that work together and adjust to the needs, with integrated resource management [12], which provides benefits to the user [11,43], the owner [38,44], and the environment [10]. Users benefit from having a place that suits their needs for comfort, health, security, and well-being; owners benefit from having an estate of higher commercial value, most cost-effective, and better operational performance; the environment benefits from reduced waste, emissions, and energy and water consumption.

While in a common building these systems are installed and operate independently, in smart buildings they are planned and coordinated together, in a single consolidated project [12]. In smart buildings, systems have emerged or gained new attributes and functionalities, mainly from the needs and demands of users and owners, and from the society's request for more sustainable solutions. These needs and demands generate motivating and driving forces, which in this article we call drivers.

Regarding the second branch—focus on technology and automation—the literature mainly addresses building automation and the use of ICT [4,11,14]. Recent studies have also explored emerging technologies [11,45–47].

Automation was one of the first features incorporated into smart buildings, enabling the centralization, monitoring, and control of several services such as heating, ventilation and air conditioning (HVAC), elevators, access control, closed-circuit television (CCTV), light, water, and power systems, in a shared network that can be automatically managed and remotely observed by internet [47], besides providing a comfortable working environment for users [39]. Like automation, technology has kept pace with the evolution of smart buildings. The incorporation of new technologies such as ICT was significant progress, although it also increased the risks related to resilience and cyber security arising from the merge of the building systems with computer technologies [48,49]. The incorporation of more recent technologies, such as the Internet of Things (IoT), has also added value to smart buildings [45,48].

The third branch focuses on identifying and understanding drivers with the potential to boost building intelligence and has received fewer contributions over time. Smith [50] was the only author found that presents the term "driver" in a comprehensive way, by considering that drivers add value to the building, which typically occurs through the inclusion of new services, or the enhancement of existing ones, with the intensive use of technology to meet the needs and expectations of stakeholders. Among the drivers, the most mentioned in the searched literature are those related to the improvement of building performance [10], and the increased convergence between the results of building operation and the principles of sustainability [15,51].

Drivers, or their expected behavior, are presented in relation to topics such as technology, integration, and flexibility, among others, and always with the word "smart", which comprises a set of factors that explain and justify the performance of the buildings' systems in certain contexts [10]. As in the literature on smart cities, drivers such as sustainability, energy, security, health and technology [5] are also present in smart buildings, addressing both common features and smart building's specific attributes. Examples of particular drivers are those that emphasize longevity, energy and efficiency [1,10,42,52]; system integration regarding the improvement of building's operational performance and collaborative work [1,15,38,53]; interaction and flexibility [40]; security, comfort and health [54]; and the use of advanced systems of building technology [12].

From the bibliographic search, we identified attributes regarding the relationship between drivers and building systems and grouped the drivers according to the main beneficiaries, shown in Figure 3.

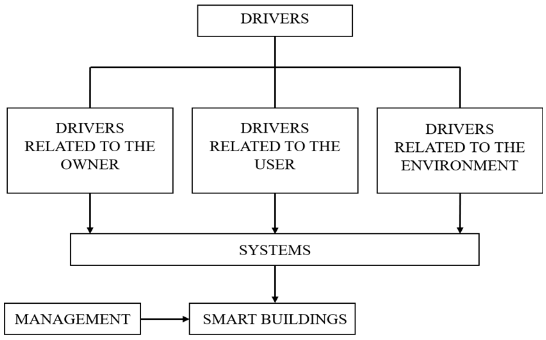

Figure 3. Brief flowchart of drivers and their relationships.

The drivers and systems' relationships are dynamic. Thus, bibliographic search also showed that, over time, new drivers emerged due to new needs and demands [10], enhancing the appearance of new systems, or modifications in existing ones.

3. Materials and Methods

This study had three main objectives: the first was to investigate the main drivers that enhance building's intelligence, by ranking them according to the main beneficiaries; the second was to explore the main systems present in these buildings, and the third was to search the relationship between drivers and systems. To achieve these goals, we used a three-step approach: bibliographic search, identification of the main drivers and systems of the smart building, and detection of the relationships between drivers and systems.

3.1. Bibliographic Search

We did a comprehensive and detailed bibliographic search in the Web of Science, Scopus and SciELO databases, and on the websites of the leading scientific journals. We also adopted the strategy of searching the references of articles and books that we had read about the theme. We took into account the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which aims to improve the outcome of systematic reviews and meta-analyses. The four phases of the PRISMA flowchart were used to summarize the results of the literature search, considering: (i) the number of articles identified; (ii) included articles; (iii) excluded articles; (iv) the reason for articles' removal. The literature search had four main stages (Figure 4):

1. Search, in the last 10 years, by using the following keywords: "smart building" (989 records) and "intelligent building" (503 records), totaling 1492 registers. Sixty-nine articles were also often cited in these papers' references, regardless of date.
2. Quick reading of titles and keywords, identifying which articles or dissertations contained the definition and structure of the smart building, from the perspective adopted in this paper, and excluding the others. Some articles were repeated throughout the search and were also removed, thus remaining 1146 records.
3. From these results, we read the abstracts to identify which ones were relevant to the research scope. A hundred and seventeen articles were entirely read, to seek mainly the basic definitions of a smart building, or suggested approaches on drivers. However, 23 of these articles were not included in our search, because they did not contribute to advance knowledge on the subject.
4. In the end, we got a total of 76 relevant articles that formed the basis for this paper.

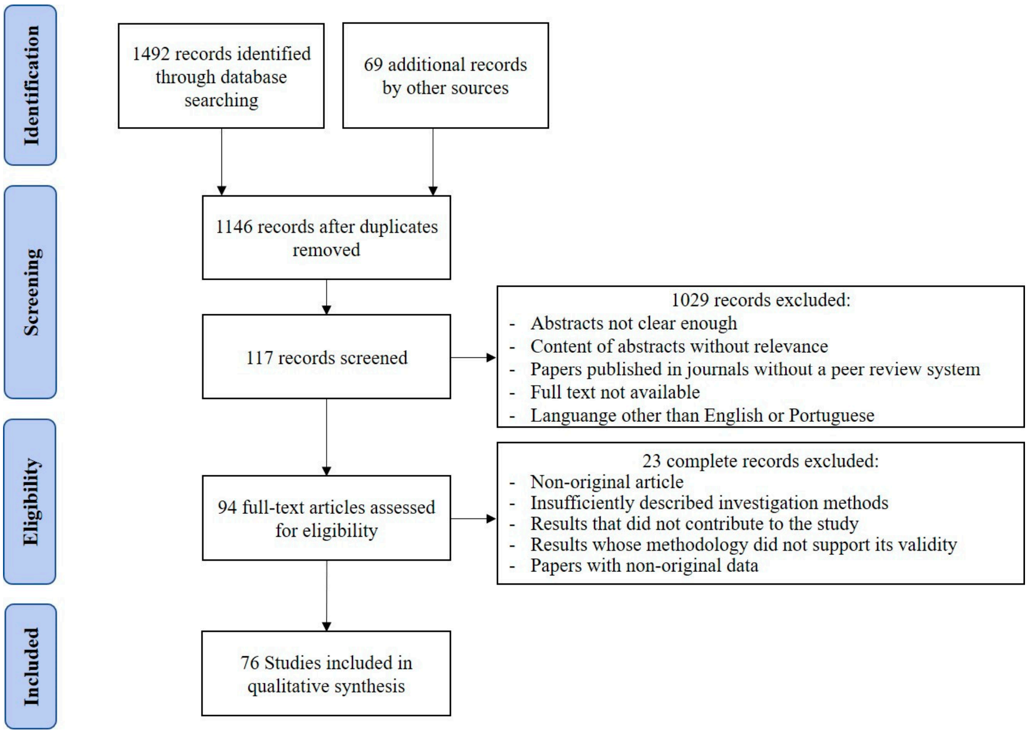

Figure 4. Bibliographic search flowchart using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method.

3.2. Identification of the Main Drivers and Systems of Smart Buildings

The reflective and interpretative reading of the articles selected in the bibliographic search served as a basis for the identification of potential drivers for smart buildings. To identify the main developments that could provide a solid theoretical basis, we analyzed the perspectives and plurality of approaches, sorted the information, correlating the main concepts and available knowledge, and finally identified a set of potential drivers.

We grouped these drivers into three categories of beneficiaries; to correlate them with the definition adopted-user, owner, and environment - without distinguishing priorities since they can be subjective. To consider a potential driver of great relevance to increase buildings' intelligence, the inclusion criterion was that more than one paper should describe it, and they would not refer to each other. As a result, we got a list of 11 drivers. Similarly, we identified eight systems as relevant.

3.3. Identification of the Relationships between Drivers and Systems

The identification of these relationships was based on the authors' view about the searched papers, and out of the experience. In several articles, the relationships were not explicitly reported, and their identification was based according to our interpretation. Given that all drivers related to all systems, to a greater or lesser extent, at this stage we identified the relationships with the greatest potential to affect a particular system.

4. Results and Discussion

As a result of bibliographic research, we observed that drivers have emerged and evolved as society demands changed. Thus, over time, they addressed the improvement of sustainability, well-being, and the efficiency of systems, among others. The answers to these quests have provided the enhancement of buildings' performance, adding value to real estate and better cost-benefit, thus increasing the demand for this type of buildings [39,55–57].

We also noticed that buildings' systems, enhanced by drivers, were evolving and incorporating technological solutions. Hence, mechanisms such as management of consumption and emission, information and communication management, and increased interoperability among systems were emerging or improving [10,11,58,59]. Smart buildings are part of the transition process of cities to become smarter and more sustainable. Thus, holistic approaches are necessary today and in the future [60]. The articles that support our results, to some degree, address smart buildings through a systemic and integrative approach, with a strong technological bias. As a consequence, the set of drivers and systems identified, as well as the relationships between them, were affected by this type of approach. By using the chosen methodology we identified 11 drivers, shown in Table 1, and eight systems, presented in Table 2.

Table 1. Main drivers of smart buildings.

Drivers	Papers
D1—Technology: Enhances the use of existing techniques and knowledge to improve or facilitate the operations demanded by building systems.	[10–12,39,45,47,48,52,57,61–65]
D2—Integration: Enhances the aggregation and compatibility of systems to improve their capacity of interaction, to increase the interoperability between processes, products, and people.	[1,11–15,38–40,45,53,54,57,62–68]
D3—Flexibility: Enhances the possibility of adjustments of environments and facilities, so that the building accepts changes over time, in response to future challenges regarding users' needs.	[1,11,14,39,40,57,66,67,69]
D4—Longevity: Enhances the extension of the building's useful life and keeps its value, through systematic updating of technologies and maintenance, and incorporation of new features to the building's systems, preventing the property from becoming outdated.	[1,10,40,42,48]
D5—Health: Enhances the use of architectural and technological solutions that contribute to the improvement or conservation of users' health, adding to physical and mental well-being.	[1,11–14,39,42,54,59,61,63,64,70]
D6—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.	[10,11,13,14,39,42,44,45,51,52,54,59,63,65,69,70]
D7—Satisfaction: Enhances the feeling of pleasure or disappointment, by comparing the expected performance of the building with users' expectations.	[10,11,22,45,51,59,69]
D8—Security: Enhances the mechanisms for the protection of the building and users, to prevent risks and limit their consequences.	[11–15,22,40,42,44,48,49,52,54,61,62,64,65,69,70]
D9—Ecology: Enhances building's integration with the environment, through architectural and technological solutions that allow the reduction in the use of natural resources, emissions, and waste, aiming to minimize the impacts on nature.	[11,12,14,22,39,40,42,51,52,56,58,63,64,66,67,71]
D10—Energy: Enhances the use of architectural and technological solutions that contribute to the adoption of alternative energies and the rational use of energy by the main sources of consumption in the building.	[1,10–14,22,38,40,42,52–55,58,61,62,64–67,69,70,72]
D11—Efficiency: Improves the performance of the building's systems, helping to reduce the consumption of natural resources.	[11–13,15,38–40,42,44,58,63,65–69,72]

Table 2. Main systems in smart buildings.

Systems	Papers
S1—Heating, ventilation, and air conditioning system (HVAC): Equipment, infrastructure, and systems for managing temperature, humidity, flow, and quality of air in closed environments.	[12,14,38–40,47,62,63,65,68–70,72]
S2—Light system: Equipment, infrastructure, and systems for managing sources of artificial light, mainly through the presence of sensors and dimming, according to the incidence of natural light.	[12,14,38–40,47,62,63,65,68,69]
S3—Energy system: Equipment, infrastructure, and systems regarding energy transmission, and management of the consumption of all systems, of the demand, and the energy quality.	[12,14,38–40,42,47,63,65,68,69]
S4—Security system: Equipment, infrastructure, and systems for managing services related to personal and asset security, mainly through mechanisms of surveillance and control of access.	[12,38–40,47,62,68,69]
S5—Telecommunications system: Equipment, infrastructure, and systems for managing telecommunications services, mainly those related to telephony, data, and image.	[12,38,39,47,69]
S6—Fire prevention and fighting system: Equipment, infrastructure, and systems for managing mechanisms of detection, alarm, and fire extinction.	[12,39,40,68,69]
S7—Vertical transportation system: Equipment, infrastructure, and systems for managing services related to the improvement of quality and efficiency of people and cargo movement, thus enhancing the well-being of users, without harming the environment.	[39,40,47,68,70]
S8—Hydraulic system: Equipment, infrastructure, and systems for managing services related to personal hygiene, water and gas supply, and rainwater and sewage collection.	[39,40,42,47,68]

When analyzing how smart buildings have been considered over time, it is possible to see that they evolved due to the influence of the context of each on the expectations and needs of owners and users, and on issues related to the environment. These different contexts, in addition to encouraging the emergence of new drivers, also caused the existing ones to evolve. Concerning to the set of systems, evolution concerns the maintenance of the capacity of smart buildings to deliver the results that are influenced by these different contexts. Concerning the set of drivers, it concerns the maintenance of the efficiency with which can influence the set of systems to have the necessary characteristics to make these deliveries. Thus, the interests of owners/investors and users, as well as issues related to the environment must be understood from the current context.

The owner has considered smart buildings mainly from the perspective of return on investment and improving market competitiveness, which is made possible mainly by improving the cost-benefit ratio. Although there may be cost savings, for example, due to improvements in the construction process, it is the benefits generated by smart buildings that improve ROI and competitiveness, making the smart buildings more attractive. However, it is essential to emphasize that the cost-benefit ratio must be considered throughout the life cycle of the building. Smart buildings usually have a higher initial cost [73], mainly due to the technology that is incorporated. However, it is the same technology that makes it possible to reduce costs throughout the life cycle, mainly due to the improvement of energy efficiency, the reduction of water consumption, and the optimization of infrastructure maintenance actions. The integration of systems increasing interoperability between processes, products, and people, the flexibility to adapt and adjust environments and installations, and longevity from the systematic updating of technologies to the maintenance and incorporation of new functionalities to the systems also contribute to the reduction costs Another important point that must be considered is the improvement of the project's attractiveness due to its greater capacity to meet the demands of users.

The calculation of the cost-benefit ratio is complex, and its correct interpretation is fundamental for the growth of the smart buildings segment. Considering what was exposed in the previous paragraph, in summary, for the decision-making process of the owner, the main results that must be considered are those related to two questions.

The first concerns which solutions to improve the intelligence of the systems should be made to increase the attractiveness of the enterprise due to the improvement in meeting the demands of users for more intelligent and sustainable services? The improvement of attractiveness helps to anticipate revenue by reducing the time needed to start the project or start its commercialization, which also increases the capacity to anticipate the payment of financed amounts, reducing expenses with fees charged by agent's financial resources. More satisfied users contribute to the company's visibility. In sustainability reports such as those of the Global Reporting Initiative, this variable is essential. However, how to measure the degree to which a given solution contributes to improving its attractiveness? One solution may be to evaluate the results of opinion polls and previous ventures.

The second concerns how many solutions to improve the increase in systems intelligence can be made? The answer is intrinsically related to the Reduction of operating costs relationship throughout the life cycle provided by the implementation of new technologies × cost of incorporating new technologies. Although values equal to or greater than one justify the choice for this type of solution, the investment capacity of the owner also interferes in this analysis. For amounts of less than 1, the result of the previous question is fundamental.

Users' interest in smart buildings is mainly due to their better ability to meet their expectations and needs in terms of comfort, health, safety, and satisfaction [11,51], both in locations work and in their homes. The development of new technologies facilitating entertainment and remote access to services has meant that the population spends most of their time inside buildings [74], which justifies that drivers relate mainly to the interaction of users with the internal environment.

By enabling users to have more control over environments, actions such as regulating natural and artificial lighting, temperature, humidity, and air quality increase the feeling of comfort. The intelligent management of data obtained from sensors and cameras enables the integration of fire, security, intrusion, and access control systems that continuously guarantee the safety of users. Equipment such as those that purify the air, control the entry of fresh air, and monitor the CO_2 level, help to maintain the user's health. All of these facilities collaborate to meet users' expectations.

Finally, the growing demands of society towards environmental sustainability, mainly from decreasing the consumption of natural resources, emissions, and waste [14,51,63], contribute to the emergence of sustainable buildings. In this category are the driver ecology, which is related to the reduction of consumption of natural resources, emissions, and waste provided by technological and architectural solutions; the energy driver, related to the improvement of energy efficiency, use of renewable energy, and energy cogeneration; the efficiency driver, related to the reduction of environmental impacts from the improvement of the performance of building systems.

In this context, considering the changes that drivers can foster, we grouped them into three categories of beneficiaries (Figure 5). Since most drivers provide benefits to more than one category, we placed them in the category to which they are most related.

Among the sustainability-related issues and climate changes, a topic that has attracted the interest of researchers is human resilience towards climate disruption, which has increased the risk of socio-natural disaster. An important focus is to build more effective mechanisms to protect society and increase well-being [60,75]. Thus, the performance of buildings is essential for increasing cities' resilience. The identified set of drivers helps to make buildings more resilient, by reducing their impacts, enhancing their adjustments to the environment, and improving the quality of life of the users, especially those related to health and wellness.

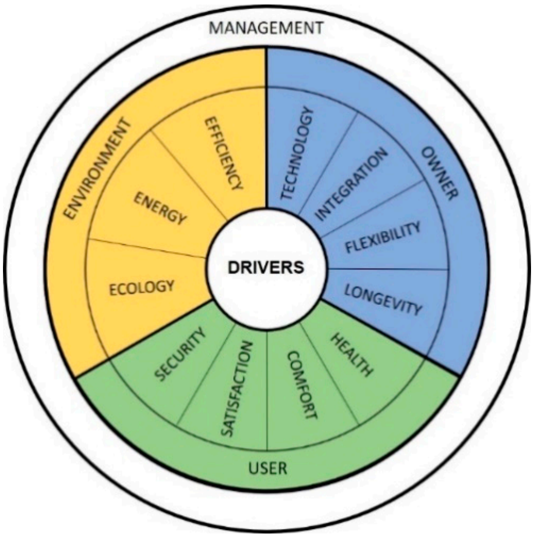

Figure 5. Smart buildings' drivers grouped by category.

Generally, all drivers are related to all systems, to a greater or lesser extent. However, when considering the category of beneficiaries, there are relationships with a higher potential to influence a particular system. Table 3 and Figure 6 summarize these relationships, both based on our view of the searched articles and our experience.

Table 3. Relationships between drivers and systems, based on our view of the searched articles.

Drivers	Systems	Papers
Health	HVAC, Light, Fire prevention and fighting, Hydraulic	[11–15,39,42,70]
Comfort	HVAC, Light, Telecommunications, Vertical transportation, Hydraulic	[10–15,39,42,52,63,69]
Satisfaction	HVAC, Light, Telecommunications, Vertical transportation	[10,13,15,38,42,69]
Security	HVAC, Light, Energy, Security, Telecommunications, Fire prevention and fighting, Vertical transportation, Hydraulic	[11–14,38,52,69]
Technology	HVAC, Light, Energy, Security, Telecommunications, Fire prevention and fighting, Vertical transportation, Hydraulic	[10–12,15,22,39,52,63,70]
Integration	HVAC, Light, Energy, Security, Telecommunications, Fire prevention and fighting, Vertical transportation, Hydraulic	[10–14,22,38,39,52,63,69]
Flexibility	HVAC, Light, Energy, Security, Telecommunications, Fire prevention and fighting, Vertical transportation, Hydraulic	[10,11,13,14,39,69]
Longevity	HVAC, Light, Energy, Security, Telecommunications, Fire prevention and fighting, Vertical transportation, Hydraulic	[10,42]
Ecology	HVAC, Light, Energy, Hydraulic	[11,14,39,42]
Energy	HVAC, Light, Energy	[10–15,38,52,63,69,72]
Efficiency	HVAC, Light, Energy, Security, Telecommunications, Fire prevention and fighting, Vertical transportation, Hydraulic	[10,11,13,15,38,39,42,69,70]

Systems	HEALTH	COMFORT	SATISFACTION	SECURITY	TECHNOLOGY	INTEGRATION	FLEXIBILITY	LONGEVITY	ECOLOGY	ENERGY	EFFICIENCY
HEATING, VENTILATION AND AIR COND. SYSTEM (HVAC)	•	•	•	•	•	•	•	•	•	•	•
LIGHT SYSTEM	•	•	•	•	•	•	•	•	•	•	•
ENERGY SYSTEM				•	•	•	•	•	•	•	•
SECURITY SYSTEM				•	•	•	•	•			•
TELECOMMUNICATIONS SYSTEM		•	•	•	•	•	•	•			•
FIRE PREVENTION AND FIGHTING SYSTEM	•			•	•	•	•	•			•
VERTICAL TRANSPORTATION SYSTEM		•	•	•	•	•	•	•		•	•
HYDRAULIC SYSTEM	•	•		•	•	•	•	•	•		•

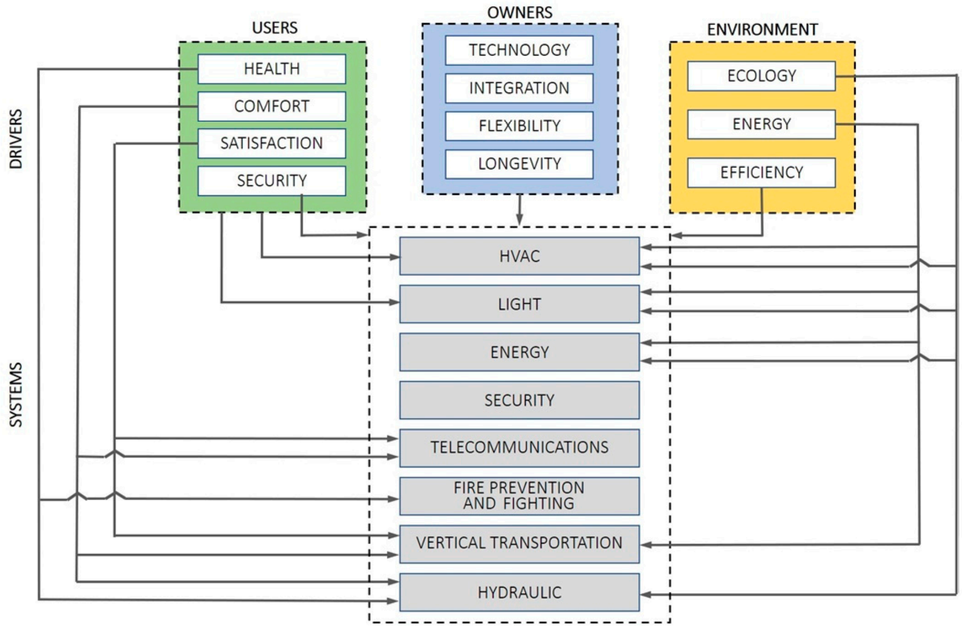

Figure 6. Relationships between drivers and systems.

However, the relationship between drivers and systems has not been appropriately explored yet. Some of the relationships in Figure 6 are hard to notice immediately, such as those between the drivers' security, health and efficiency, and some of the systems. From the perspective of the users' category, the driver "security" relates to all systems, which was expected. By enhancing the building's and users' protection mechanisms, it interferes with all systems. The "health" driver relates to the HVAC system, mainly because it is responsible for air quality, reducing the chances of contamination, in addition to keeping the proper temperature; to the light system, because it can affect vision when light is out of the standard required by the norm; to the prevention and firefighting system because it prevents damage to the user (burns, smoke inhalation, etc.); to the hydraulic system, especially due to the facilities for personal hygiene.

The "comfort" driver relates to the HVAC system because it is responsible for airflow and temperature; to the light system, because it regulates the positioning and intensity of the lighting points; to the telecommunications system, especially regarding the sources of information, entertainment, and internet access; to the vertical transportation system, by reducing efforts and increasing accessibility; and to the hydraulic system, mainly due to the degree of privacy of the facilities, type and convenience of the equipment, and the availability of products for personal hygiene.

Except for the hydraulic system, the driver "satisfaction" interacts with the same systems as the driver "comfort", but from a different perspective, since the focus is on meeting expectations, on creating a feeling of pleasure or disappointment. As an example, a new, refrigerated elevator that is unable to meet transport demands provides comfort to users but makes them unsatisfied with the delay in the service.

The four owner-drivers relate to all systems, which is understandable since all must have advanced technology for continuous and improved operation, maintenance, and optimization; they must have integrated services and results to improve performance and deliver better results; they must have flexibility so that spaces, processes, and infrastructure can adjust to the new demands and needs of users and owners; and they must aim to achieve longevity, from a continuous process of maintenance and improvement of infrastructure, and from operational and administrative actions of the systems.

As for the environment, except for the hydraulic system and the vertical system, the drivers "energy" and "ecology" relate to the same systems, but under different perspectives. The energy driver relates to systems that somehow interfere with the building's energy efficiency, aiming at its rational use, including the vertical system. Yet, the ecology driver is more related to reducing impacts on nature, caused by the excessive use of natural resources, emissions, and waste. With regard to the hydraulic system, the ecology driver relates to it mainly because of water waste and the emission of pollutants. The efficiency driver, on the other hand, relates to all systems, especially regarding the yield of the facilities, from the improvement of the output of the building's systems. Table 4 presents several examples of the relationships between drivers and systems.

Table 4. Examples of the relationships between drivers and systems.

Drivers	Systems	Buildings
Technology	HVAC, Energy, Light, Security, Telecommunications,	PTK1 (Petah Tikva, Israel): sensors control and monitor services such as lighting, temperature, and ventilation. 50 3D cameras are located in the lobby.
	Light	Glumac (Shanghai, China): Wireless daylight sensors communicate and automatically adjust the lighting fixtures in the room, increasing or decreasing light intensity, while maintaining a consistent level.
	Energy	Hindmarsh Shire Council Corporate Centre (Victoria, Australia): Has an electronic control and monitoring system to verify the effectiveness of the measures adopted to reduce energy consumption.
	Security	NASA Sustainability Base (Moffett Field, Calif.): features intelligent control technology inspired by the agency's aircraft safety program.
	Telecommunications	Environmental Systems headquarters (Wisconsin, USA): monitors located in the lobby show real-time performance information.
	Vertical Transportation	Jeddah Tower (Saudi Arabia): Scheduled for opening in 2022, 10% of the elevators will have a speed of 60 km/h, since from the ground floor to the top, it is 1 km high.
	Hydraulic	Burj Khalifa (Dubai, United Arab Emirates), Capital Tower (Singapore): It uses the humidity of the air, with the capture of this moisture and condensation using a cooling system to transform it into water.
Integration	Light, HVAC, energy, telecommunications, security, Fire Prevention	RBC Waterpark Place (Toronto, Canada): have several devices integrated through an Ethernet connection, from those related to lighting and environmental controls to digital signage, safety, and measurement.
	Light, HVAC, Energy	The Edge (Amsterdam, Netherlands): Heating, cooling, fresh air, and lighting are fully integrated into the Internet of Things.
	Energy, HVAC, Security, Fire Prevention	Brisbane Skytower building (Queensland, Australia): has a building automation system responsible for the integration of several building systems.
	Security, HVAC, Energy	CNC Business Center (Brasilia, Brazil): The access card reading on one of the building's turnstiles is integrated with the air conditioning system, which automatically turns on the cooling of your workroom.
	HVAC, Hydraulic, Energy, Light, Fire Prevention	The Bullitt Center (Seattle, Washington): The direct digital control of this building is triggered by a system that monitors, records, and controls several mechanical systems.

Table 4. *Cont.*

Drivers	Systems	Buildings
Flexibility	Light, HVAC	The Edge: mobile application makes the building more flexible to suit users' preferences about lighting and HVAC.
	Light, telecommunications	RBC Waterpark Place, The Edge: the reconfiguration of lighting zones and the versatility in the use of energy provide greater flexibility in reconfiguring spaces.
	Energy	NASA Sustainability Base has an intelligent and adaptable energy management system due to the various sensors that report data instantly.
	Telecommunications	Tottenham Hotspur Stadium (London, United Kingdom): automated hardware systems allow the floor to be changed in 25 min. Cinerama Building (Sao Paulo, Brazil): the work environments were designed to receive any type of configuration. RBC Waterpark Place: It is also possible to optimize conference rooms in which the environment assumes various seating configurations based on automated calculations.
	Vertical transportation	Capital Tower: users can inform various tasks according to their needs (for example, booking an elevator to reach their floor at a specific time).
Longevity	Telecommunications, security, HVAC, Energy,	Brisbane Skytower building: It will have a passive optical LAN (POL) solution for enterprise applications and is said to be prepared for the next wave of technological upgrades, as buildings are increasingly adopting control, energy management equipment, sensing, and surveillance, powered by network requirements and supported by the growing use of IoT, cloud computing and Big Data.
	HVAC	Burj Khalifa: Intelligent algorithms identify and analyze suspicious data that indicate the need for corrective and maintenance actions on the mechanical components of the HVAC system.
Health	HVAC	Bullitt Center, Capital Tower, RBC Waterpark Place, Taipei 101 (Taipei, Taiwan): carbon dioxide monitoring sensors identify room occupancy and estimate fresh air intake levels, ensuring that occupation the air quality is adequate. Glumac: five air purification systems and a planted green wall reduce pollution.
	HVAC, Fire Prevention	Environmental Systems headquarters: Health damage caused by fires, such as burns and smoke inhalation, is prevented through the automated management of the system.
	Light	RBC Waterpark Place: individualized lighting management contributes to visual health.
Comfort	Light, HVAC	Al-Bahar Towers (Abu Dhabi, United Arab Emirates): The facades with the automatic solar regulation system. The Edge: an application knows the preferences for light and temperature of people who work in the building and improves the environment according to those preferences.
	Light	Ventura Corporate Towers (Rio de Janeiro, Brazil), Duke Energy Center (Charlotte, USA): the automatic lighting regulation according to the intensity of natural light that reaches the environments. New York Times building (New York, USA): It has computerized blinds that regulate the flow of light and heat to the interior, increasing thermal comfort. RBC Waterpark Place: allows the individual control of each light.
	Vertical transportation	Burj Khalifa, Capital Tower, RBC Waterpark place, Taipei 101, Yokohama Landmark Tower (Yokohama, Japan): Elevator availability and speed management.
	Hydraulic	The Crystal Building (London, United Kingdom): has a solar thermal hot water system.
	Telecommunications	Bill Gates' Home (Washington): It has an underwater sound system to listen to your favorite music while swimming in the pool, hidden speakers on the walls to allow music to go from room to room, and several computer screens throughout the house with artwork that can be changed any time.

Table 4. *Cont.*

Drivers	Systems	Buildings
Security	HVAC	Burj Khalifa: It has pressurized refuge areas to minimize the migration of smoke to the interior of the district, in case of fires.
	Light, security, Telecommunication	The Edge: has luminaries equipped with an infrared sensor and motion and temperature detection that are managed by BAS. It also uses a small robot that, through automatic navigation or by remote control. At the entrance to the employee's garage, a camera takes a photo of the vehicle's license plate so that BAS can combine it with the employee registration and whether or not to grant access.
	Energy, Security, Fire Prevention, vertical transportation	Burj Khalifa: certain elevators have exclusive energy generators and are managed in such a way as to allow controlled evacuation during fire or safety events.
	Telecommunication, Security	Duke Energy Center, RBC Waterpark Place: have surveillance camera management and monitoring and automatic port blocking, as well as firewalls for data protection.
	Security	Environmental Systems headquarters: BAS monitors fire extinguishers to ensure that their installation remains correct, that they maintain adequate pressure, and are free of obstructions.
	Security, hydraulic	Sao Paulo Stock Exchange (Sao Paulo, Brazil): has sensors that enable BAS to automatically activate the security center, as, for example, in the case where the hydraulic records are handled without permission.
	Energy, security	United Nations Headquarters building (São Paulo, Brazil): has digitally controlled energy generators for power supply in the event of emergencies, which are automatically activated by BAS, keeping all safety circuits active.
	Fire Prevention, vertical transportation	Duke Energy Center, RBC Waterpark Place: Equipped with a fire alarm system that automatically alerts the Security Control Center and the elevators serving the alarm locations are retrieved to the lobby levels.
Ecology	HVAC, Energy	The Edge: Aquifer thermal energy storage system provides all the energy needed for heating and cooling, and solar panels that provide electricity.
	Energy	PTK1, Headquarters of Siemens (Munich), Glumac: The building's energy is supplied by renewable sources. Leadenhall Building (London, United Kingdom): use of reactive solar blinds, which transform solar energy into electricity.
	Hydraulic	Capital Tower: Uses highly purified recycled water. The Edge, Intel SRR3 (Bengaluru, India), The Crystal Building, Duke Energy Center: Rainwater reuse.
Energy	Energy, HVAC, Light	The Crystal Building: The Energy Management System controls all electrical and mechanical systems in the building, saving energy.
	Energy, HVAC	New York Times Building: It has an electric power generation system that supplies 40% of the building's energy with the residual heat used for heating and cooling.
	Light	The Edge: The LED lighting system is powered by Ethernet integrated with sensors allowing to adjust energy usage automatically.
Efficiency	HVAC, Light, Energy, Security	PTK1: algorithms that use Artificial Intelligence analyze data in real-time to make decisions. The Edge: Occupancy, movement, lighting levels, humidity, and temperature are measured continuously to maximize efficiency
	Vertical Transportation, Energy	Capital Tower, RBC Waterpark Place: fast elevators are managed to trigger the quickest route with the lowest energy consumption.
	Energy, Hydraulic	RBC Waterpark Place: an electronic system monitors the energy and water usage in the building and determines efficiency levels. PTK1: 40% more energy efficient than a typical office building and water systems use 75% less water.
	Telecommunications	The Edge: hand dryers in the bathroom have built-in sensors that capture data on usage, alerting facility staff when cleaning is needed.

The cases presented are an example of the benefits provided by the drivers to the smart building systems that increase the growth potential of this segment in the real estate market. Intelligent systems, able to act automatically and/or report information on constant monitoring of building performance, as well as more integrated and adaptable spaces and infrastructure over time, enable the increase of the useful life of buildings and reduce operational costs related to productivity and maintenance, making them more attractive to owners and investors. In addition, the scenario of accelerated development of new technologies with the potential to strengthen the relationship between users and services offered by buildings, strategically align the changing patterns of rental and use, making smart buildings an agile and powerful asset class [76].

Smart buildings also provide strategic advantages for companies, by increasing the well-being and health of employees, improving the interaction and sharing of information and ideas, and the ability of employees to interact and control the work environment.

Another important advantage is that buildings with smarter systems enable more sustainable practices that are essential to address issues related to improving the sustainability of cities, such as reducing consumption and emissions. In this scenario, it is to be expected that smart buildings will be increasingly present in the sustainability agendas of those responsible for public policies and city management.

Another point that must be considered is that BAS in terms of hardware and software has also evolved. In large buildings, thousands of sensors produce gigabits of information, which tend to grow as new technologies and stakeholder demands emerge, which means that designers increasingly consider BAS's flexibility and capacity to support these developments, including the expansion of data processing and artificial intelligence routines.

Finally, it should be emphasized that an intelligently built environment does more than encourage new smart ventures; it also encourages existing buildings to become smarter and enables citizens and businesses to be empowered by controlling their system [6]. In this context, the situation closest to the ideal is that in which new ventures, or the transformation of existing ones, occur in line with the plans and actions of municipal administrations to improve the intelligence of cities. However, historically, buildings and infrastructure have not been planned considering the integration between them [28].

We hope that property owners/investors will be increasingly attracted by the benefits arising from the continuous evolution of smart building systems generated by drivers and that those responsible for public policies and city management will increasingly become aware that cities with smart infrastructure connected to smart buildings are fundamental for improving the efficiency and effectiveness of meeting citizens' expectations and needs, to increase the growth of the smart buildings sector.

5. Conclusions

Smart buildings are part of the transition process of cities towards becoming smarter and more sustainable. Hence, the concept of a smart building has incorporated changes and extensions over time; to deal with the challenges posed by the way buildings are appropriated and perceived by society. Currently, the concept of a smart building is related to several areas of knowledge, where the emergence and use of new technologies has been relevant. As technology advances, new products and services are developed and desired by the population, thus increasing the demand for buildings that can incorporate them into the routine of their users, facilitating their daily life and improving its quality, together with aspects related to sustainability.

From the bibliographic research, it was possible to determine that drivers which foster buildings to be smarter emerged and evolved, as the demands of society changed. Powered by drivers, building systems also evolved and incorporated new technological solutions.

Based on the methodology adopted, we identified 11 drivers and eight systems, and from the analysis of the main beneficiaries, drivers were grouped into three categories: users, which mainly relate to health, well-being, and meeting expectations; owners, which especially relate to the improvement of the cost-benefit ratio; and the environment, which mainly relate to reducing consumption and emissions, and improving the interaction of the building with the environment.

The main contributions of this article address the key players involved in the process of evolution of smart buildings: the owners/investors and the users. Thus, identifying the main drivers and systems present in these buildings, as well as the relationships between them and the main beneficiaries, collaborates for the decision-making process of the owner about the characteristics and functionalities of the construction systems to be adopted, according to its objectives, mainly those related to the return on investment (ROI) and improving the competitiveness of the market. It also improves the building's sustainability, mainly by reducing the consumption of natural resources, emissions, and residues, and provides more inputs to municipal managers, so that public policies and urban legislation may benefit the society by meeting its expectations.

This research has the typical limitation of studies that are based on a literature review. Although we carried out an extensive and detailed bibliographic search, there is always a risk that an important article has not been included.

The articles that supported the results, to a greater or lesser extent, addressed smart buildings through a holistic, systemic, integrative approach, with a strong technological bias. As a consequence, the set of drivers and systems identified, as well as the relationships between them, were affected by this type of approach. We noticed how complex is the understanding of intelligence associated with a building, and which mechanisms are mainly used to express this intelligence. As a suggestion for future work, the main objective should be to get opinions from experts to confirm and rank the drivers found.

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