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BARRIERS AND CHALLENGES OF SMART BUILDINGS PROJECTS IN THE CONTEXT OF CONSTRUCTION 4.0

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Abstract

The development and use of technologies, tools, and methods based on integrated and comprehensive approaches have been fundamental for integrating smart buildings with the urban environment and for a smarter and more sustainable built environment. In an Industry 4.0 context, barriers associated with innovation and technology that hamper smart building projects still coexist with structural barriers. In this work, we identify the main barriers to developing smart building projects based on extensive and detailed bibliographic research and on the view of professionals with experience in the subject. The results showed that 23 barriers identified in the literature were considered important by the survey respondents, of which five were considered the most important.

Keywords

Smart Buildings, Sustainable Buildings, Barriers, Challenges, Built Environment, Construction 4.0.

Introduction

Smart buildings have been the object of study of several works over the last decades. The singularities identified in smart buildings show that the project team can face barriers and challenges when designing, building, and operating.

The first mentions of the term Smart buildings were made in the 1980s; however, there is no consensus on a definition that encompasses all the characteristics necessary for a building to be considered smart (Omar, 2018). Allied to this factor, the growing development of technologies (Wong et al., 2005) makes it possible to incorporate a wide range of systems into the building (Pašek & Sojková, 2018), which can make them more expensive (Qolomany et al., 2019; Wong et al. al, 2005) and more complex management (Yang et al., 2021). In a context of increasing technological development and given the need to incorporate recently developed technologies, the identification of barriers and challenges for the development of the smart building project enables greater assertiveness in the expected results of the project.

In this work, we identify the main barriers to developing smart building projects based on extensive and detailed bibliographic research and the view of professionals with experience in the subject.

This paper is structured as follows: Section 2 contextualizes the barriers identified in the literature. Section 3 presents the procedures used to carry out the bibliographic research, identification of barriers, the survey of expert opinions, and the data analysis. Section 4 presents and discusses the research results. Conclusions are provided in Section 5.

Barriers to the Development of Smart Buildings Projects

In the researched literature, we identified the following potential barriers for the development of smart buildings projects (Table 1), which will be contextualized below: lack of consensus on the concept of smart buildings, project's complexity, the need for systems optimization, increased demand for building design changes, the need to plan different construction techniques and sequences, the presence of a large number of systems incorporated into the building, meeting specific user requirements, meeting the needs of smart building owners, contractual specifications, user expectations regarding technologies to be used, insufficient economic resources, higher construction costs, unavailability of sustainable and intelligent materials and equipment, maintenance of intelligent buildings, need to manage large volumes of data, need to control energy management, construction industry structure and organization, time to approval of new technologies within organizations, resistance to change traditional practices, confidence to undertake new and untested technologies, need for specialized personnel, behavioral issues of project team members, and shortage of government policies.

Several studies have been carried out to discuss the conceptualization of smart buildings (Wong & Wang, 2005); however, there is no consensual definition (Omar, 2018; Ghaffarianhoseini et al., 2016; Qolomany et al., 2019) which can directly impact in its design due to the absence of specific and commonly accepted criteria. The absence of specific and consensual criteria about what constitutes an intelligent building can impact the definition of the scope of an intelligent building. Allied to this factor, smart building projects are more complex due to the use of technologies, materials, and construction methods that differ from traditional practices (Ghansah, 2020; Yang et al., 2021), demanding a greater need for training and higher costs. There may also be an increase in the need to change the design due to the characteristics and specifics of smart buildings, including unforeseen circumstances (Ghansah et al., 2021).

Smart building users have specific requirements that must be met. For this, there is a need to match users' expectations with the requirements of the building's control systems (Omar, 2018). Users may also have expectations regarding the technologies to be used: intelligent buildings can produce expectations regarding the well-being, safety, and comfort that will be provided by their systems, which need to be managed (Ghansah et al., 2021). Also, consider meeting the needs of owners of smart buildings, which aim to minimize costs and maximize the return on investment, safety, and comfort of users (Pašek & Sojková, 2018).

The planning of the smart buildings projects can present particularities given the use of technologies, materials, and construction methods different from the traditional ones, identifying the need to plan different techniques and construction sequences (Ghansah et al., 2021). Considering these specifications, sustainable and intelligent materials and equipment can be challenging to obtain, given the singularities to be met by the project (Ghansah et al., 2021).

The construction costs of smart buildings are higher when compared to traditional buildings, especially concerning materials and equipment (Ghansah et al., 2021; Belani et al., 2014). As they have higher costs, economic resources may be insufficient (Ghaffarianhoseini et al., 2016; Ehrenhard et al., 2014). As for the systems present in buildings, there is a need to use a wide range to meet the functions performed by smart buildings (Pašek & Sojková, 2018.) Such systems demand a greater need for optimization to achieve goals such as cost reduction and energy consumption and maximize building performance (Shaikh et al., 2014).

Technologies applied to smart buildings require specific knowledge on the part of project, construction, operation, and maintenance management teams, requiring specialized personnel (Ghaffarianhoseini et al., 2016; Ghansah et al., 2020; Belani et al., 2014), dealing, among other factors, with large volumes of data generated by building systems (Pašek & Sojková, 2018; Marinakis, 2020) and the need to control energy management - the presence of large numbers of systems in smart buildings demands consumption control functions power. (Shaikh, 2014; Ma & Jørgensen, 2018). Behavioral issues of team members can also affect the project. Aspects such as lack of communication and conflicts of interest can impact the design of smart buildings (Ghansah et al., 2021) in addition to resistance to changing traditional practices. The smart building design team may be resistant to technologies, materials, and construction processes different from those traditionally used, and there may be difficulty in understanding the sustainable specifications in the contract details (Ghansah et al., 2021).

The structure and organization of the construction industry make it difficult to produce and incorporate innovations and new technologies (Ghansah et al., 2020; Ghansah et al., 2021). Another factor is the time for approval of technologies within the organization, which may take longer for technologies other than conventional ones (Ghansah et al., 2021). This may be motivated by the confidence necessary to undertake new and untested technologies, which present a higher degree of risk for execution and require training (Belani et al., 2014).

The main challenges of smart building maintenance are maintenance costs and strategy, and occupant behavior (Osunsanmi et al., 2020; Umair, 2021). Government policies can also affect the design of smart buildings due to reduced support from government policies and institutional structures for the development of the sector and Smart technologies (Ghansah, 2021; Belani et al., 2014; Ehrenhard et al., 2014).

Table 1 summarizes the 23 barriers to developing smart building projects and the authors who cited them.

Table 1. Selected barriers

Barrier	Source
Lack of consensus on the concept of smart buildings	Samar et al., 2021; Omar, 2018; Ghaffarianhoseini et al, 2016; Qolomany et al, 2019
Project's complexity	Samar et al., 2021; Ghansah, 2020; Yang et al, 2021
The need for systems optimization	Shaikh et al., 2014
Increased demand for building design changes	Ghansah et al, 2021; Samar et al., 2021;
Need to plan different construction techniques and sequences	Ghansah et al., 2021
Presence of a large number of systems incorporated into the building	Pašek & Sojková, 2018
Meeting specific user requirements	Omar, 2018
Meeting the needs of smart building owners	Pašek & Sojková, 2018.
Contractual specifications	Ghansah et al., 2021
User expectations regarding technologies to be used	Ghansah et al., 2021
Insufficient economic resources	Ghaffarianhoseini et al, 2016; Ehrenhard et al, 2014;
Higher construction costs	Ghansah et al, 2021; Samar et al., 2021; Baghchesaraei, 2016; Zheng et. al, 2016; Belani et al, 2014;
Unavailability of sustainable and intelligent materials and equipment	Ghansah et al., 2021
Maintenance of intelligent buildings	Osunsanmi et al, 2020; Samar et al., 2021; Umair, 2021
Need to manage large volumes of data	Pašek & Sojková, 2018; Marinakis, 2020
Need to control energy management	Shaikh, 2014; Ma & Jørgensen, 2018

Barrier	Source
Construction industry structure and organization	Ghansah et al, 2020; Ghansah et al, 2021;
Time for the approval of new technologies within organizations	Ghansah et al., 2021
Resistance to changing traditional practices	Ghansah et al, 2021; Zheng et. al, 2016
Confidence to undertake new and untested technologies	Belani et al., 2014
Need for specialized personnel	Samar et al., 2021; Ghaffarianhoseini et al, 2016; Ghansah, 2020; Belani et al, 2014;
Behavioral issues of project team members	Ghansah et al., 2021
Shortage of government policies	Ghansah, 2020; Belani et al, 2014; Ehrenhard et al, 2014

Materials and Methods

We adopted an approach frequently used in studies that aim to research variables of a given phenomenon and the degree of importance which these variables contribute to this phenomenon. It consists of four steps: bibliographic research, identification of barriers that impact the growth of the smart building sector, survey of expert opinions, and data analysis.

3.1. Bibliographic Research

Comprehensive bibliographic research was conducted on the Web of Science, Scopus, SciELO, and the main scientific journals' websites, covering works published in the last ten years. The searched keywords were: " barriers," "challenges," and "smart buildings." For the systematic literature review, we adopted the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes - PRISMA (de Alcantara et al., 2020; Maldonado et al., 2020).

Initially, we carried out an exploratory reading of the works considering titles, abstracts, and most relevant keywords to select the works adhering to this work's theme and exclude works that did not have evidence or information on the subjects covered. We discarded works whose abstracts did not contribute to the researched topic, were not peer-reviewed, or were not available in full for reading. Then we performed a selective reading, excluding those that were not original, whose results did not contribute to the theme, and whose results were not supported by the methodology. Finally, we performed a detailed reading of the remaining articles. Reading these articles made it possible to create a spreadsheet containing the most relevant excerpts to support and respond to the research problem.

3.2. Survey of Expert's Opinions

We used a questionnaire on an online platform (Google Forms) containing three sections: (a) conceptualization of the barriers; (b) questions regarding demographic data; (c) questions addressing the importance of selected barriers, which were presented at random to prevent the responses from being influenced by the order they appeared. The pre-test was carried out with the preliminary version of the questionnaire to identify doubts and inconsistencies. We invite professionals who work in the concerned field to answer the pre-test and the revised questionnaire. The 31 respondents used the five-point Likert scale, ranging from "extremely important" to "minimally important," to express their opinions on the importance of each barrier.

3.3. Data analysis

We used Cronbach's alpha to assess the data collection instrument and the respondents. We used the relative median method (Maldonado et al., 2020) to analyze the data. This method establishes an indicator as a function of the distance from the median to the closest class using the Likert scale's semantics. For example, Figure 1 is formed by two lines representing two variables with a median equal to four. In the first row, the median equal to four is much closer to the frequency represented by the number three. The median shifts to the right in the second line as frequencies equal to five are entered. Although both lines have a median of four, the variable represented by the second line can be interpreted as being more important, since it received more classifications of five and maintained the other frequencies.

1	2	2	3	3	3	3	3	3	**4**	4	4	4	4	4	5	5	5	5										
1	2	2	3	3	3	3	3	3	4	4	4	4	4	**4**	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Figure 1 – Example of the median position.

We use the following formula to calculate the relative medians:

$$
\mathrm{Rm} = \left\{ \begin{array}{lr} 1 + \dfrac{\mathrm{P_r}}{\mathrm{j_1}} & \text{for } \mathrm{m} = 1 \\ \mathrm{m} + \dfrac{\mathrm{P_r} - \left(\sum_{\mathrm{i}=1}^{\mathrm{m}-1} \mathrm{j_i} + 1\right)}{\mathrm{j_m}} & \text{for } 2 \leq \mathrm{m} \leq \mathrm{N} \text{ and } \mathrm{m} = \text{integer} \\ \mathrm{m} + 5 & \text{for } 1 \leq \mathrm{m} \leq \mathrm{N} \text{ and } \mathrm{m} = \text{fractional number} \\ \mathrm{N} & \text{for } \mathrm{m} = \mathrm{N} \end{array} \right\} \tag{1}
$$

where Rm is the relative median, m is the median, Pr is the median position, N is the number of respondents, and ji is the number of respondents assigned the semantic classification of i.

4. Results and Discussion

Cronbach's Alpha (0.84) value confirmed the questionnaire's reliability and the survey data. The main results are the barriers presented in Table 1 and the survey data discussed below. Figure 3 shows the barriers classified by the relative median. All barriers were considered important by the experts (the relative medians were higher or equal to 3.0), corroborating the view of researchers who published on the subject.

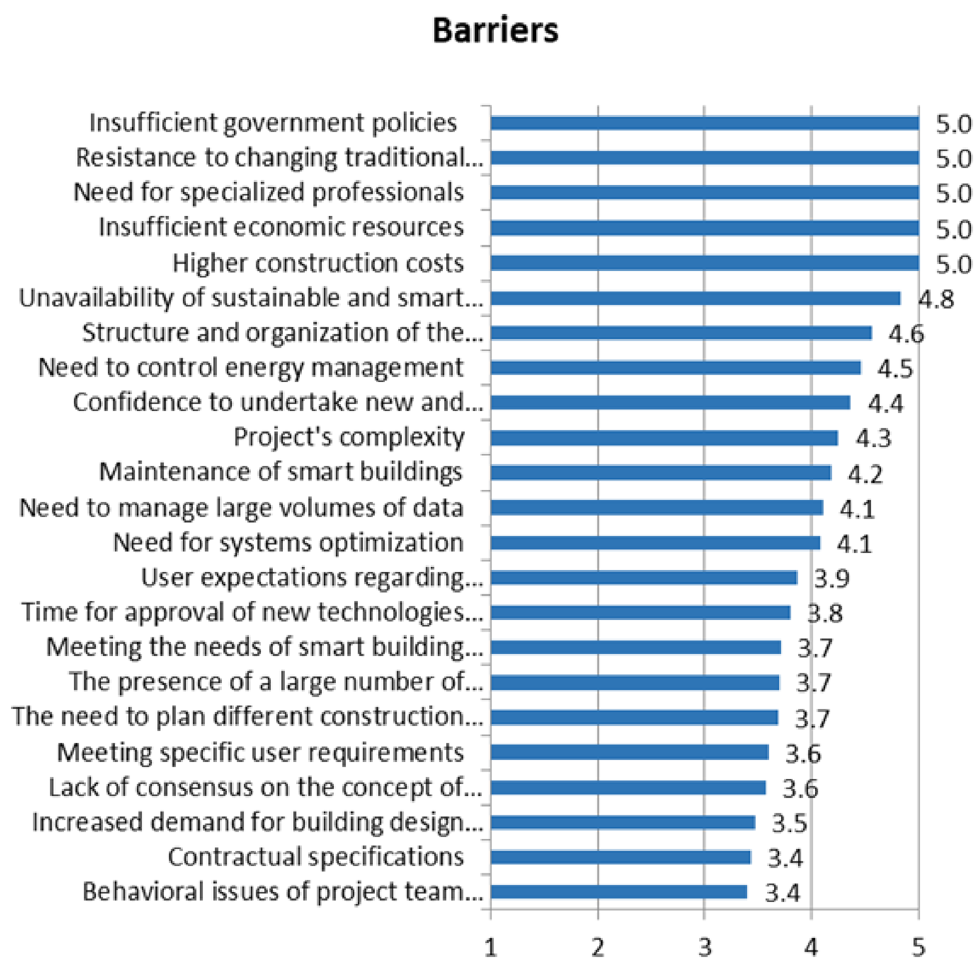

Figure 2. Barriers ranked by the relative median

The respondents considered five barriers extremely important (the relative medians equal to 5.0): insufficient government policies, resistance to changing traditional practices, need for specialized professionals, insufficient economic resources, and higher construction costs.

Government policies usually direct regulatory instruments formed mainly by legislation and technical standards, creating a more stable environment for public and private investments and users. They also play an important role in reducing the bureaucracy of the regulatory system, which inhibits innovation and competitiveness. Another important point is that the concepts of smart buildings and smart cities are intrinsically related since smart buildings play an important role in increasing the intelligence of cities. They are part of the complex ecosystems that are the basis of smart cities, which integrates smart building systems with smart city systems, provides a smarter urban system, and leverage building intelligence by enabling smart decisions in real-time on both levels (Froufe et al., 2020). In this context, government policies must provide mechanisms to adapt the infrastructure of cities to the needs of smart buildings. However, in many cities, especially those in developing countries, smart buildings have been built in areas without smart infrastructure, which makes building intelligence only refer to its smart management. In this context, the main focus of government policies has been to solve structural problems in cities.

Regarding resistance to changing traditional practices, in many countries, the construction sector, when compared to other productive sectors, is widely cited as the one with the lowest technological evolution, mainly due to its characteristics. In the construction processes of many companies, there is still a lack of formalized procedures, which serve as a reference for the execution of services and the training of workers on the routines considered the most appropriate. This makes it impossible to standardize deliveries, increases waste and rework, and makes worker skills the main factor in the work process, feeding the emergence of informal procedures developed by workers according to the skills acquired over time, which undergo variations, much more as a result of the high turnover of the workforce than as a result of a natural process of improvement. The solution to these structural problems still remains the focus of the construction sector in many countries, to the detriment of incorporating more innovative practices compatible with those demanded by smart buildings, which add value to the end-user however, as highlighted by Zheng et al. (2016), in a context where monetary risk, which in addition to the ROI associated with it is also represented by bank lending and regulation, less agile companies, such as those in the construction sector, cannot afford to add value to the end-user without seeing the return on investment.

Regarding the need for specialized professionals, among construction professionals, there is still a low level of awareness regarding the benefits and characteristics of smart buildings and the practices and skills demanded by these projects. The different characteristics of technologies and equipment demanded by smart buildings, mainly due to the insufficiency of standards that standardize requirements and characteristics, segment professionals according to their technical knowledge about a certain equipment/technology. In addition, there is also a lack of professionals who can provide technical assistance to building owners and managers because there are few owners and managers who are experts in smart technologies. There is also a lack in the market for companies to train professionals specifically focused on smart buildings' design, construction, and operation.

Regarding insufficient economic resources, in Brazil and a significant portion of underdeveloped and developing countries, recent years have been marked by political and financial crises, which have hampered investment in the smart building sector. Concerning public investments, they have been mainly aimed at solving emergencies or areas considered to be more priority. This scenario makes the development of the sector highly dependent on private resources. However, the private sector has faced difficulties in bank financing, especially regarding interest rates. Developed countries have also experienced the need for greater private sector financing. According to Smarten (2018), in Europe, there is still a need for a substantial amount of private financing. Considering that the cost of bank financing is directly proportional to the risk, public funds with federal, state, and municipal contributions would collaborate to reduce the cost and risk of financing.

Regarding higher construction costs, the cost of construction of a smart building is high compared to a traditional building (Belani et al., 2014), mainly due to the incorporated technology (Froufe et al., 2020).). According to Baghchesaraei (2016), the construction costs of traditional buildings are also formed by the building technology systems that are at the heart of a smart building, mainly those related to telecommunications, building automation, and life safety systems. However, in smart buildings, the more intensive use of technology and the need for its integration increase the initial costs of the enterprise. In research carried out by Ghansah (2021), the high cost of smart sustainable materials and equipment was identified as the main barrier to the adoption of smart building technologies. Even with the development of new technologies that allow greater applicability and versatility at a lower cost, and the existence of several studies that conclude that smart buildings are more profitable throughout their life cycle, that is, that the final added value influences the economic viability of their production, mainly because they allow the reduction of operating costs, there is still resistance on the part of entrepreneurs about the advantages of incorporating smart technologies to improve the cost-benefit ratio.

Although several barriers are more intrinsically related to the characteristics of Industry 4.0, such as, for example, need for systems optimization, increased demand for building design changes, the presence of a large number of systems incorporated into the building, user expectations regarding technologies to be used, and need to manage large volumes of data, the five barriers were considered extremely important by the respondents (insufficient government policies, resistance to changing traditional practices, need for specialized professionals, insufficient economic resources, and higher construction costs), can mainly be associated with structural problems in Brazilian civil construction, which are also present in most underdeveloped and developing countries.

Conclusion

In an Industry 4.0 context, barriers associated with innovation and technology that hamper smart building projects still coexist with structural barriers. Based on extensive and detailed bibliographic research, we identified 23 barriers for the development of smart buildings which were considered important by 31 professional professionals who work in the concerned field, of which five were considered the most important (insufficient government policies, resistance to changing traditional practices, need for specialized professionals, insufficient economic resources, and higher construction costs).

The survey results confirmed the authors' view of the consulted works since the professionals evaluated all drivers as important. However, it should be taken into account that research that is based on expert assessment has some degree of subjectivity resulting from the evaluator's interpretation of what is being assessed.

This work has the typical research limitations based on the literature review to support the results. Even though comprehensive and detailed literature research has been carried out, there is always the possibility that significant work has not been considered.

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