Establishment of a smart building assessment framework in the context of Smart Cities

Abstract

Purpose – This study suggests an assessment framework for improving smart building performance in the broader context of smart city development, considering dimensions like environmental sustainability, building characteristics, intelligence, computation management, and analytics. The framework is crafted to guide future research, aligning with the growing emphasis on sustainability and intelligence in evolving urban landscapes within smart cities.

Design/methodology/approach – In the initial phase, the concepts of 'Smart City' and 'Smart Buildings' are analyzed through a systematic literature review, considering the impact of governance on city sustainability and growth, along with the role of public policies in transforming buildings and cities. The empirical research evaluates innovation levels in small and medium-sized European cities, proposing a new framework with validated dimensions and sub-dimensions. This validation involves input from international experts through a Focus Group.

Findings – The key research findings validate the new proposed assessment framework for smart buildings within smart city development. The experts' insights align with and support the dimensions identified in the bibliographic research, providing a comprehensive understanding of the role of smart buildings in sustainable urban development.

Originality/value – This framework not only provides insights for a new model with specific dimensions and sub-dimensions but also serves as a guide for formulating strategies and policies to enhance innovation in these settings. What amplifies the strength of this approach is the validation and consolidation process involving international experts in the field.

Keywords Smart City, Smart Buildings, Public Policies, Assessment framework, Building Development, Urban Planning.

Article Classification Research paper

1. Introduction

Cities are being and will be revolutionized by new "smart" technologies which allow the transparent, sustainable, and efficient provision of public and administrative services (Sousa et al., 2020). Of particular interest are sensors, blockchain and big data processing, possible through the use of artificial intelligence, which has the potential to create personalized services to citizens (Allam and Dhunny, 2019). This requires hybrid and integration competences, governmental policies, and transparency in the use of information. Literature has shown initial results in the augmentation of public energy sustainability (Chui et al., 2018), public safety, urban mobility, air quality (Schürholz et al., 2020) and dialog innovative approaches using these systems

(Secinaro et al., 2022) (Grossi et al., 2021). The use of new technologies for the management of smart cities, such as artificial intelligence, big data and blockchain, is one of the main focuses of the European resilience and recovery plan. This plan was devised as a response to the economic and social damage caused by the covid-19 pandemic. By addressing local challenges, deliver better services to citizens and working towards the European Green Deal objectives, working with and for Smart Cities and communities is essential.

"Smart City" is a term derived from adopting and applying mobile systems through practical data management networks, which considers all the components of the city. Urban planners are focused on making cities "smarter", using systems such as the Internet of Things (IoT), cloud technology and big data. These systems offer ways of improving life in the cities in various aspects, such as mobility, resource management, planning and infrastructures. Each city applies these technologies differently, as priorities vary among regions and countries (Kirimtat et al., 2020). There are many definitions for "Smart City”. The goals of smart cities include smart citizenship, to enhance the quality of life and the surrounding environment; smart economy, for smart businesses and market management; smart governance, using innovation and technology to promote and facilitate improved decision-making and planning within governing bodies, encouraging people to engage in the "Smart City"; smart mobility, for adequate vehicle capacity and urban mobility; smart environment, for air and water quality, waste management and energy efficiency and smart living, for buildings and infrastructure for education, tourism, healthcare and public safety (Parra-Domínguez et al., 2022).

Literature offers various definitions for "Smart Buildings". However, the specific characteristics of this class of buildings have yet to be determined (Dakheel et al., 2020). The concept is focused on the existence of quantitative guidelines to achieve energy efficiency and technological innovation (Gomasa, 2021). Literature defines four main key features, or basic functions, of smart/intelligent buildings: Climate Response, the capacity of the building to react to climate conditions (both present and future) and to minimize the building's energy loads; Grid Response, the building's response to data it receives from the grid to improve economic and energy efficiency; User Response, the building's capacity to provide its users with real-time interaction with integrated technologies such as comfort settings; and Monitoring and Supervision, the capacity of the building to conduct real-time management and monitoring of its technical systems and the inhabitants behavior (Dakheel et al., 2020).

However, regardless of these "responses", other basic features must be considered, such as Energy Storage Systems, Advanced HVAC (Heating, Ventilating and Air Conditioning) and lightning systems, Sensors, and Legislation on smartness indicators. The latter feature is related to definition of policies and standards to enhance energy and technological innovation, leading the way into smarter cities. At building level, the European Commission and the Building Performance Institute of Europe have defined ways to measure the performance of Smart Buildings, however, a clear framework to assess and measure how "smart” a building or city is does not exist.

City and urban planning policies dictate lifestyles, health and sustainability as a whole. To promote adequate policies, several questions must be considered, such as air pollution, accessibility, employment, mobility, infrastructures, and many more (Adlakha, 2022). The United Nations New Urban Agenda indicates the importance of city governance and planning, to achieve the UN's Sustainable Development Goals (SDGs) (United Nations, 2016). Government defines taxes, land usage, housing prices, public services, industry, mobility uses and prices, infrastructures, and promotes economic development. For cities to be sustainable and the application of these policies to be successful, an integrated planning methodology must be used. This must the various levels of government and across all governance sectors. Also, policy should be informed by evidence and accurate data (Lowe et al., 2022).

Smart cities and buildings use sensors to gather essential and necessary information about the city, its inhabitants and the networks that are used to share information in real-time. The applications of these sensors can be divided into six groups: energy, health, mobility, security, water, and waste management (Roccotelli and Mangini, 2022). Regarding individual buildings, the same groups can be considered. Sensors are used to achieve optimal interior environmental comfort, with variables such as temperature, moisture, and light. These systems have impacts in terms of energy efficiency. To achieve such control, buildings are oftentimes dependent on various sensors to connect the indoor environment with the cooling, heating, and HVAC systems, for comfort. Lightning and HVAC seem to consume 70% of the energy used in commercial office buildings (Dong et al., 2019), and oftentimes this is achieved through non-renewable energy sources. This amount of spent energy is also related to the occupancy of a building, if the systems can recognize how many people are using the building, and at what specific time, that leads to more efficient energy use.

There are research gaps in literature specifically regarding the lack of interdisciplinary approaches, not fully integrating expertise from fields such as urban planning, social sciences and human well-being (Zhu et al., 2022). There's also a gap regarding the assessment of long-term performance and adaptability of smart buildings and cities. Over time, technological, environmental, and social factors are subjected to change, and assessment frameworks should be sensitive to these changes (Apanavičienė and Shahrabani, 2023). On another hand, while frameworks consider sustainability, there's a need for more specific metrics and standardized benchmarks, related to the integration of renewable energy sources and overall environmental impact (Dakheel et al., 2020). This research aims to approach these challenges by proposing a specific framework which takes these questions into account.

The objective of this research is to develop an assessment framework for smart buildings in the scope and development of smart cities. First, it is important to comprehend the concepts of "Smart City" and "Smart Buildings", in terms of their definitions and applications. Afterwards, the importance of public policies is highlighted in the path towards making cities and buildings smarter, and the role of governance in the sustainability and development of cities. Bibliographic research is conducted to comprehend existing research, and how these concepts intercept one another. Then, an existing assessment framework for the level of innovation of small and medium sized cities in Europe is used as a base for the new proposed assessment framework for smart buildings. Connecting this previous model and the information from bibliographic research, a new framework is proposed, with specific dimensions and sub-dimensions, according to key scientific questions. To validate this new assessment framework, a Focus Group Session with experts is conducted. The experts are asked an assortment of questions, related to the dimensions of the framework, to comprehend if the considered dimensions and sub-dimensions are sufficient, if they are valid and important, and if there are other dimensions that should be added, removed, or altered. Finally, a new assessment framework for smart buildings is developed, using the outputs from the bibliographic research, and the feedback of the experts.

2. Methodology

2.1. Flowchart

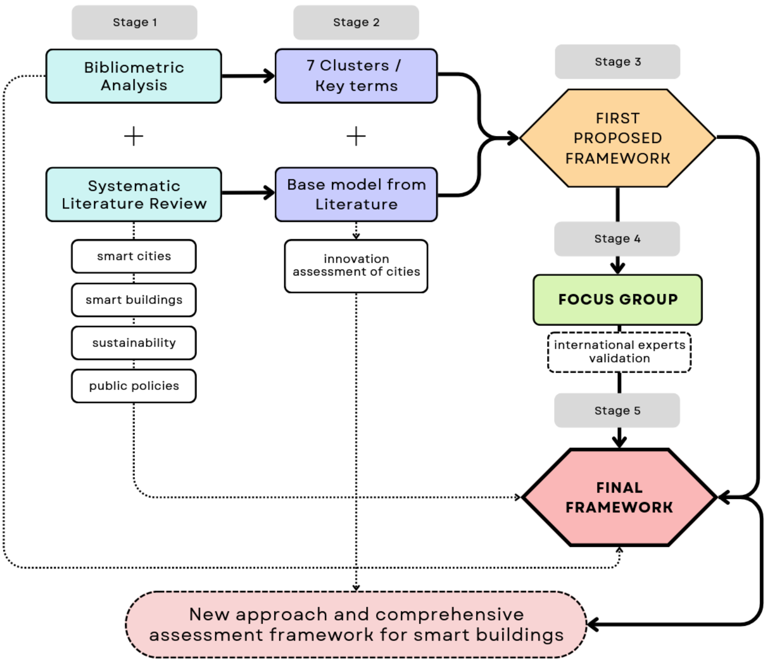

Figure I
Methodology flow diagram
(Source: Authors own creation).

2.2. Research Stages

The research was divided into five stages (see Figure 1), the first one, a bibliometric analysis and a systematic literature review.

The second stage of the research consists of defining the set of clusters/dimensions through the information obtained from the previous research stage. To produce the first proposal of the assessment framework, the model proposed in (Sousa et al., 2020) is used as a base, which assesses cutting-edge technologies having an impact on small and medium-sized cities in Europe and identifies the main dimensions for promoting innovation. This model considers both dimensions of technology, also present in smart buildings, dimensions of governance, essential to the management and development of smart cities, and dimensions of sustainability. The built environment is responsible for shortages in natural resources, being the largest consumer of raw materials and energy in the world and generating the highest amount of waste (Çimen, 2021). As such, sustainability is a key factor when considering the assessment of buildings. The third stage of the research focuses on proposing a new initial framework which considers the seven clusters/dimensions of scientific concern and the base model identified in literature. The fourth stage is a Focus Group session, to get feedback from experts to adapt and validate the previous findings. Lastly, the fifth stage is the proposal of a new framework which considers both the information gathered from literature and the feedback of the experts.

2.3. Fourth Research Stage - *Focus Group*

Conducting a Focus Group session in qualitative research has become common in past decades, especially in the fields of Social Sciences, Health, Management, and Education. A Focus Group is a planned and targeted discussion among a small (authors opinions vary between a minimum of 3 and a maximum of 12 participants) group of people and is a qualitative method for gathering data on a specific topic. Focus Group sessions should last between thirty minutes and three hours, depending on the author. This method is particularly helpful as a supplement to other data collection techniques, as it can provide in-depth analysis on the topics. This method is an extension of the interview method, being a group interview mixed with a discussion. The participants of these groups should be selected individuals who are skilled or experienced in the subject and can provide insight on the targeted topic. Spontaneous interactions between participants are encouraged and fundamentally distinct from other methods in which data can be collected separately. When compared to data gathered through ne-on-one interviews, the type and scope of data generated through group social interaction is frequently deeper and richer. Online focus groups are not a distinct sort of focus group discussion per se, rather, they are an evolution of more conventional methodologies made possible by the internet. These are conducted in on-line settings, whether through chat rooms or conference calling (Gundumogula, 2020).

To validate the previous framework and assign values to its dimensions, an On-line Focus Group Session with experts was held on the 29th of March 2023, from 14h00 to 15h30 (Greenwich Time). The group consisted of 6 participants and a moderator (see Table I).

Table I
Focus Group experts' *participants expertise (Source: Authors own creation).*

The session consisted of 15 questions for the participants, regarding the dimensions of the framework. During the session, the participants were also able to work together in a Miró board (an on-line whiteboard where people can work individually or with a team). This board consisted of two main elements, a table with the questions, where the experts could leave extra feedback if they wished, and a representative cluster scheme, with all the dimensions of the assessment framework, so they could vote on those which they believed to be more important. Although all of the participants contributed verbally during the Focus Group Session, not all inserted notes on the questions on the table, as this was an optional step. The participants were instructed to write on the whiteboard if they felt they had extra comments or feedback to offer, other than the one that was already offered during the group discussion.

The Focus Group Session was held on-line, in Microsoft Teams, and lasted 1h30. In the first part of the session, the Miró Board was presented, and the participants were given instructions on how to provide extra feedback on the table, if they wished to, and to vote on the framework's dimensions that seemed of higher importance for them. Afterwards, each participant took a couple of minutes to self-present. On the first phase of the Focus Group Session, participants were asked to vote on the framework dimensions they deemed more important when evaluating smart buildings for smart cities. The second phase of the session, the experts had to answer a group of pre-scripted questions, and each participant had a determined number of minutes to provide feedback. After all the participants gave their feedback on a determined question, the moderator moved to the following question. Regarding the diverse nature of the questions, it was possible for the participants to answer more than one question occasionally, which was considered when taking notes and assessing the information of the session. Due to data protection, all the participants signed previously an informed consent, regarding their participation in the Focus Group Session, as well as giving permission to use their name in the research, as participant experts.

The Focus Group Session considered 15 questions, as follows:

1. In your opinion, what is a "Smart Building"?
2. In your opinion, what is a "Smart City"?
3. How can the industry of construction contribute to decarbonization?
4. Can Smart Buildings improve the air quality of cities?
5. Do Smart Buildings contribute to environmental protection? In what ways?
6. Resilience and adaptability to future scenarios is essential for Smart Buildings?
7. Are using renewable energies and optimal energy management essential for a smart building?
8. Are networks important and essential for a smart building?
9. What type of data can be gathered on a smart building/city to improve and evaluate the user experience?
10. Is AI important in the context of a smart building?
11. Are BIM models necessary for smart buildings/city, to improve and evaluate user experience?
12. What is the role of life cycle assessment (LCA) in a smart building? Is it essential?
13. Should preserving historical buildings (vs new construction) be part of urban public policies?
14. Does data gathered in smart buildings/cities) pose issues in terms of data privacy? How should this be approached in a smart building?
15. Are there any subjects regarding smart buildings that weren't addressed, and should be considered?

The results of the Focus Group Session, and experts' feedback, are presented in the following section, as well as the proposed final framework.

3. Results and Analysis

The main objective of this research is to create an assessment framework for smart buildings, in the scope of the development of cities, as they evolve and become smarter. To do so, bibliographic research was conducted, to comprehend what makes a building/city smart, and how these types of buildings can be evaluated. Afterwards, an assessment framework with specific dimensions was proposed, based on previous bibliographic research. To validate this framework, a Focus Group Session with experts was conducted. The participants voted on the framework dimensions which were more important, and they also answered a set of pre-scripted questions, regarding those same dimensions. The results of all the research stages are presented below, which culminate in a new proposed framework.

3.1. First Stage - Bibliographic Analysis and Systematic Literature Review

Bibliographic research considering both the concepts of "Smart Cities" and "Smart Buildings" was conducted for all publications between the years of 2018 to 2023, in the Scopus database, which came up to a total of over four thousand documents. In order to better assess these results, the research was then limited to articles in peer-reviewed journals, which brought down the total number of documents to 1832. The selection of the 123 research papers was based on a systematic literature review process. Initially, 1832 papers were identified through bibliometric research. However, for the systematic literature review, a refined set of 123 research papers were chosen. These papers were published between 2018 and 2023 and are exclusively sourced from peer-reviewed journals, accessible in the Scopus Database. To enhance specificity, the initial key terms "Smart Cities" and "Smart Buildings" were supplemented with the key term "public policies," resulting in the final selection of documents. Notably, a focus was placed on including published reviews in the chosen set.

The literature highlights gaps, including a lack of interdisciplinary approaches in smart city research (Zhu et al., 2022). Another gap is the assessment of long-term performance and adaptability in smart buildings and cities, requiring frameworks sensitive to changing technological, environmental, and social factors (Apanavičienė and Shahrabani, 2023). While sustainability is considered, there's a need for more specific metrics, particularly related to renewable energy integration and environmental impact (Dakheel et al., 2020).

3.2. Second Stage – Cluster/Key Terms Definition and base model choice

Afterwards, through a bibliometric analysis of key terms/keywords, it is possible to define seven main clusters/dimensions (see Figure 2). To do this, the software VOSViewer was used, a tool for constructing and visualizing bibliometric networks. The first cluster is focused on biodiversity, pollution, air quality, ecology, climate change, environmental protection, resilience, among others, having an essential focus on the environment. The second shows a focus on buildings, heating/cooling systems, electric power, energy management and conservation, renewable energy and comfort. The third focuses on ambient intelligence, 5G, cybersecurity, the Internet of Things, sensors, communications, and data transfer. The fourth, has a major focus on computer simulations, computation theory, machine learning, smart devices, data mining, urban transportation and traffic management. The fifth focuses on 3D modelling, Building

Information Modelling (BIM), Computer-Aided Design (CAD), laser scanning, life cycle assessment, virtual reality and point clouds. The sixth relates to city management, ecosystems, historical preservation, public administration and public policies. Lastly, the seventh focuses on big data, blockchain, industry 4.0, metadata and advanced analytics.

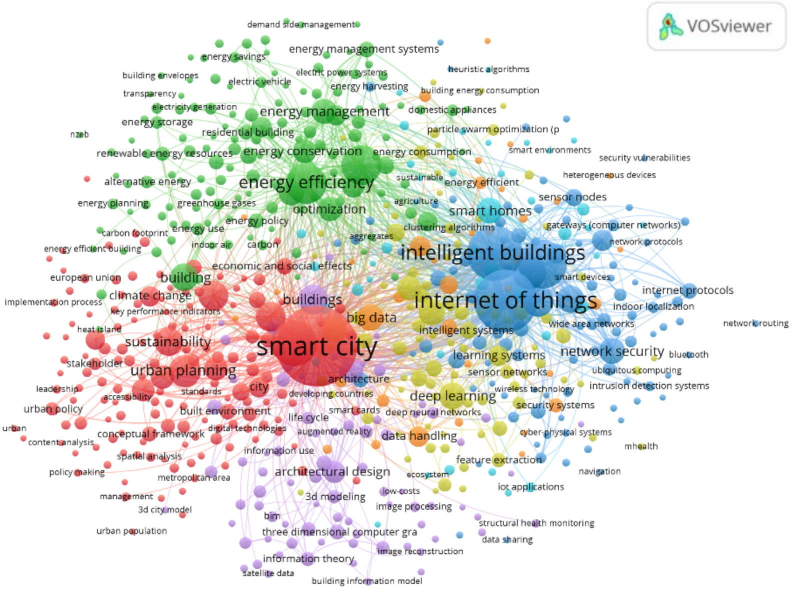

Figure 2
Key terms in publications considering the concepts of "Smart Cities" and "Smart Buildings" (Source: Authors own creation).

3.3. Third and Fourth Stage – Fist proposed framework and Focus Group Session

The focus group participants were asked to vote on the proposed dimensions, defined through the bibliographic analysis, to assess which were the ones they considered most important, and which should be given greater weight in the framework.

The most voted dimensions were "Environment" and "Buildings", both with a total of 6 votes. Within the "Environment" dimension, the sub-dimensions of "Resilience" and "Environmental protection" were given equal importance (2 votes each), while "Air Quality" was considered the least important, with one vote. Regarding the "Buildings" dimension, "Energy Management" was given greater importance, with 3 votes, and the "Use of renewable Energy" lesser importance, with 2 votes. Next, the dimension of "Digitalization of Construction" was deemed the most important, with 5 total votes, "Life Cycle Assessment" being considered the most important sub-dimension, with 2 votes, and "Building Information Modeling" the least important, with just one vote. "Analytics" was the most voted dimension next, with 4 total votes, "Metadata" being considered the most important sub-dimension, with "Privacy" receiving no votes. The dimensions of "Management", "Computation" and "Intelligence" were all granted the same importance by the participants, having 3 votes each. On "Management" no votes were given to the sub-dimension "Historic Preservation", as opposed to "Public Policies" with 2 votes. On "Computation", no votes were given to "Machine Learning", as opposed to "Smart Devices", deemed more important, with 2 votes. Lastly, on "Intelligence", no votes were given to the sub-dimension "Networks", and "Sensors" was deemed more important, with 2 votes. Taking into account this data, the expert group considered the most important dimensions (in a macro level) to be both "Environment", and "Buildings", with all subfollowed by “Digitalization of Construction”, with all sub-dimensions being important, “Analytics” next, with the “Privacy” dimension considered of less importance, and finally “Management”, “Computation” and “Intelligence”, with the dimensions of “Historic Preservation”, “Machine Learning” and “Networks” being given less importance (see Table II).

Table II Dimensions of the proposed framework, with the votes of importance from the experts (Source: Authors own creation).

Regarding the feedback the experts gave on the questions, starting with the first and second questions, related to what they understood as a “smart building” and a “smart city”, one of the experts suggested that smart buildings/cities are a mixture that combines sensors and interacts with the people that use the buildings and live in the city. These are sensors that evaluate, for instant, water and energy management. Another expert indicated that the concept of “smart” stands for a technological approach of the built environment, as it is related to data collection and information management. The problems that exist with heritage buildings were also addressed, as these buildings have potential to be reused with minimal intervention, and don’t fit into the idea of “smart”. Many of the experts shared that they struggled with the concept of “smart”, depending on the type of building that it’s related: whether it is simply a question of data gathering for the improvement of people’s usage of buildings and cities, and how useful that is indeed. Another expert commented that smart cities must fulfill the needs of humans, granting the resiliency of buildings and the needs of society. All participants agreed that there are many environmental issues which “smart cities” should be able to resolve. For instance, sensors should be used for energy efficiency purposes, and guarantee the sustainability of the built environment. Technology in cities and buildings should be used to address these questions, rather than just existing as a potential to store data. The consensus was that a smart building is a building with sensing technology that transforms data into useful results such as savings, automation, and the management of resources. This can be accomplished either autonomously or by interacting with people. These buildings should clearly be different in terms of determined needs, such as size, type, or the age of users.

Smart buildings should promote well-being and be resilient, they should also ensure energy savings, export energy, and ideally integrate waste materials, contributing for both people and nature's well-being.

On the questions related to the decarbonization of the built environment, the air quality of cities, and the environmental protection, all participants agreed that the design of smart buildings should make cities healthier, ensure that waste is treated appropriately, decrease pollution and the heat island effect. This can be done through elements such as bio solar roofs, as indicated by one of the participants. Nature should not only be respected in the cities, but it should also be an integral part of it and of buildings. Some of the experts believe that smart buildings can contribute to environmental protection only in specific questions, such as collecting and managing data which can help the low consumption of resources, through environmental control. The integration of nature-based solutions in building design, such as green roofs, can help reduce carbon footprint, promote energy savings, and improve the environmental quality in the city. More than this, if the articulation with environmental services is considered, indoor air quality can be achieved, but it is unlikely that the air quality in cities will be improved. The group also had doubts regarding the contribution of smart buildings to environmental protection, as they believe it depends if these issues were considered already during the design and construction of the building. If they weren't considered then, it is unlikely that the buildings can contribute to environmental protection afterwards.

Regarding the questions of resilience and adaptability to future scenarios, the participants agreed that buildings, smart or not, should be resilient by default, as adapting buildings in the future will be more difficult and costly.

When considering renewable energy and optimal energy management for smart buildings, the participants considered this question essential. A smart building should support all its energy needs, or at least 70% of them. One of the participants stated that in housing, for instance, this was easily achieved. It was also added that ideally, smart buildings should be able to not only support the building, but also export energy back to the grid and, if the use of renewable energies isn't possible, then the focus should be in optimizing the existing building systems.

Regarding the importance of networks on a smart building, although it hasn't been voted by the participants as an important sub-dimension of the framework, they considered them important for building management, as probably it wouldn't be possible to have a smart building without any kind of network that would connect the buildings' intelligence (data storage, processing and analysis) to the source of data and the external world.

Regarding the questions related to the type of data that can be gathered on a smart building to improve user experience, participants considered a few: information related to the usability of spaces, perceptions of comfort, wayfinding, safety, security, social inclusion, energy needs, among others. One of the participants pointed out that all environment-related variables can be relevant for the user, as raising people's awareness is proved to be the first step into changing behaviors.

Participants didn't consider the use of Artificial Intelligence in smart buildings to be of utmost importance in the present. Perhaps for future buildings, but they agreed that there are technologies which are already effective enough, which do not involve AI, and offer concrete visible results.

On the questions related to the Digitalization of Construction and Building Information Modeling (BIM), and whether these are important for smart cities development, some experts felt this was a very subjective question. While BIM models were important to monitor the building, and digital technology and sensors data can be gathered and inserted into a BIM model, this information should be mixed with qualitative analysis, as the quantitative analysis by itself is not enough.

These sorts of analysis still lack accuracy and should be better devised. It was also indicated that in business, many times, companies will ask for BIM frameworks because they want to assess energy management questions and NZEB possibilities for saving energy. In new constructions, experts felt BIM is necessary, however, in existing buildings, it will only be necessary in big public buildings. It was also indicated that just having the BIM framework isn't enough, these frameworks should be used together with interactive feedback solutions and being powered by sensor data to provide users useful real-time data (if possible), to truly make them useful in addressing user's experience. One of the experts also mentioned that while BIM does allow for professionals to use outputs of it for environmental analysis, such as carbon-footprint assessment, the information is not enough, and the access to it is not easy. Also, the problem of existing/heritage buildings was mentioned again, as these account for about 60/70% of the built environment, and there still isn't a proper way to change or adapt these buildings, even with the digitalization of construction. While there are some tools for mapping buildings, BIM models don't seem to contribute greatly to the case of heritage buildings. One of the experts suggested that sensors can be used in heritage buildings for the same goals of smart buildings, such as interior temperature management or humidity control. Another one of the experts indicated that heritage buildings "don't need to be smarter than they already are", and that people should adapt to older buildings and live comfortably with them, not the other way around.

Regarding the question of Life Cycle Assessment (LCA) being essential, all experts agreed that it was. However, also related to the issues of BIM models, the environmental analysis still lacks a lot of information and, often, this information is not accurate. This is a problem that will likely be resolved in the next decade or so but, now, it's not developed enough to conduct accurate analysis.

When considering the necessity of the preservation of historical buildings versus new construction, and whether this should be part of public policies, the consensus was that preserving historical buildings should be a public concern, and it isn't necessary to convert them into extremely smart buildings. The use of technology, in these cases, can be used mostly for analysis and evaluation of use. The challenge of how to use and adapt technology in these cases is also harder than for new constructions. When it comes to the smart city, however, maintaining older buildings (not historical) should be considered only if it truly ensures less environmental impact. If not, maintaining those buildings should not be mandatory by policy.

Regarding if the data gathered in smart buildings/cities poses issues in terms of privacy, the consensus among the experts was affirmative. The privacy of users should always be considered when adding sensors and technology into buildings and, ideally, all users should know where their data is being stored, how and by whom it will be used. Unfortunately, data privacy is not always guaranteed in people's lives due to the use of smart phones, for instance, or even just by using the internet. There is only a general illusion of privacy. Anyways, this should be mitigated as much as possible when planning the systems for smart buildings.

When asked whether the experts felt all dimensions of the framework were appropriately important, and if they wished to add anything else, the experts had the general opinion that all the dimensions complemented each other appropriately. One of the experts mentioned that smart buildings are also passive buildings, and that question should be added to the framework somehow. Stakeholders should also be accounted for in the assessment, as these are the ones creating the policies and managing the smart city. One of the experts felt it would be important to know which stakeholders to involve in the management of smart buildings. Both in professional terms and for policies management. Two of the experts felt that cost/benefit should also be a dimension which should be considered, as financial questions are essential when dealing with any part of the development of cities and societies.

3.4. Fifth and final Research Stage - *New proposed framework*

After conducting the Focus Group session, some changes were made to the previous proposed framework, in order to add the suggested dimensions to it, following the experts feedback (see Table III).

Table III
New proposed framework, after feedback from the experts (Source: Authors own creation).

The sub-dimension of “Stakeholder intervention” is added to the main cluster of “Management”. This way, stakeholders will also be accounted for in the assessment of the smart building, as a driving force. Next, the sub-dimension of “Historic Preservation” is altered to “Building Adaptation”, following the experts feedback on the issue of existing buildings, and how these should be adapted, instead of simply mantained.

Heritage or historical buildings are just too specific, specially when evaluating smart buildings for smart cities. The cluster of "Environment" and its sub-dimensions remain the same, with no alterations. The dimension of "Digitalization of Construction" is deleted, and its sub-dimensions of "Life Cycle Assessment" and "Building Information Frameworkling" migrate to the "Buildings" dimension, as these are all questions that are addressed in the scope of the individual building. Another sub-dimension is also added, following the experts feedback, named "Cost/Benefit". All the other dimensions remain the same. While experts agreed that, at the moment, AI was not a very important dimension of smart buildings, it will likely be in the future and, as such, the sub-dimension of "Machine Learning" is kept in the framework, as well as "Metadata". Although there are sub-dimensions of the framework that weren't voted by the experts, these are still dimensions that showed up in literature as questions of importance, and so they are kept in the framework. The question of "passive buildings" is not added to the assessment framework, as there is not a general consensus on the use of passive buildings in all types of climates. The new proposed framework now considers 6 dimensions, and 17 sub-dimensions. The new proposed framework is shown in Table III.

According to the experts' votes during the focus group, and the suggested alterations to the dimensions and sub-dimensions of the framework, weights are defined. Overall scores are given to the dimensions, at macro level, according to the experts' votes, which amount to a total of 100%. The weight value is given considering the number of votes of the experts. For example, the dimension of Environment had 6 votes out of 30, and so, it amounts to 20% of the total framework score. The new sub-dimensions, or not-voted sub-dimensions, but which were still considered important in the discussion, are given a minimum value of 2%. This way, all parts of the framework are considered in the assessment. In order to achieve the total 100% score, assessed buildings must fulfill the requirements of all the sub-dimensions.

As a final result, "Buildings" is the most important dimension, amounting to 37% of the assessment score, including "energy management", as the most important sub-dimension, which was the most voted for by the experts, at 12%. "Environment" is the second most important dimension, amounting to up to 20% in the assessment scale, with "Resilience" and "Environmental protection" as the most important sub-dimensions. "Analytics" comes next, with 13% of total possible overall score, since it was the most voted of all the following dimensions, and lastly, all the remaining dimensions amount, individually, up to 10%. This allows the possible users to work with a 100% value scale.

4. Discussion

The proposed framework is a tool to evaluate the planning and implementation of smart buildings. It is based on technologies that have the potential to disrupt the traditional way of construction, operating, and using buildings. In a context where technological possibility is immense, but also where the real gains are difficult to quantify, such a tool guides public and private decision-makers on both strategic and operational level.

The framework was developed in two phases: first, a study of the scientific production, based in papers published on the Scopus database, where the bibliometric research yielded seven clusters/dimensions. A posterior analysis and discussion were carried out with a multidisciplinary group of experts, both with research and well-developed professional backgrounds. In this focus group the seven initial dimensions and 15 sub-dimensions were rearranged into six dimensions and 17 sub-dimensions, reflecting not only the relative weight the experts attribute to each sub-dimension but also their arrangement and regrouping.

With almost twice the double of the next category, "Buildings" is the most important dimension. As the framework looks at Smart Buildings, it could be considered redundant to consider a category with this name, but its sub-categories, Energy Management, Use of Renewable Energy, Building Information Modelling, Life Cycle Assessment, Life Cycle Costing, indicate that Buildings pertains to the energy performance of the building, its direct and indirect impacts on the environment and value over its lifetime, and the tools employed in the design and construction, but also possibly on Digital Twins. It is relevant to see that the experts do not directly value the environmental impact of the construction of the building, perhaps because the building structure, envelope, walls and systems, are considered a static pre-condition. The fact that Energy Management is the sub-dimension with the most votes strengthens the operational aspect of this category.

Environment is the second dimension, and among the three sub-dimensions the one related to human well-being is the least voted, indicating a bias towards building performance. The four remaining categories Analytics, Intelligence, Computation and Management are the lowest ranked and almost paired in importance, which is interesting as it shows that the most technological layer is given less weight. The emphasis given to the Privacy subdimension of Analytics is relevant.

The study contributes to the discussion of policies, including public incentives, that foster the growth of smart buildings with the goal of improving users experience, but also to make buildings positive contributors to the environment and the city. Current research and the expert group coincide on topics on which European regulation has been increasingly demanding: building energy performance, resilience, user well-being and privacy. Also, the private sector, through building certification schemes such as BREEAM, LEED or WELL, is following the same path. The instrumental technologies which are employed to ensure this performance deserve less attention from experts, because their impact is still seen as not significant to attain results, or because there is a larger focus on the outcomes.

In terms of practical application, the framework can be adopted by companies in smart building technologies and urban development, to assess their possibilities and impact. Investors and decision-makers in real estate and construction industries, for instance, may use the framework to guide their investments. In education, the research can be integrated into curriculum for architecture, engineering, urban planning, and environmental science programs. It serves as a practical framework for teaching students about the integration of smart technologies in building design and city planning. On the policy front, the framework could influence the development of regulations and policies related to smart buildings and smart cities. Governments may use the insights to incentivize sustainable practices in building design and operation. In research, the study contributes to the existing body of knowledge on smart buildings and smart cities. It provides a structured framework for future researchers to build upon, advancing the understanding of the intersection between technology, urban development, and sustainability. Societally, research, when effectively communicated, can increase public awareness of the importance of smart buildings in contributing to sustainable and intelligent urban environments. Implementing recommendations from the framework could positively impact the quality of life in urban areas, including improved air quality, enhanced resilience to environmental changes, and increased use of renewable energy sources.

To conduct a more accurate validation of the framework, however, it would be necessary to bring together more experts and conduct more focus group sessions, to account for the feedback of a larger number of professionals. This is a limitation of the research, which allows for further work to be conducted.

5. Conclusion

This article presents the development of an evaluation framework for smart buildings in the context of the development of smart cities. The framework is based on extensive bibliographic research and incorporates six dimensions of key terms related to the scientific concerns in the field. These dimensions are Environment, Buildings, Intelligence, Computation, Management, and Analytics.

To validate and complete the proposed framework and assign values to its dimensions, an online Focus Group Session was conducted with experts in the field. The participants provided their insights and feedback and answered a set of pre-scripted questions- The experts' feedback played a crucial role in refining the evaluation framework. The results of the Focus Group Session indicated that the dimensions of environment and buildings are the most important, with all their respective sub-dimensions being of high significance. The experts emphasized the need for smart buildings to contribute to environmental protection, improve air quality, and exhibit resilience and adaptability to future scenarios. They highlighted the importance of renewable energy use and optimal energy management for buildings. These findings are consistent with what was found in the bibliographic research.

This research contributes to the discussion of the contribution of smart buildings to the sustainable development of smart cities, providing an assessment framework supported by multiple dimensions. The insights from the experts further validated the framework and provided valuable guidance for future research and development in the field of smart buildings. With the continuous advancement of technology and the growing importance of sustainable and intelligent urban environments, the proposed evaluation framework can serve as a valuable tool for assessing and improving the performance of smart buildings in the context of evolving cities.

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