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Review

Advancing Building Assessment Tools: Achieving Sustainable Development Goals through the Fusion of Internet of Things Occupant-Centric Principles and Sustainable Practices

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Abstract: The impact of global climate change on the built environment emphasizes the need for sustainable development goals (SDGs) using technological solutions, such as the Internet of Things (IoT). The significance of innovative building assessment (BA) tools plays a pivotal role in bridging the existing gap between the theoretical and actual operational performance of buildings. The main research question is how can a new generation of BA tools leverage the IoT to optimize occupant well-being and achieve SDGs' targets. This article delves into the pivotal role played by the IoT and occupant-centric concepts in advancing sustainability initiatives and facilitating the achievement of SDGs. The novelty of this paper lies in its exploration of the current state of IoT integration as a strategic imperative for SDGs' achievement and climate change mitigation. Consequently, a paradigm shift is evident in this work, showcasing a comprehensive comparison between conventional and IoT occupant-centric BA tools and introducing a correlation study between IoT occupant-centric systems and future SDGs' targets. Lastly, current gaps and valuable insights into future research possibilities are offered.

Keywords: assessment tool; building performance; IoT solutions; occupant-centric; SDGs; sustainability

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1. Introduction

Nowadays, Sustainable Development Goals (SDGs) show the necessity of utilizing technological advances, resources, knowledge, and tools to achieve climate neutrality and net zero-emission buildings by 2050 [1]. In ref. [2], it showed a consistent upward trend in the Earth's average temperature, leading to frequent natural disasters, with renewable energy accounting for only 30% of the electricity sector. Additionally, there has been a notable surge in the consumption of fossil fuels in the previous decade. In ref. [3], it was shown that building monitoring can optimize real-time energy demands and environmental conditions. This can positively or negatively affect the well-being, satisfaction, and productivity of an occupant. The strategy outlines the steps for achieving a fair and inclusive transition for the EU to attain climate neutrality by 2050, aligning with the "European Climate Law" proposal to formalize this political commitment into a legal mandate [4]. The building sector is one of the largest energy consumers and is responsible for approximately 40% of the energy demand and 36% of CO_2 emissions [5]. Buildings play a significant role in reducing energy consumption and carbon emissions. In this context, the EU has proposed a set of directives and policy tools for building energy transformation [6]. The European Commission established ambitious commitments to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 while setting a cost-effective path to achieve climate neutrality by 2050 [7]. Energy Performance Certificates (EPCs) are an essential part of the Energy Performance of Buildings Directive (EPBD) that promotes policies to help to achieve energy-efficient buildings by 2050 by introducing new aspects and elements for dynamic EPCs [8].

Building information modeling (BIM), digital twins, the Internet of Things (IoT), and Artificial Intelligence (AI) are currently popular technologies in the building sector. These technologies can offer integrated information to enhance long-term building performance [9]. The IoT has become an essential component in nearly every construction project, playing a crucial role in building operations [10]. These systems are designed to enhance the health and well-being of the occupants while ensuring the efficient functioning of the building, including features like failure detection, energy monitoring, occupancy tracking, and access monitoring [11]. Shareef and Rauf [12] introduced the adaptive and sustainable IoT integration model (ASIIM), a novel framework that leverages the IoT to enhance building performance, occupant comfort, and energy efficiency. The integration of IoT systems in building-related applications has become increasingly widespread, particularly with the implementation of mandatory fixtures and meters in various countries [13]. Examining the sustainability of building IoT systems represents a departure from traditional practices for both building managers and researchers [14]. The common belief has been that environmental effects, including embodied carbon (the upfront carbon footprint associated with creating the system) and the operational energy consumption of building automation systems, were considered minimal when compared to the focus on reducing the operational energy use for heating, ventilation, cooling, and lighting [15]. However, with the increasing adoption of IoT in buildings, a more holistic evaluation is needed [16]. This necessitates a comparison of the environmental impact of various heating sources alongside the embodied and operational energy consumption of the entire IoT system [17]. Only through such a comprehensive assessment can we determine the true sustainability benefits of building IoT systems and identify the most efficient heating solutions for a truly sustainable building [18].

Optimizing building operations through occupant-centric control is an intelligent approach that adapts to occupant behavior, enhancing energy efficiency without compromising human comfort [19]. By 2025, over 80% of property owners aim to adopt technologies for improved sustainability, environmental control, predictive facility management, and digital connectivity and infrastructure [20]. Smart room sensors with connectivity capabilities play a key role in providing the necessary data and control to enhance efficiency, health, and comfort [21]. The integration of digital technologies with mechanical systems is poised to usher in a new era of advanced environmental controls, elevating the tenant experience while aligning building owner costs with occupant needs and regulatory standards [22]. This convergence allows building owners to harness the power of the IoT and other intelligent technologies, paving the way for a future where the occupant-centric experience is characterized by uniqueness, comfort, and sustainability [23].

Subsequently, the current building assessment tools should incorporate a more comprehensive and meaningful set of indicators to create a desire for long-term improvement in building performance [24]. It is important to ensure their inclusion in the calculation methodologies to promote the building life-cycle process [25]. Energy consumption in buildings is highly dependent on occupant energy-use behaviors, and intervening in these behaviors could function as a cost-effective approach to enhancing energy savings [26]. Without understanding the comprehensive energy-use behaviors of occupants, there is a high possibility that behaviors are inappropriately interpreted and thereby modified incorrectly [27]. Despite the availability of smart meters, sensors, and IoT devices, there is still a gap in terms of the approach to associating individual occupants with such real energy-use data [16]. IoT has a significant impact on the daily behavior of potential users [28]. There is a need to build a dynamic building assessment tool that can be extended to introduce a set of additional indicators into calculation procedures [29]. Maximizing the utilization of resources while decreasing the waste output from buildings and their environmental impact are considered essential design aims to fulfill circularity in buildings [25].

Although building rating systems exist, there is a knowledge gap with the existing building assessment systems under energy consumption changes based on the occupants' dynamic needs and climate change [30]. It introduces a variety of improvements in terms of information, such as energy, smart readiness, well-being, comfort, financial, and sustainability indicators with the use of advanced IoT tools [31]. Smart readiness indicators (SRIs) qualify the capacity of a building to adapt its general performance to the occupant's needs to allow energy flexibility in the performance according to the network parameters [32]. Current systems are based on assessing some key indicators, regardless of overlooking the user's behavior and the actual energy performance of the building, which might change dynamically over time [33]. This study investigates the literature gaps for developing current BA tools to integrate the effectiveness of more adaptive buildings. In particular, the impact of IoT occupant-centric concepts on developing BA tools under the SDGs' targets.

Overall, another challenging problem is that today's efficient buildings are not the same as those of tomorrow because of all the challenges of climate change, the dynamics of occupants using spaces, and the advances in smart technologies. The main research question is how can a new generation of BA tools leverage the IoT to optimize occupant well-being and achieve the SDGs' targets. These changes will change the performance of buildings and their efficiency. The core of smart and sustainable buildings is their adaptability and flexibility. Atamewan [34] underscores the importance of daylighting for sustainable architecture in developing countries. In other words, we need to introduce a new generation of building assessment tools not only for decision-makers such as designers and researchers but also for non-expert groups such as stakeholders, owners, and end users. This gap can be filled by addressing the following questions:

R.Q1. Why develop a new generation of BA tools?
R.Q2. What are the potential advancements in using the IoT with BA tools?
R.Q3. What are the correlations between IoT occupant-centric impacts and SDGS' targets?

Therefore, the purpose of this study is to show the current state and IoT integration as vital strategies towards SDGs and climate change mitigation through developing a new generation of BA tools with the conceptions of IoT to thoroughly answer the above research questions and benefit the development of BA tools. The research includes some operational objectives, which are discussed as follows: (1) Review and evaluation of occupant-centric concepts; (2) Exploring potentially different case studies of IoT applications; (3) Identification of intersection areas between IoT indicators and SDGs' targets to achieve sustainability; and (4) Developing IoT occupant-centric and new concepts for future building assessment tools.

The contribution of this study lays the foundation for further research examining the role of emerging technologies in enhancing building performance and adaptive ability in response to climate change for SDG elaboration. This paper is structured as follows: Section 2 explains the methods used in this study. Section 3 demonstrates the thematic synthesis map analysis by defining the three cluster themes. Section 4 discusses the intersection areas of IoT occupant-centric concepts between sustainability and SDGs' targets. Section 5 presents a discussion of IoT occupant-centric and new concepts of building assessment tools and future directions. Finally, the limitations, challenges, and conclusions are presented.

2. Materials and Methods

The present study involved a systematic review and initiated a literature screening using specific keywords to compile a comprehensive dataset. This research undertook an extensive review of the literature, consulting two databases and employing search terms (and various combinations with Boolean connectives such as OR/AND). The literature search was conducted in the ELSERVIER (Scopus database), HINDAWI, MDPI, and WOS databases including IEEE papers, encompassing journals, books, and conference proceedings published from 2010 to 2023. A keyword co-occurrence analysis was performed to identify the focus areas within the building performance field, providing a comprehensive understanding and visualizing development trends with correlations of the research topics. Specifically, keywords such as ("assessment tools" OR "building performance") AND ("architecture" OR "building") AND ("occupant behavior" OR "occupant centric"

OR "occupant comfort" OR "thermal comfort") AND ("green buildings" OR "interactive buildings" OR "IoT" OR "advanced data analysis" OR "building operational data" OR "sustainability") AND ("SDGs" OR "climate change") were used.

The study adopted mixed methods throughout the paper. First, for the literature review and collection, we combined two approaches: a bibliometric and systematic literature review (SLR). This step included six stages: (1) identification, (2) screening, (3) eligibility, (4) bibliometric analysis, (5) systematic analysis, and (6) synthesis. Second, the resulting publication databases were individually reorganized using the machine learning tool ASReview Lab, a validated platform, which is an ML tool that reorganizes the selected literature from most relevant to irrelevant [35]. Using these combined approaches can boost the advantages of achieving robust and consistent findings. Following the literature search, this study performed a thematic map analysis to identify different cluster themes and synthesize the qualitative data from the selected literature.

Additionally, the eligible articles were then shortlisted based on their relevance (Supplementary Materials). From the selected databases, the search yielded a combined total of 1008 publications and 710 publications for the initial query and for the second query in sequence, respectively. After removing the duplicates, the remaining records were 76 manuscripts. Subsequently, the publications underwent screening for relevance by evaluating the title and abstract against the inclusion and exclusion criteria, considering scale and context. This screening process resulted in 47 records. Unfortunately, 8 records could not be accessed due to data inaccessibility except for their abstract. The remaining 39 records were thoroughly examined for qualitative analysis. Figure 1 presents the systematic literature review adopted from the PRISMA flow diagram method (it is a method used to refine the databases and quality of reporting as in [36]).

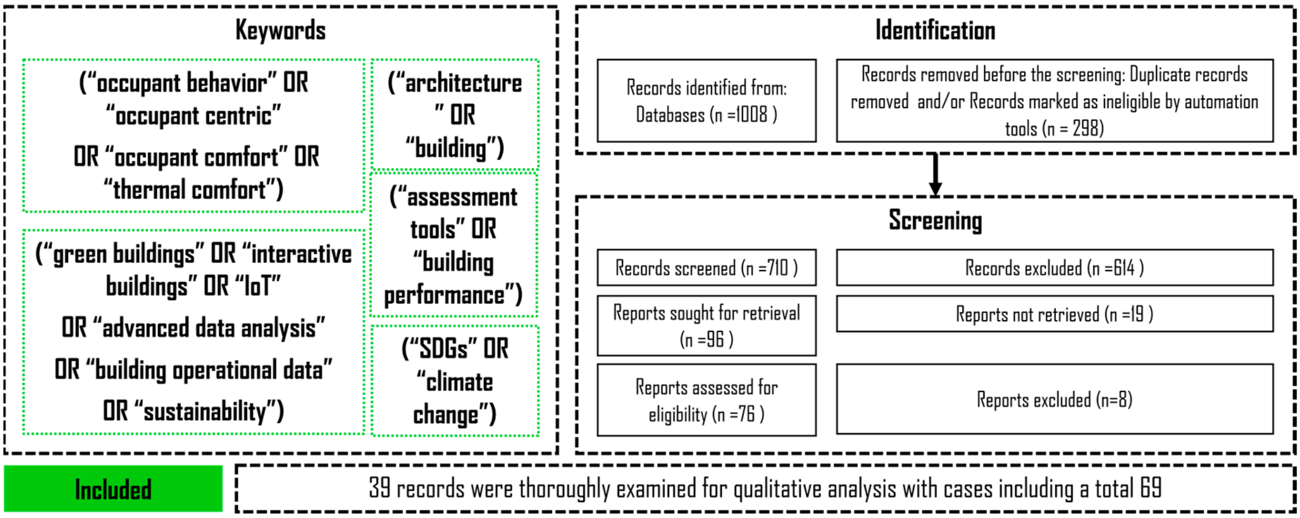


Figure 1. Graphically represented statistics of the systematic literature review. Source: the authors.

In addition to statistical analyses, a bibliometric analysis was conducted. In (Supplementary Materials), we illustrate the case study selection methods after explaining the criteria used to select the case studies, which included Theme, Sub-Category, Title, Keywords, Journal, Publisher, Published, Year, Database Source, Authors, Location, DOI, Theory Based, Aim, General Methodology, Detailed Method, Findings, Limitations, and Gaps, practical or research-based case, and an existing implementation of IoT technologies and applications. Data collection methods were used to gather data from each case study. The data analysis techniques included a thematic analysis for qualitative data or statistical methods for quantitative data collected from IoT sensors. This type of analysis enables an objective assessment of the literature relevant to a theme, a detailed examination of the research landscape within the subject area, and the identification of emerging research trends. The selected articles were analyzed as follows: Step 1: All 69 selected research articles in

Figure 2 were analyzed to review their data using a bibliometric analysis. Step 2: After the review step, the selected articles were summarized by content such as title, keywords, journal, publisher, database source, authors, location, DOI, aim, theory-based, general, and detailed methodology, findings, limitations, and gaps. Step 3: The selected articles were categorized into 3 main cluster themes to detect gaps, challenges, and future approaches in this field. Subsequently, the three deducted cluster themes were categorized as follows:

- Cluster theme 1: Evolution of occupant-centric concepts, which discuss the development of theoretical models of occupant behavior in buildings.
- Cluster theme 2: Development of building performance assessment tools and rating systems, which discuss the development of assessment tools and rating systems in buildings with an understanding of the individual occupants' usage.
- Cluster theme 3: Integration of digital technologies and IoT solutions, which discusses the utilization of ICT building technology and IoT devices for understanding the individual occupants' usage. All are discussed in detail below.

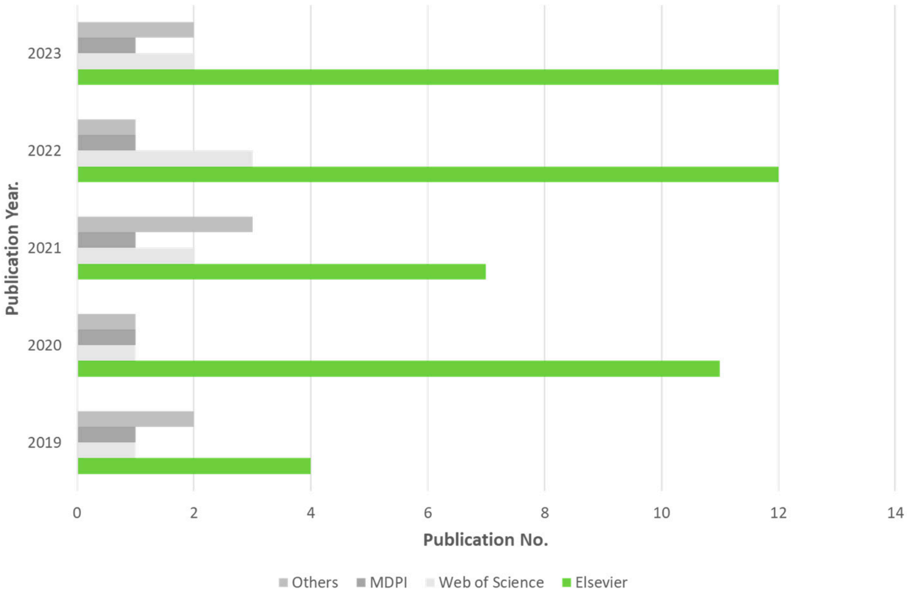


Figure 2. Allocations of the selected 69 articles used in this study according to the year of publication. Source: the authors.

3. Results

3.1. Cluster Theme 1: Evolution of Occupant-Centric Concepts

The first cluster theme includes all the articles on developing theoretical models of occupant-centric concepts (OCs) and occupant behavior (OB). In recent years, there has been a growing focus on enhancing the energy efficiency of building operations, improving indoor environmental quality, increasing occupant satisfaction, and achieving energy savings. This shift towards occupant-centric building (OCB) and occupant-centric control (OCC) reflects a broader trend in the building industry [37]. Occupant-centric control views occupants as central elements of building management. It employs diverse sensing technologies to gather environmental data and interactions between occupants and buildings [38]. By assessing the comfort level, work efficiency, and health status of occupants in different environments, occupant-centric control optimizes the operation of the Environmental Control System (ECS) [39]. Control strategies that derive from occupants' behavior emphasize the interaction between occupants and equipment, enabling the inference of occupants' preferences presented Figure 3.

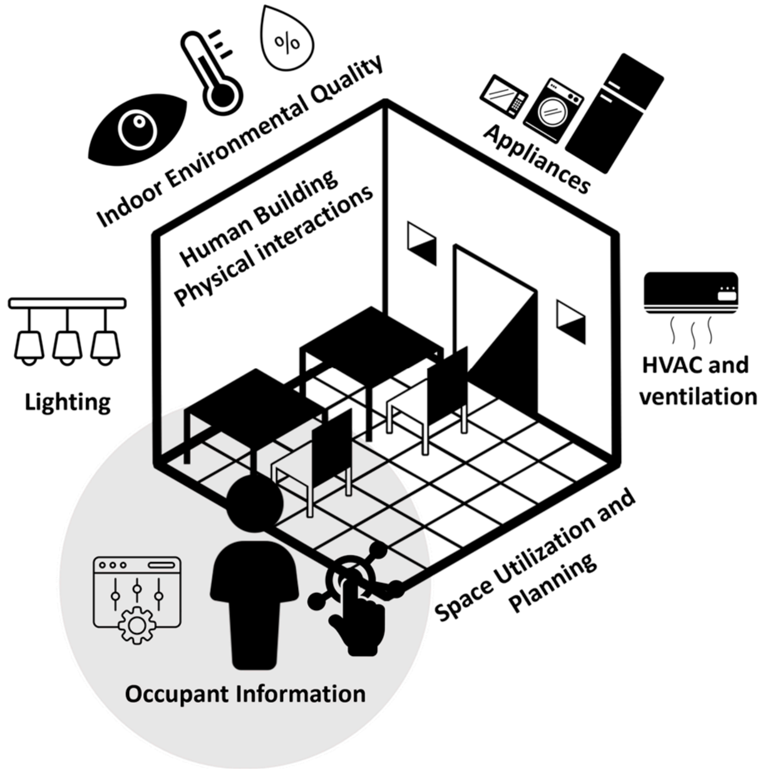


Figure 3. Occupant-centric concepts. Adopted by the authors.

Building performance is nowadays considered to be at the interface between the building and the social sciences [40]. Therefore, it is essential to enhance the evaluation process based on a set of indicators. Building performance is largely defined by six main variables: climate, building envelope, building services and energy systems, building operation and maintenance, occupants' activities and behavior, and indoor environmental quality provided, as placed in the IEA Annex 53 project [41]. Building performance assessment can be categorized into performance-based and feature-specific approaches [24]. The performance-based approach compares performance indicators, such as energy use and carbon dioxide emissions, to determine the efficiency level. With a feature-specific approach, it is necessary to check whether certain specific features are met for credits to be awarded. The energy efficiency level is then determined using the total awarded credit [42].

Additionally, the first step of constructing any assessment tool is to define the key indicators and attributes. It differs upon the aim or the target the end user needs. According to [43], the main domains of indicators are as follows: *smart readiness* indicators (building systems), human-centric indicators (thermal comfort, visual comfort, and IAQ), building life-cycle assessment indicators (LCA) (environmental aspect of the building's operational performance), and life-cycle cost indicators (LCC) (financial indicators aim to increase user awareness about the energy efficiency of buildings). For QEMs and smart readiness indicators, they present human comfort, space allocation, space distribution, access control, space management, building services, flexibility and maintenance, working efficiency, maintenance, space utilization, building intelligence, management and security, and appliances [44]. In addition, the user requirements in [45], ISO 6241-1984 (E) are listed as follows: suitability of space, durability, tactility, dynamic requirement, tightness, stability, fire safety, safety in use, visual, hydrothermal, air purity, acoustical requirement, hygiene requirement, and economic requirement.

Investigating building performance quantification systems through the use of KPIs is vital to propose a new development metric. According to [20], KPIs are the most efficient way of measuring building performance indicators. For instance, at the building level, the 2010 EPBD recast [46], European Commission [47], and Building Performance Institute

Europe (BPIE) [48] supported the move forward to smart buildings (SBs). The EPBD has introduced SRI in buildings to measure the performance of SBs. Moreover in [49], it formulated a quantitative approach for characterizing energy flexibility, taking into account not only technical aspects or services at the building level but also incorporating its interaction with the energy system, occupants, and other relevant factors. The indicators were categorized into two primary groups: low and high frequency. Low-frequency factors encompass aspects such as climate change, economic factors, technology improvement, energy costs, and building utilization. On the other hand, high-frequency factors include energy use, energy prices, internal/solar gains, user behavior, hourly energy prices, and ambient temperature. Table 1 presents a summary of occupant-centric metrics described in the performance literature.

In [50], the authors studied the previous literature to establish KPIs and categorized these indicators into four pillars as follows: financial indicators (FM cost, current replacement value, maintenance backlog, capital renewal, and maintainability), physical indicators (physical condition degree, resource consumption, indoor environment, property, and real estate), functional indicators (productivity, space utility, adequacy of space, and logistics), and survey-based indicators (POE, learning environment, community, and appearance). In [51], fuzzy TOPSIS was used to select the best alternative or to rank a group of alternatives, which have different criteria and attributes. This technique has been proven through several studies that it is capable of overcoming the uncertainties that arise when considering the opinions of individuals in the weight determination processes and its ability to transform linguistic data into crisp numerical values. The main purpose of this cluster is to highlight the occupant-centric approaches and concepts.

Table 1. Summary of the occupant-centric metrics discussed in the performance literature.

Code	OC Performance Indicators	Attributes	Example Ref.
O.C. M.1	Occupant Information	Social norms, personal attitude, degree of control, comfort experience, clothing level, and activity rate.	[30,52,53]
O.C. M.2	Lighting Controls/Automation	Comfort, scheduling, daylight harvesting levels, light status, and energy control.	[54,55]
O.C. M.3	Indoor Environmental Quality	Humidity, air temperature, visual, acoustic, and ventilation aspects.	[56,57]
O.C. M.4	HVAC Controls/Automation	Weather data, natural lighting information, natural ventilation information, comfort, scheduling, daylight harvesting levels, light status, and energy control.	[58,59]
O.C. M.5	Occupant interactions	Blind, window, and fan controls.	[60,61]
O.C. M.6	Space Utilization and Planning	Activities and usages, orientation and view, fenestration proportions and scale, and envelope control.	[54,55,62]
O.C. M.7	Building Operations	Energy control, management, and facility systems.	[63,64]

A New Paradigm for Occupant-Centric Control

The limitations of current building assessment tools are how it is possible, at a practical assessment tool level, to analyze building portfolios in light of the organizations' requirements while combining building science and social aspects. Even if the building has an efficient energy source, it will still be the inhabitant who ultimately determines how energy-efficient a space will be. Occupants should also be offered a better control over their comfort conditions through improved usability and a better understanding of user expectations, attitudes, perceptions, and behavior. So, more sophisticated evaluation strategies that interrelate human factors directly with the physical performance of a building should be developed. One of these research gaps is the lack of unified assessment attributes that can be considered the primary aspects that can be adopted in different regions to make consistent assessments and comparisons among different regions [65,66]. So, this developed system should be globally flexible to be adaptable to various contexts. This means the model constructed in this study can be updated and reconfigured based on the main inputs from each context. The developed system should be implemented from the preliminary stages of a design considering the building life-cycle as pre-design, design, and post-design. Figure 4 presents a comprehensive comparison between the conventional BA system and the future occupant-centric BA system.

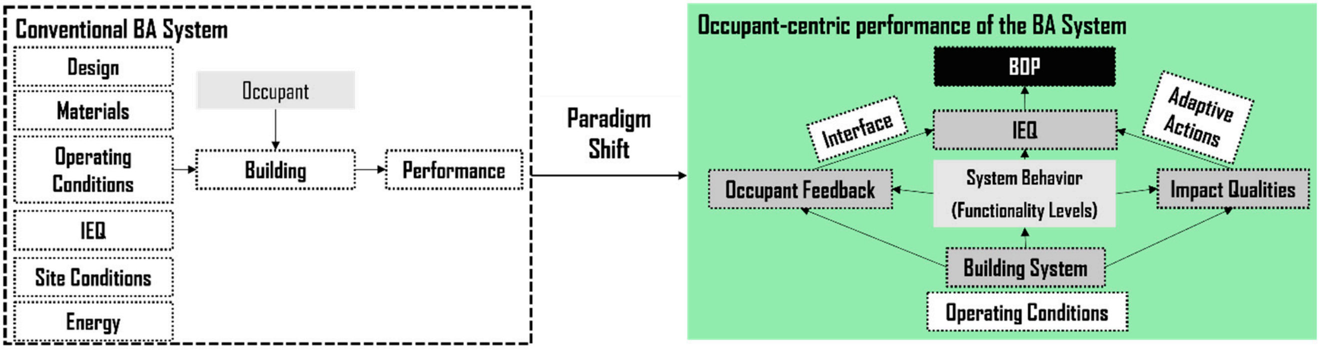


Figure 4. Comprehensive paradigm-shifting comparison between conventional and occupant-centric BA systems. Source: the authors.

3.2. Cluster Theme 2: Building Performance Assessment Tools and Rating Systems

The second group concentrates on methods for comparative analysis, specifically comparing various sustainability assessment standards, although its emphasis is largely contextual. Energy classification seeks to provide data at the performance level, that is, the efficiency level and carbon emissions, to the building stakeholders, including the users of the building, owners, and designers [67]. Energy performance diagnosis involves determining the existence of faults and their causes in buildings to improve the performance of buildings in addition to energy benchmarking, certification, and labeling [68]. In [69], the authors divided the main usage of building performance assessment into four items as follows: *building environment assessment schemes*, *energy certification*, *whole-building benchmarking tools*, *and hierarchical assessment and diagnosis tools*. The existing worldwide building assessment tools include *LEED*, *BREEAM*, *CASBEE*, *DGNB*, *Green Star*, *Green Mark*, *VGBC*, *Green Pyramid*, *AIIB Rating System*, *and EMs*. Although different design codes have been developed in the past decade, there is little published information that assesses the effectiveness of their implementation. Although there are different assessment tools, these methods assess buildings from the perspective of the impact and sustainability of the built environment. It has also been reported that a reduction in energy use is not necessarily what occurs in all smart buildings [70]. In addition to the assessment tools, some energy codes have emerged, such as the *EU Energy Performance of Buildings Directive*, *Code for Acceptance of energy efficient building construction (GB 50411-2007)* [71], *ASHRAE* [72], *(ISO 6241-1984 (E))* [45], *Performance of Building Standards to arrive at the user requirements as data for user satisfaction and comfort*, *Indoor air quality standard (GB/T 18883-2002)* [73], *and external windows and doors (GB/T 7106-2008)* [74]. The Building Performance Evaluation (BPE) assesses the effectiveness of structures, measuring not only energy efficiency but also environmental conditions and occupant quality by gathering and examining both quantitative and qualitative data [75]. In light of these considerations, the Royal Institute of British Architects (RIBA) [76] from the UK has categorized the activities required to enforce the rules of building performance evaluation.

Moreover, building assessment schemes are used to assess buildings' smartness and sustainability performance through life-cycle approaches. In [20], the authors identified four primary features of smart buildings: climate response, grid response, user response, monitoring, and supervision. At the same time, in [77], it is ascertained the five fundamental features of smart buildings: automation, multi-functionality, adaptability, interactivity, and efficiency [78]. The authors established the principal key indicators for assessment tools, categorizing them into key factors such as climate (including temperature, humidity, and solar radiation), building-related characteristics (encompassing type, area, orientation, and materials), building service systems and operation (involving space cooling/heating and hot water supply), user-related characteristics (involving user presence), and the building occupants' behavior and activities (including turning lights and TVs on/off). Additionally, they considered social and economic factors (such as the degree of education and energy cost) and indoor environmental quality requirements (such as preferred indoor air quality and comfort). In [79], the authors highlighted the identification of both single and multiple criterion assessments that are essential for inclusion in the building evaluation process. These criteria encompassed aspects such as energy use, operational primary (non-renewable) energy, life-cycle energy use, and embodied energy, with a specific emphasis on greenhouse gas production, particularly CO_2. Additionally, the assessment covered indoor air quality, with a focus on the thermal environment, thermal comfort in unair-conditioned buildings, operating plant load, and various costs, including initial or capital costs, operating costs, fuel, power, maintenance, etc., along with life-cycle costs (sum of the initial plus discounted future costs). Furthermore, their considerations extended to other environmental degradation practices, such as using nuclear fuel, atmospheric pollution, and using timber from non-sustainable forests.

Furthermore, users have the option to conduct several criterion assessments related to energy use and loads, including peak, monthly, and annual loads (heating and cooling); monthly and annual energy use breakdown; and annual site and primary/source energy. For indoor thermal comfort, the assessments cover the highest and lowest operative and radiant temperatures, relative humidity, and discomfort degree hours [80]. Life-cycle costs are evaluated in terms of the initial, operating, and maintenance costs, while the life-cycle of embodied energy in construction relies on factors such as building geometry, material data, embodied energy tables, and the building's expected lifetime [81]. Considerations of CO_2 gas production and other environmental degradation practices, such as the use of nuclear fuel, atmospheric pollution, and the utilization of timber from non-sustainable forests, are also incorporated into the assessment framework [82].

The development of an assessment tool that enables the understanding of buildings aims to present decision-making information on how a building works [83]. There are many available techniques to assess a building's performance. There are three different categories of energy modeling techniques: white models (engineering models), black models (statistical methods), and gray models (hybrid models) [84]. Some of them depend on a qualitative approach and others on a quantitative approach. This depends on the indicators and the target of the evaluation tool [85]. Some of these methods can be summarized as the calculation method: assessing all the crucial performance indicators within buildings; measurement-based method: involves measuring the technical performance of buildings; visual documentation: keeping a visual record, which includes photographs of design features, videos, and thermographic images when applicable, to emphasize features and pinpoint issues; survey/questionnaire: relies on a selected sample of occupants to provide information regarding the building and its usage; structured discussions and interviews with participants; and hybrid approach: utilizing various evaluation methods in combination [86].

In ref. [87], the authors developed and validated a comprehensive framework for the construction of rating tools considering societal and governmental factors by conducting in-depth interviews with a variety of Pakistani stakeholders. Following the interview data stage, a final framework with key indicators reflecting each of the five sustainability characteristics was developed. In ref. [44], the authors created a framework for evaluating the sustainability of residential buildings in Pakistan that is specially designed to place a greater emphasis on social issues. According to [67], the building performance score (BPS) assess sustainability in terms of the three key elements of environmental, economic, and social concerns. It was made to develop a score model for building performance without reducing the environmental impact. In ref. [88], the authors introduced a methodology framework for dynamic LCA that can consider dynamic changes in building attributes over time and capture interactions between various sustainability indicators. The main purpose of this cluster is to develop BA tools while considering the existing benchmarking, quantification tools, and models.

3.3. Cluster Theme 3: Integration of Digital Technologies and IoT Solutions

The third category focuses on the utilization of ICT building technology and IoT devices for understanding the individual occupants' usage. In the 2018 recast of the energy performance of building directives, the European Commission [29] emphasized the need for improved schemes to ensure the best possible evaluation of the actual energy performance of buildings, considering all the parameters related to their construction and operation not only to improve the building performance certification process but also to provide more thorough reports to end-users. Even though the introduction of smart meters, sensors, and IoT solutions has a considerable role in an abundance of energy-related data, the majority of the current BA tools and certificates do not leverage their existence to reach accurate ratings. So, how does a building satisfy the needs of its occupants and can its performance be evaluated?

Moreover, sustainable advancements in modern information and communication technology (ICT) and smart and sustainable building technologies are becoming more vital and adaptive to dynamic occupant behavior [89]. Buildings can now be optimized to provide comfortable and responsive environments to their occupants. Siemens has indicated that the use of smart building technologies could reduce the energy consumption of buildings by 30% [90]. Smart and sustainable buildings are equipped with smart metering, information and communications systems, security systems, and intelligent and responsive systems that can interact with building occupants and ambient conditions to provide a comfortable indoor environment [91,92]. According to [93], progress in smart and sustainable buildings is being achieved by four drivers: intelligence (level and degree of intelligence), enterprise (firms using the buildings), materials and design (the physical forms of buildings), and control (interactions between occupants and buildings). Laypeople without expertise in architecture, urban planning, or other building-related fields also refer to stakeholders who represent building demand and make decisions about private and public buildings. BA tools for laypeople have not been systematically developed. Consequently, these tools should be easily and thoroughly created for laypeople.

The concept of emergent behavior in *IoT* systems is gaining more attention within *IoT* control. The *IoT* presents a significant economic way that affects all industries, and it is expected that USD 11 trillion will be spent via *IoT* technologies by 2025 [94]. There are many challenges posed by rapid digitalization, new applications, and the interoperability of connected devices for increasing the demand for human health and productivity [95]. According to market insights of *IoT* reports, the number of *IoT* devices is expected to grow to 22 billion by 2025 versus 12 billion non-*IoT* devices [96]. There is also a targeted intent to reduce 20% of the energy and resources used in buildings by 2025, according to the US Environmental Protection Agency. Energy consumption around the world will increase by 56% in 2040, according to the U.S. Energy Information Administration [97]. Furthermore, the EU's 2050 roadmap is targeted at reducing energy and gas emissions by about 40%. IoT-based technologies enable collecting data to assess how buildings behave, in addition to proposing data-driven solutions to enhance the indoor air quality (IAQ), energy consumption, and carbon footprint. IoT ecosystems could improve energy efficiency by filling the gap between simulations and real measurements. They study the energy demand increases from nearly 36% to 39% in 2050. In the end, they present different scenarios related to investigating routes by applying technology and networks to reduce energy [98]. This promotes the open availability of data so that third parties can offer valuable services such as enhancing the research and educational environments in universities [99]. The study in [100] developed an IoT lab system to monitor overall activities not only in the research labs but also in the whole building.

Additionally, different optimization models have been discussed, including physical-based (white box), data-driven (black box), and grey box (hybrid) approaches [56]. The physical-based mass model can simulate energy performance and indoor environment through software tools: *EnergyPlus 24.1.0*, *TRNSYS v18*, *eQuest 3.65*, *or OpenModelica 1.23.0* [101]. Agent-based modeling

(ABM) is focused on modeling the interaction between building systems and occupants. In [102], the authors formulated a multi-agent-based control framework aimed at identifying conflicts between building energy consumption and occupant comfort. This framework segmented building automation into several subsystems, employing a distributed collection of agents that included both a central agent and local agent to replicate the occupants' preferences and needs. However, the model faced limitations, particularly concerning the validation of agent-based simulation, especially in stochastic occupancy modeling, which requires enhancement with real-world data. Additionally, there was a lack of autonomy observed in many building agents and human agents, resulting in controlled indoor environment sensors overseen by authorized agents only [103]. According to [104], the occupants could regulate their behavior patterns to decrease energy consumption if provided with knowledge about energy-saving activities. In [105], the authors proposed a framework for IoT indicators that consists of three main areas: input data, throughput that represents controlled variables, and outcome or impacts. In addition, the study presented how the IoT deals with its building under four main levels: modes of users' preferences and activities of occupants, space parameters, building control, and organizational aspects, such as costs, system maintenance, data, and facility management. It illustrated the IoT ecosystems in buildings as complex models for assessment tool development. The main purpose of this cluster is to illustrate the different aspects of IoT integrations into BA tools. Table 2 presents different study cases of IoT applications in sustainable buildings.

Table 2. Case study summary of IoT applications in sustainable buildings.

Example Ref.	Indicator Code	IoT Application	Key Technologies	Aim
[106]	*IoT Ind.1*	Occupant devices and wearables	Utilizing wearable devices, location awareness through Bluetooth low-energy (BLE) infrastructure, and image recognition with barcode tags and RFID technology.	- Assist users with the necessary information, creating engaging content, and ensuring interactive experiences. - Monitor and adjust indoor environment conditions based on users' locations.
[54]	*IoT Ind.2*	Occupancy sensing intelligence and data	Leveraging smartphone applications, occupancy sensors, Microsoft's Power Business Intelligence (Power BI) platform, and facilities management services provided by CBRE.	- Turn off electronics in the area when not in use. - Coordinate schedules and track colleagues. - Book a locker. - Accommodate 2850 employees across 1080 desks. - Customize preferred lighting and thermal comfort preferences. - Include options for individuals with disabilities.
[107]	*IoT Ind.3*	Geo-fencing and space utilization	Utilizing IoT software, sensors, and cloud platforms for data analysis.	- Adapt the operating system based on the user's proximity. - Set the desired temperature and schedule its activation based on the user's location. Integration with one's car can synchronize air heating or cooling with the estimated time of arrival from the navigator. - Monitor the condition of the indoor environment based on users' positions.

Table 2. *Cont.*

Example Ref.	Indicator Code	IoT Application	Key Technologies	Aim
[108]	*IoT Ind.4*	Building a physical structure	Utilizing IoT software, sensors, and cloud platforms for data analysis.	Adapt the integration of the building's orientation and form and the system.
[109]	*IoT Ind.5*	Monitoring space utilities, such as lighting and HVAC	Leveraging IoT software, sensors, and cloud platforms for analysis, accessible through smartphones, tablets, or PCs.	Enable building managers to efficiently monitor multiple units and buildings, ensuring optimal operational efficiency, minimal energy consumption, and reduced overall life-cycle costs. Smart thermostats use occupant movement data to automatically adjust the temperature as needed.
[110]	*IoT Ind.6*	Energy and facility management	Utilizing sensors, actuators, smart plugs, smart meters, and a universal home gateway (UHG).	Regulating high peak loads or during periods of high pricing can lead to savings in lighting, cooling, and overall costs, as the system can effectively shut down electronics in unused spaces.
[111]	*IoT Ind.7*	Indoor Environmental Quality and Analysis	Utilizing sensors, actuators, smart plugs, smart meters, and a Hadoop system for the ingestion and analytics of big data.	Manage oxygen levels and luminosity and detect/smooth hazardous gases or smoke.

4. Discussion

Building assessment (BA) tools have been around for a long time and emerged in the 1970s as a response to growing concerns about energy use in buildings [112]. These tools have been instrumental in promoting sustainable building practices. In the early days (1970s–1990s), BA tools were primarily focused on measuring a building's energy efficiency [113] by looking at the static features of the building itself, like the amount of insulation or the size of the windows. However, these tools did not consider how the building was used by people or how occupant behavior impacted energy consumption [33]. This meant that the assessments were not always as accurate as they could be. By the 2000s and 2010s, BA tools became more comprehensive [114]. They started to take into account things like water usage, indoor air quality, and the materials used in construction. This was a positive step, but these tools still relied on standardized user profiles. This meant that the unique needs and behaviors of real people were not always reflected in the assessment [113].

Today, in the 2020s, the world of building design and operation is becoming increasingly complex [115]. We are seeing a rise in smart technologies, like the Internet of Things (IoT), and a growing awareness of the impact of climate change. Unfortunately, the existing BA tools are struggling to keep up [29]. The current tools cannot integrate real-time data from IoT sensors, which could provide a much more accurate picture of how a building is being used [29]. They also do not consider how climate change, with its extreme weather events, will affect a building's performance over time [29]. Additionally, they do not address the evolving needs of building occupants who want more personalized comfort and control over their environment [116]. The good news is that there is a need for change, and this change is coming [117]. The next generation of BA tools needs to be more adaptable and responsive [118]. This means embracing real-time data, factoring in climate change, and placing the needs of the people who use the building at the forefront [119]. By addressing these shortcomings, BA tools contribute to a future where our built environment is truly sustainable and adaptable.

4.1. Intersectional Areas of IoT Occupant-Centric Concepts between Sustainability and SDGs' Targets

The IoT plays a crucial role in advancing SDGs by offering data-driven insights into human interactions with the environment. Connected sensors can continuously monitor real-time air quality or water usage, issuing alerts when pollution levels are unsafe, or when resources are used inefficiently [120]. This empowers us to make informed decisions about our surroundings and enables the development of smarter, sustainable cities that are resilient to climate change and natural disasters. Furthermore, IoT solutions, such as smart homes and connected health systems, contribute to enhancing access to education and healthcare services, particularly for underserved populations or those in rural areas. These technologies provide real-time information and support services, addressing critical needs precisely when they arise [121]. Unlocking the potential of IoT technologies for sustainability demands strategic planning and implementation across various sectors. To successfully leverage these technologies and achieve the SDGs by 2030, global governments must invest significantly in building a robust infrastructure that facilitates seamless connectivity among diverse devices [122]. Based on the study presented above, Figure 5 illustrates the correlation areas between the IoT and SDG targets to achieve sustainability.

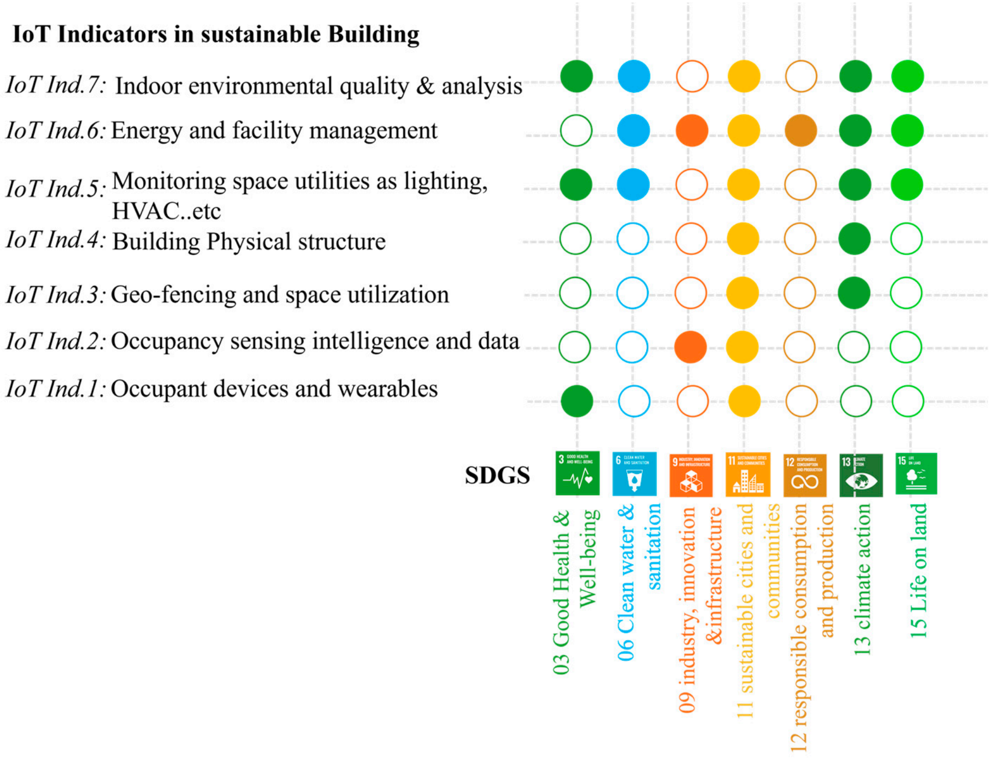


Figure 5. Intersectional areas between IoT indicators and SDGs' targets to achieve sustainability. Source: the authors.

Based on the previous literature, some interpolation areas were deduced. The intersection of the three cluster themes of building assessment tools, occupant-centric concepts, and the IoT is essential nowadays. This can limit the performance gap between the real and simulated building performance under the circumstances of climate change [123]. Measuring real behavioral change is challenging [124]. Researchers should conduct investigations on standardizations of the lack of approaches for evaluating IoT solutions. Generally, there are methodological and knowledge gaps about the ability of a building to adapt and have flexibility for its use. There is a need for supplementary methods to relate socio-economic trends and new technological developments. How can we promote a new generation of building assessment tools under the circumstances of climate change, user dynamics, and the IoT? Figure 6 illustrates the correlations and interactions among the three cluster themes of building assessment tools, occupants, and the IoT. Graphical illustrations were created by the authors of this study and logos were adapted from [1]. Research areas, gaps, and suggested solutions are indicated as well. The following thematic synthesis map analysis presents the deducted gaps as follows: a methodological gap as a performance gap between real and simulated building performance under climate change. Therefore, there is a need for additional reliable models to simulate occupant behavior and actions. In addition, it proposes a new generation of BA tools aimed towards achieving SDGs' targets, climate change, user dynamics, and IoT. Second, a knowledge gap was inferred from the challenges in measuring real behavioral change and a lack of standardizations of approaches for the evaluation of IoT solutions. Standards and theories are needed to adapt such technologies into our buildings.

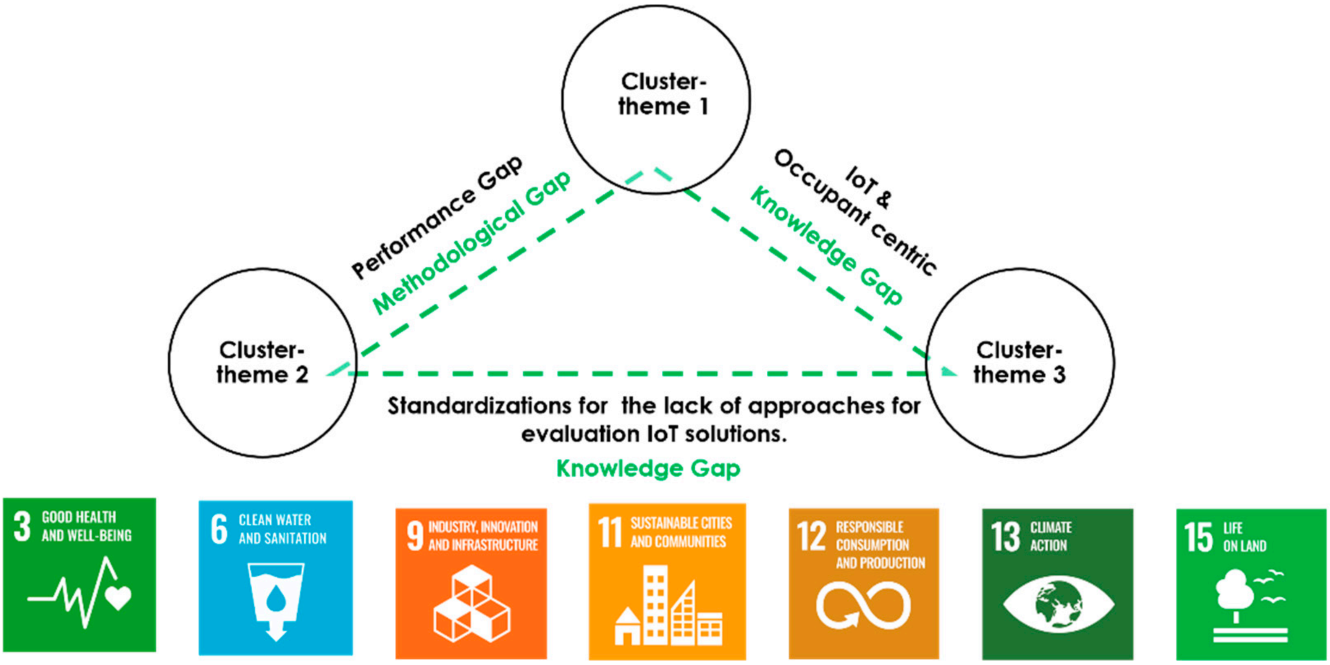


Figure 6. Thematic map analysis between IoT occupant-centric concepts, BA tools, and SDGS' targets. Source: the authors.

4.2. IoT Occupant-Centric and New Concepts for Building Assessment Tools

Furthermore, the selection of the impact quality of services derived from the literature analysis of IoT case studies, critical adaptive solutions, and considerations of occupant-centric concepts includes choosing the necessary indicators and collecting the required data attributes. Subsequently, data clustering becomes imperative for exploring the collected data and organizing them effectively. This requires identifying the relevant fields for the building assessment tool, such as the type of building under examination, prevailing climatic conditions, user demographics, occupants' requirements, building utilities, physical structure, local community, key stakeholders, practitioners, existing and interconnected systems, future opportunities, and other pertinent factors. Hence, the identification of indicators plays a crucial role in formulating the method for assessing building performance. Consequently, the IoT occupant-centric system consists of the three phases of input, interactive process of functions phase, and outcomes, which contribute to the emergence of the quality of services. Figure 7 illustrates how IoT occupant-centric systems intersect the data of any space between physical measurement for building performance and users' requirements. In addition, the concluded impact quality of services' indicators emerges from each paradigm.

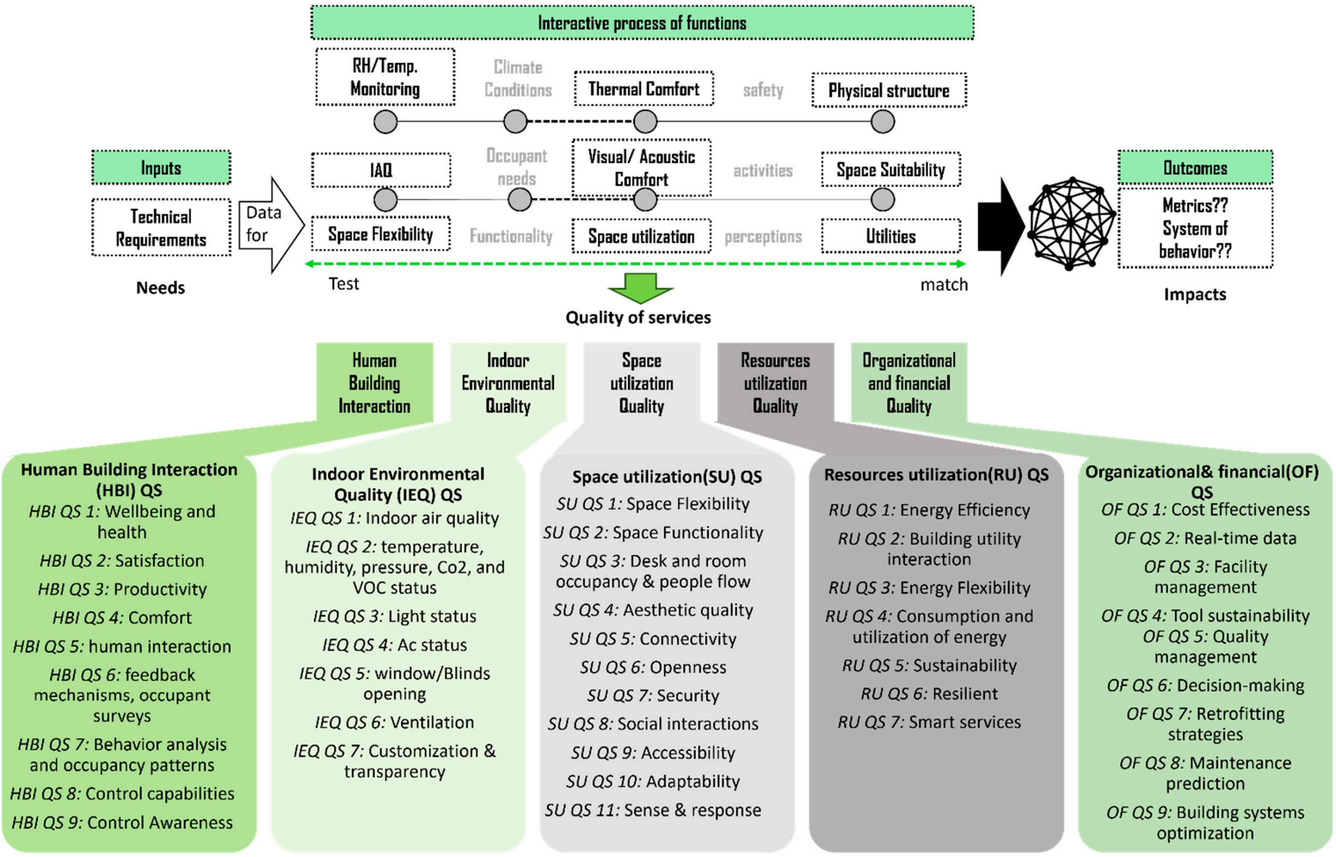


Figure 7. IoT occupant-centric system and the proposed quality of services' indicators. Source: the authors.

Figures 8–12 illustrate the correlations between the proposed tool for IoT occupant-centric quality of services' indicators and SDGS' targets. The integration of IoT technologies in buildings can contribute to achieving SDGs by enabling occupant-centric solutions that enhance sustainability, efficiency, and user experience. The IoT can support occupant-centric approaches aligned with the goals of SDG3, SDG6, SDG9, SDG11, SDG12, SDG13, and SDG15. IoT sensors and devices can monitor energy usage in real-time, optimize HVAC systems, and automate lighting controls based on occupancy patterns, leading to reduced energy consumption and lower carbon emissions. IoT sensors can monitor indoor air quality, temperature, humidity, and lighting levels to create a healthy and comfortable indoor environment for occupants, thereby improving their well-being and productivity. IoT-enabled water monitoring systems can track water usage, detect leaks, and optimize irrigation systems, promoting efficient water management practices within buildings and contributing to water conservation efforts. IoT technologies in buildings can support smart city initiatives by enabling data-driven decision-making processes, optimizing resource utilization, and enhancing the overall quality of life for urban residents through improved building performance and occupant comfort. IoT-enabled smart meters and devices can promote responsible energy consumption practices among building occupants, encourage waste reduction, and support sustainable production processes within the built environment. By leveraging IoT technologies to create occupant-centric solutions that prioritize sustainability, health, and well-being, buildings can play a significant role in advancing the SDGs and promoting a more sustainable and resilient future for both occupants and the environment.

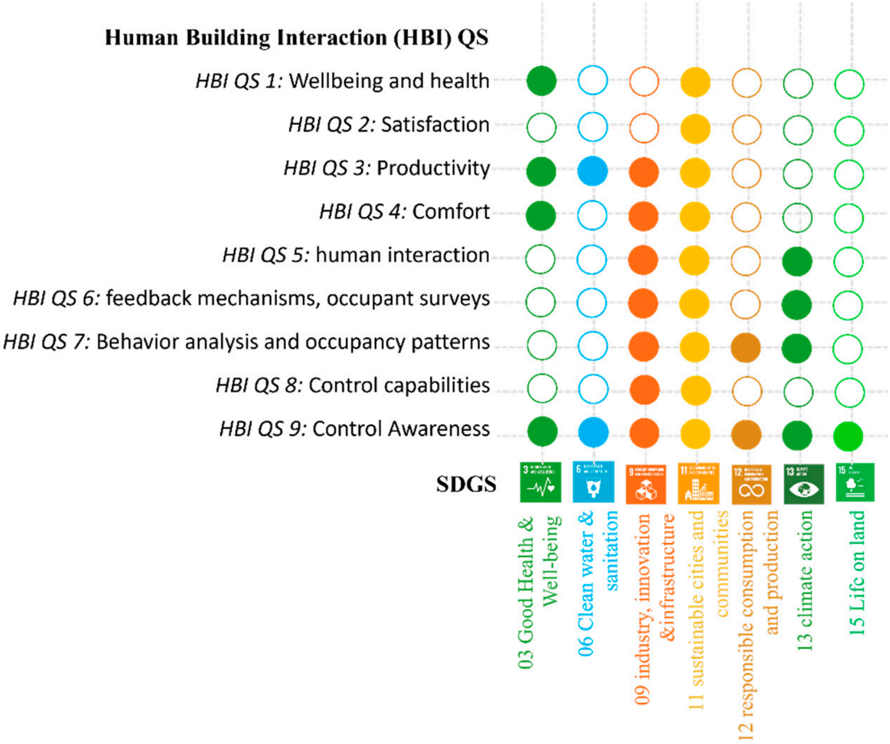


Figure 8. Correlations between IoT occupant-centric (HBI) QS indicators and SDGS' targets. Source: the authors.

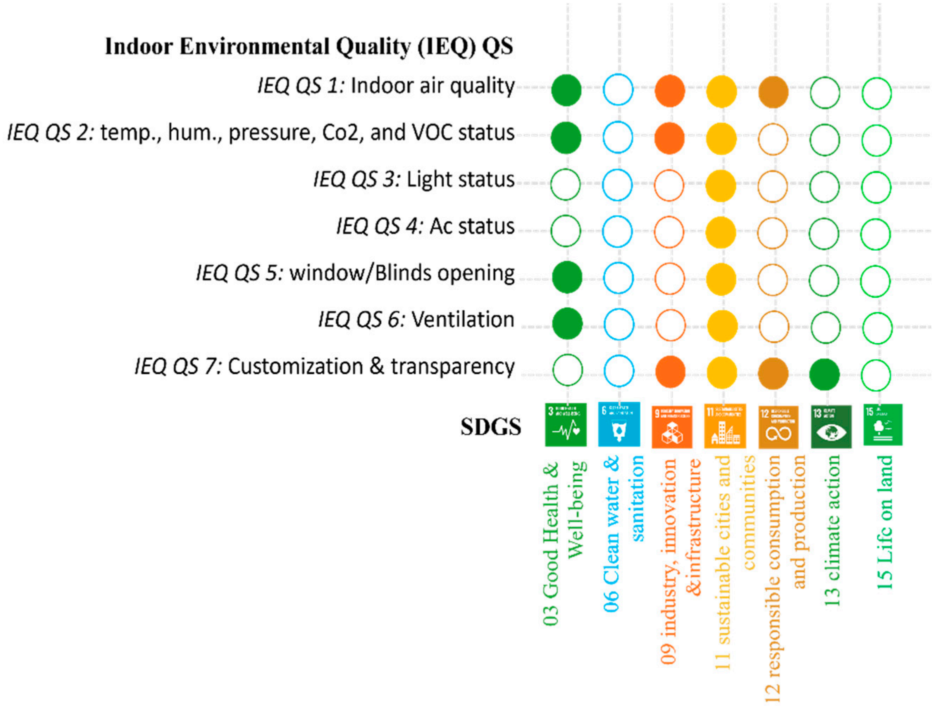
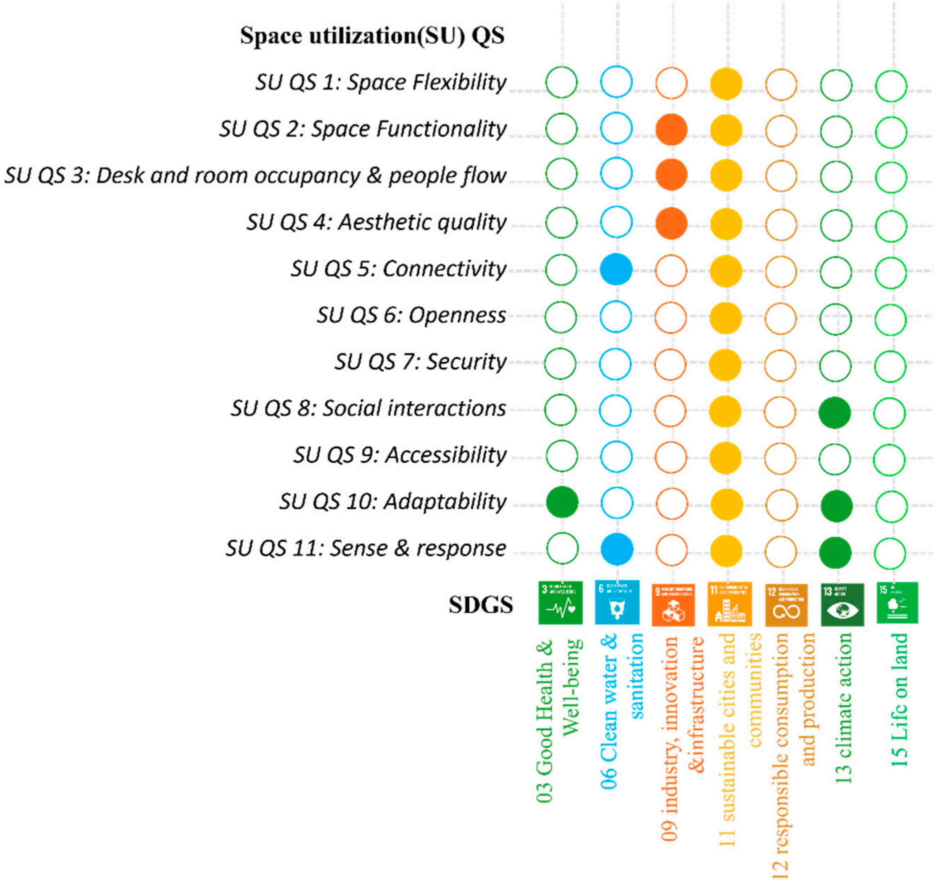
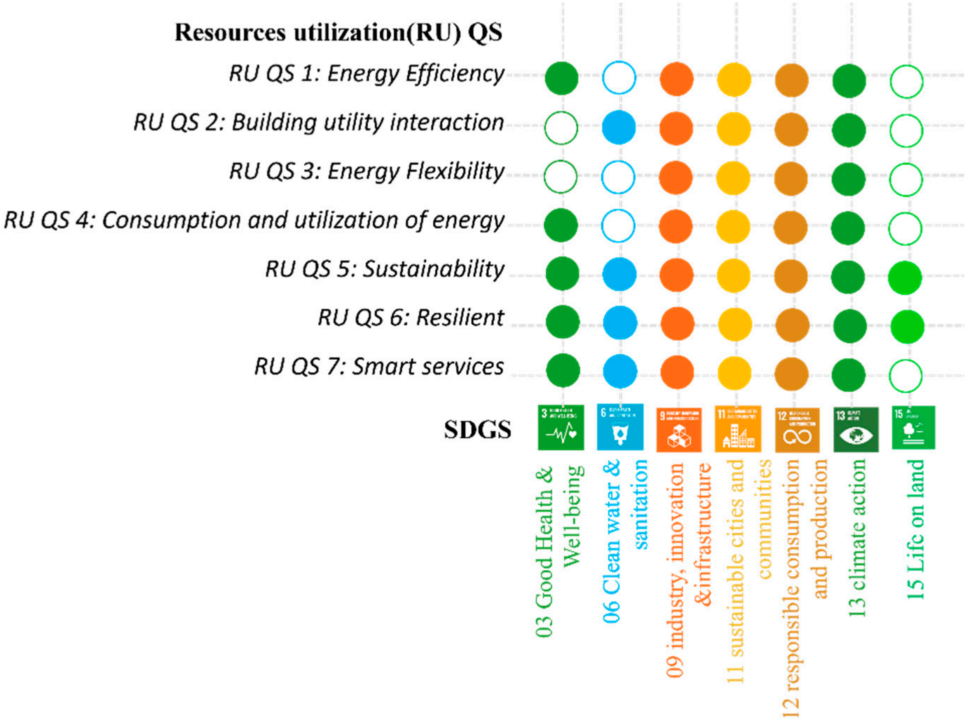


Figure 9. Correlations between IoT occupant-centric (IEQ) QS indicators and SDGS' targets. Source: the authors.



Space utilization(SU) QS	03 Good Health & Well-being	06 Clean water & sanitation	09 industry, innovation &infrastructure	11 sustainable cities and communities	12 responsible consumption and production	13 climate action	15 Life on land
SU QS 1: Space Flexibility	○	○	○	●	○	○	○
SU QS 2: Space Functionality	○	○	●	●	○	○	○
SU QS 3: Desk and room occupancy & people flow	○	○	●	●	○	○	○
SU QS 4: Aesthetic quality	○	○	●	●	○	○	○
SU QS 5: Connectivity	○	●	○	●	○	○	○
SU QS 6: Openness	○	○	○	●	○	○	○
SU QS 7: Security	○	○	○	●	○	○	○
SU QS 8: Social interactions	○	○	○	●	○	●	○
SU QS 9: Accessibility	○	○	○	●	○	○	○
SU QS 10: Adaptability	●	○	○	●	○	●	○
SU QS 11: Sense & response	○	●	○	●	○	●	○
SDGS	3	6	9	11	12	13	15

Figure 10. Correlations between IoT occupant-centric (SU) QS indicators and SDGS' targets. Source: the authors.



Resources utilization(RU) QS	03 Good Health & Well-being	06 Clean water & sanitation	09 industry, innovation &infrastructure	11 sustainable cities and communities	12 responsible consumption and production	13 climate action	15 Life on land
RU QS 1: Energy Efficiency	●	○	●	●	●	●	○
RU QS 2: Building utility interaction	○	●	●	●	●	●	○
RU QS 3: Energy Flexibility	○	○	●	●	●	●	○
RU QS 4: Consumption and utilization of energy	●	○	●	●	●	●	○
RU QS 5: Sustainability	●	●	●	●	●	●	●
RU QS 6: Resilient	●	●	●	●	●	●	●
RU QS 7: Smart services	●	●	●	●	●	●	○
SDGS	3	6	9	11	12	13	15

Figure 11. Correlations between IoT occupant-centric (RU) QS indicators and SDGS' targets. Source: the authors.

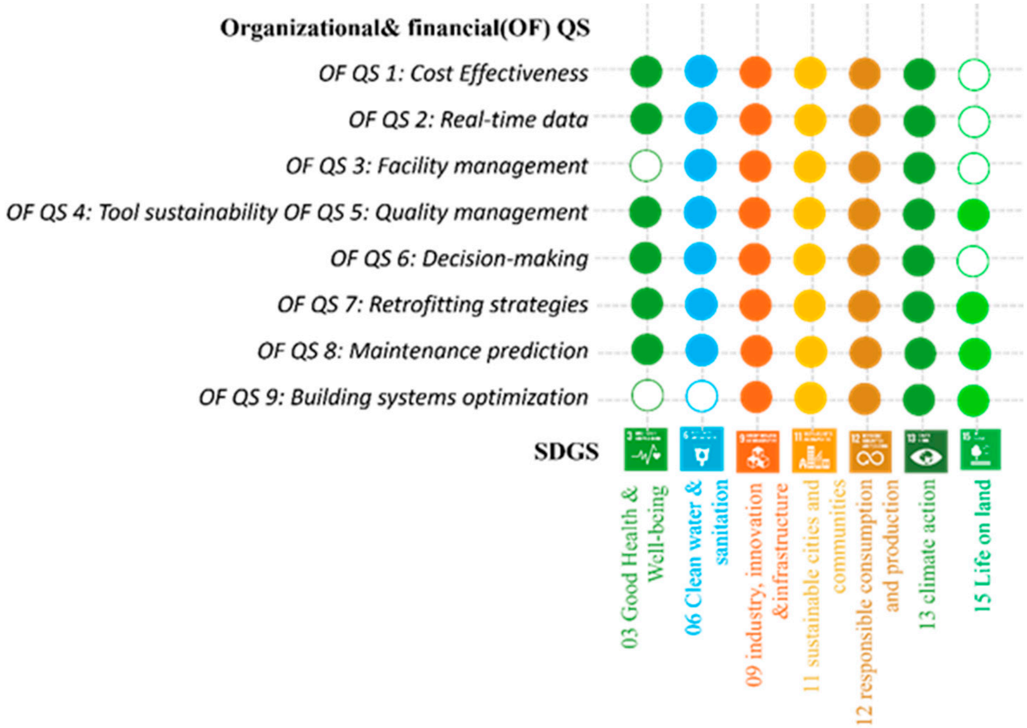


Figure 12. Correlations between IoT occupant-centric (OF) QS indicators and SDGS' targets. Source: the authors.

4.3. Current and Future Possible Research Areas

Last but not least, the forward-looking perspective of this study not only underscores the immediate impact of IoT integration but also positions it as a catalyst for future sustainability goals. In this final section, the article meticulously identifies current gaps in the literature and provides valuable insights into potential avenues for future research. Thus, it not only contributes to the ongoing discourse but also charts a course for advancing knowledge and practices in the intersection of IoT, occupant-centric approaches, and sustainable development. Emphasizing innovation at its core, this work endeavors to transcend traditional paradigms. It envisions the groundbreaking generation of BA tools that not only respond to the demands of the present but serve as catalysts for a sustainable future. The linchpin of this transformation lies in the fusion of IoT technology with occupant-centric interdisciplinary principles. Figure 13 illustrates the proposed new generation of IoT occupant-centric tool outcomes within SDGs' targets for future work areas. By leveraging the capabilities of IoT occupant-centric tools to improve building performance, enhance user experience, and promote sustainability, stakeholders can make significant progress toward achieving the targets set forth by the SDGs, ultimately leading to a more sustainable and resilient built environment.

In future investigations, a three-layer decision-making framework can be employed to identify the various IoT occupant-centric attributes and to establish a framework based on a decision-making method. Some of the indicators can be evaluated based on a structured questionnaire with the integrated stakeholders (private, public, and governmental agencies) and observation. At the same time, others will be based on measuring the in situ status using IoT-based building physical monitoring and observations. The aim is to define the basic variables actions and systems that include occupant use behaviors in the building space, and this will be updated in the upcoming model tools and analysis. Lastly, this framework will be able to propose adaptive solutions for various dynamic states. It will take the input data of occupants and buildings, calculate the different scores and weights for each indicator, and then suggest various solutions for users, owners, or designers of how these spaces can be more efficient and reach higher building performance targets that could also mitigate climate change impacts in the future. The verification and validation of this model can be used by IoT, BEMS Sensors, and agent-based modeling (ABM) systems to generate reference models with precise datasets. The main goal of this tool is to be globally adaptable and flexible in various contexts. This will happen by modifying the data selection and inputs and reupdating the weighting formula results based on the different key input data and correlations. In addition, when evaluating the existing building in specific conditions, users can use this tool to modify and re-evaluate the existing state of their spaces based on their desires. This will raise the awareness of users on how to efficiently use their buildings, as well as that of the designers and the owners.

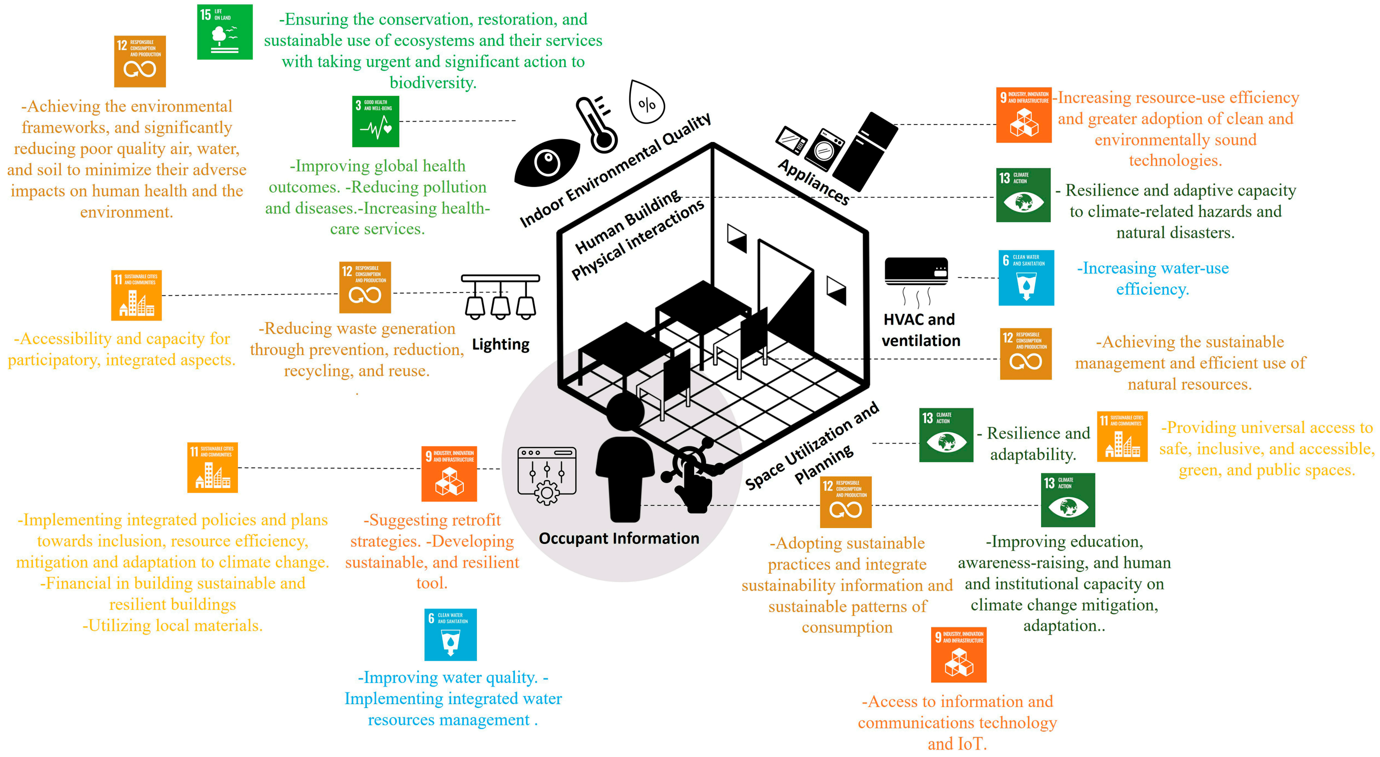


Figure 13. New generation of IoT occupant-centric tool outcomes within SDGs' targets. Source: the authors.

The United Nations recognizes the importance of sustainable building practices, but current rating systems have limitations [125]. The existing tools struggle to account for how people use buildings and are not integrated with smart technologies, like the IoT [126]. This is a critical gap, especially considering the impact of climate change on our built environment [20]. To achieve the UN's Sustainable Development Goals (SDGs), according to [1], we need to embrace innovation. This paper proposes a new approach: an occupant-centric assessment tool that leverages IoT solutions. This tool will not only raise awareness about building efficiency but also improve a building's overall performance. The paper outlines a clear development process, including creating a robust set of indicators and comparing this new method to traditional tools. Ultimately, this research offers valuable insights for researchers and policymakers, paving the way for a future where buildings are sustainable, smart, and responsive to the needs of their occupants.

4.4. Challenges and Recommendations

The wide use of the new generation of BA methods could help researchers to identify the most suitable strategies for sustainable construction and design. The awareness of occupants about sustainable practices and smart technologies needs to be increased. A new generation of IoT occupant-centric tools can have significant outcomes within the targets of the SDGs by aligning building performance with sustainability, efficiency, and user well-being. On the other hand, regulations and building codes centered on circularity must be a part of the buildings' design and construction processes.

Finally, in terms of future studies, the areas that need additional investigation are as follows:

- Gaining a more profound insight into occupant-centric interactions is essential to narrow the gap between the anticipated and actual BOP. This involves addressing the challenges associated with incorporating factors related to building occupants and their behavior into the decision-making process of building design.
- Standardizing the utilization of IoT and smart readiness, coupled with explicit strategies, is pivotal in exploring diverse interdisciplinary approaches to tackle future challenges posed by climate change and smart technologies.
- Delving into the levels of building functionality and the varied uses of spaces constitutes a crucial method for achieving circularity in building practices. Further research on building processes and monitoring is imperative for the successful promotion of circular building strategies.
- The examination of occupant satisfaction should extend to considering participant characteristics, like gender, age, proximity to windows, and work history within buildings. These non-environmental factors significantly influence satisfaction levels within building environments.
- A more in-depth exploration of the relationship between energy consumption and occupant satisfaction is necessary for a comprehensive understanding of performance attributes, enabling more accurate predictions of building performance.
- Developing a set of guidelines and benchmarks for assessing the energy efficiency of buildings and subsequently using these metrics to shape the creation of a novel building performance assessment tool is a crucial step in advancing sustainable building practices.

Figure 14 presents the current existing gaps and future research possibilities in building assessment tools. Taking into consideration the results of this paper, the latter can help academics and researchers engaged in innovative research in the field of building performance tools.

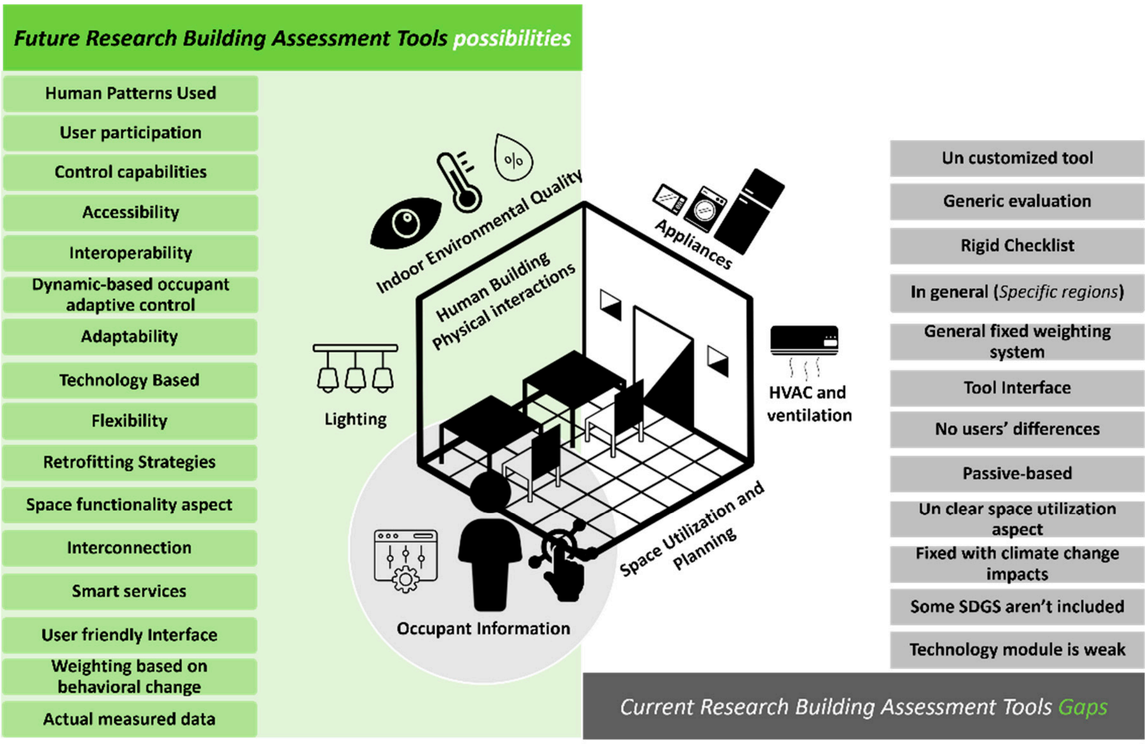


Figure 14. Current knowledge gaps and future research possibilities in building assessment tools. Source: the authors.

Despite progress in building assessment tools, limitations persist. Currently, the focus is often on energy efficiency, neglecting occupant comfort and well-being. Additionally, integrating data from various building systems and IoT devices proves challenging. The lack of standardized metrics for occupant-centric performance further hinders effective evaluations. Even with collected data, translating them into actionable recommendations for building management remains an obstacle.

The future of building assessment tools lies in a shift towards occupant centricity. While traditional tools focus on energy efficiency, future iterations will integrate well-being metrics alongside it. Overcoming the current challenges, like data integration from various sources and a lack of standardized metrics, is crucial. This will require advancements in data analytics and the establishment of common frameworks. Ultimately, user-friendly interfaces that provide clear, actionable insights for both building managers and occupants will be key in creating buildings that are not just sustainable, but also optimize health, comfort, and productivity, contributing significantly to broader sustainability goals. Looking forward, the future of building assessment tools lies in incorporating occupant-centric design, utilizing advanced data analytics, establishing standardized metrics, and designing user-friendly interfaces. These advancements will not only ensure sustainable buildings but also optimize occupant well-being and contribute to achieving broader sustainability goals.

5. Conclusions

Although rating systems exist, there is a knowledge gap in the existing BA tools regarding occupants' dynamic needs and the integration of smart technologies, such as the IoT, and climate change. The imperative to address the repercussions of global climate change on the built environment underscores the critical necessity for sustainable development goals (SDGs) and the integration of cutting-edge technological solutions, notably the Internet of Things (IoT). This paper adds a contribution to guide the development of the current building regulations and raise the awareness of occupants about the various indicators that affect building efficiency. By following a comprehensive methodology, the development of an occupant-centric assessment tool based on IoT solutions can effectively enhance the sustainability, energy efficiency, and overall performance of buildings. Regular reviews and updates to the model will ensure its continued relevance and effectiveness. The findings from the study are expected to provide further guidance towards the development of BA tools and future building certificates. They may help researchers by providing a clear and effective roadmap to investigate various interdisciplinary approaches to develop solutions to the future challenges of climate and smart technologies for sustainable building practices in a regional context, which are also limited by the most recent methods to control the built environment [127].

This paper emphasizes the main step of the tool development process for building a set of indicators with the key guidelines of this tool. A comprehensive paradigm-shifting comparison between the conventional and IoT occupant-centric BA tools is presented. This work summarizes IoT and occupant-centric approaches presented in previous works to discuss the intersection areas between IoT occupant-centric indicators and SDGs' targets to achieve sustainability. Subsequently, it demonstrates the different correlations between the newly generated IoT occupant-centric tool outcomes within the SDGs' future targets. We can develop standardized performance metrics that can be used to compare the performance of buildings. Lastly, the current gaps in knowledge and the future research possibilities of building assessment tools are presented.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings14061798/s1. The attachment file provides a detailed analysis map of the systematic literature review that explains the criteria used to select the case studies.

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List of Abbreviations

AI	Artificial Intelligence
BA Tool	Building Assessment Tool
BIM	Building Information Modeling
BOP	Building Operational Performance
DPCs	Dynamic Energy Performance Certificates
EU	European Union
EPBD	Energy Performance of Buildings Directive
EPCs	Energy Performance Certificates
IoT	Internet of Things
IoT OC	IoT Occupant-Centric
OB	Occupant Behavior
OC	Occupant-Centric
SBs	Smart Buildings
SDGs	Sustainable Development Goals
SRIs	Smart Readiness Indicators

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