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A systematic evaluation approach for integrating smart sustainable buildings and cities

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Abstract
A smart sustainable building uses advanced technologies and sustainable practices to boost energy efficiency, reduce environmental impact, and increase occupant comfort; a smart sustainable city uses technology to improve residents' quality of life and promote sustainability. This research aims to a systematic approach to the "Smart Sustainable Building-City Integration Evaluation Model (SSB-CIEM)" for integrating smart sustainable buildings and cities. The methodology begins with a qualitative literature review on smart and sustainable buildings, cities, and SSB-CIEM. Then it continues with the bibliometric analysis of articles obtained from Scopus. The comprehensive content analysis of selected articles reveals trends, strengths, and weaknesses. The findings highlight six main areas for a holistic SSB-CIEM: Resilience, environment, governance, aesthetics, mobility, and welfare and well-being. The systematic approach to SSB-CIEM, which offers a holistic perspective by completing the shortcomings of existing evaluation approaches, encourages practitioners to strengthen the necessary technology infrastructure in six areas determined for integrated building-city in architecture, engineering, and urban planning projects. The model presents the preliminary areas that practitioners can consider when integrating building-city projects and supports government decision-makers in reviewing national smart city action plans and local government infrastructure projects. Such a systematic evaluation approach is one way of considering the socio-economic and cultural benefits of cross-scale communication between buildings and cities, implemented with state-of-the-art technologies at local and central scales.

Keywords
Integration evaluation, Smart sustainable building, Smart sustainable city, Systematic approach, Systematic literature review.

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1. Introduction

In the last few decades, some notions, such as smart, sustainable, inclusive, sustainable just (Nederhand et al., 2023), and resilient, have emerged as popular solutions to rapid population growth problems in cities (Nederhand et al., 2023). One of these notions, smart cities, stands out significantly because of the use of digital technologies to solve urbanization problems (Xia et al., 2022). Smart homes, smart grids, and smart meters, which constitute smart city components, work harmoniously in a smart environment for better living conditions (Al Dakheel et al., 2020). This cooperation, which works through a systematic network based on ubiquitous ICTs (Information and Communication Technologies) and integrates all smart services by involving citizens in this structure, helps raise the standards of building and city services (Sladoljev et al., 2019). For this reason, it is necessary to establish coexistence between the smart systems of both smart cities and smart buildings (Sladoljev et al., 2019). This coexistence means establishing a building-city relationship through the Internet of Things (IoT) by connecting household appliances to a network and equipping the buildings with sensors (ITU, 2021; Sladoljev et al., 2019).

The development of smart building technologies encourages the transition to a new era in building-city related services. Integrating smart building systems into smart city digital platforms can increase cities' smartness levels. At this point, the role of smart buildings is to increase the city's capacity to use all the functions offered by smart areas and to be designed to enable smart building services, smart materials, and smart construction features to serve city systems (Apanaviciene et al. 2020a). With smart sustainable building and city integration, buildings can harmoniously use their smart and sustainable functions through ICT with the city's capacities. Buildings, one of the most critical components of the city, have a vast integration potential with the city's digital and physical infrastructure in the areas, such as resilience, environment, management, aesthetics, mobility, and welfare and well-being. Matching buildings and cities capacities in these areas with ICT infrastructures can ensure sustainable city goals are achieved in terms of citizens' welfare and minimizing the global climate crisis. For example, city-integrated smart buildings are connected microgrids that can produce energy while consuming it and feed the grid, while utilities are responsible for managing energy-producing resources and organizing their distribution (Stieninger, 2016). For this reason, not only the micro (building) scale resource production-consumption data becomes vital in evaluating interoperability data at the macro (city) scale. Although many building evaluation tools have been produced to establish sustainability, there is a need for cross-scale treatment. Conte & Monno (2012) propose a cross-scale model that includes the building and the associated environment, but again, the evaluation includes the overall building and its sustainability.

Essentially, there is a massive leap in the number of smart city projects, so the speed of academic and industrial studies is growing to evaluate cities' performance with the smartness criteria (Caird et al., 2016; X. Li et al., 2019). The idea of what smart buildings should be like is taking place with increasing interest in academic, popular, and industrial literature (Buckman et al., 2014; Froufe et al., 2020). However, smart sustainable building-city integration evaluation is a relatively new discourse. An effort to integrate a smart building with a city by interacting with the components of the smart city has raised the issue of evaluating the levels of these efforts. Nevertheless, Apanaviciene et al. (2020a) investigated the potential of buildings to benefit from city's capacities with the ICT infrastructures and to become smarter in the fields of smart energy, smart mobility, smart life, and smart environment. On the other hand, since existing evaluation tools evaluate building and city smartness and sustainability separately, there is a need for a systematic evaluation approach for integrated smart sustainable building-city. This research aims to analyze smart and sustainable building evaluation studies to identify key features and weaknesses to achieve holistic SSB-CIEM. For this purpose, the research is structured as follows: Literature background in section 2; Methods in section 3; Results in section 4; Bibliometric analysis in section 4.1.; Discussion in section 5, Content analysis (Research trends) in section 5.1.; Strenghts and weaknesses in section 5.2., Systematic approach proposal in section 5.3.; Maturity and data management in SSB-CIEM in section 5.4; Conclusion in section 6. The findings contribute to the literature by analyzing existing building-city evaluation tools to identify smart sustainable building-city intersection areas over strengths and weaknesses. Such a systematic study will provide the necessary information for conceptualizing holistic SSB-CIEM. Suggested SSB-CIEM can assist architects, urban planners, and engineers throughout the project's lifecycle.

2. Literature background

This section explains the sustainability approach, reveals the importance of a smart, sustainable building-city and the latest related digital technologies, and current knowledge of smart and sustainable building-city evaluation approaches. Afterward, the dark points of the Smart Sustainable Building-City Integration (SSB-CI) concept come to light. The review is useful for providing an in-depth look at the need for SSB-CI and digital technology-aided application areas.

2.1. Sustainability

While cities are places where 55% of the world's population lives, the expectation for this figure is to increase to 68% by 2050 to find better opportunities in fields such as work and education (UN-Habitat, 2022; UN Habitat, 2020). A considerable increase in the rate of urbanization required international policies. In the 1970s, policymakers started to talk about the concept of sustainable development. Since then, many international meetings have occurred, including the assembly where the Paris Agreement, which included critical decisions, was signed. The United Nations organized "The twenty-eighth session of the Conference of the Parties (COP 28)" about climate in December 2023. COP 28 includes a 'global review' of climate change mitigation targets in the Paris Agreement (2016). Countries revealed that efforts to reduce greenhouse gas emissions, resilience to climate change, and support (financial and technological) to vulnerable nations are slow while placing particular emphasis on the choice of renewable energy sources instead of fossil fuels (United Nations, 2023). In light of those mentioned above, it is clear that international policies and research have supported smart and/ or sustainable building-city practices for a more livable world by reducing the effects of climate change. However, the potential benefits to sustainability of systematically addressing the integrated smart sustainable building-city concept are ignored.".

The sustainability as a concept, risks, and triggers of environmental crises, social and economic factors, and dominant urban development paradigm (housing crisis, unplanned urbanization); is the basis of the awareness that future life will endanger as a result of ecological and social deprivation (resource scarcity) under the influence of increasing social disruptions (globalized market, lack of skilled labor) (Bibri & Krogstie, 2017). The fact that cities consume 70-80% of the resources while occupying 2% of the world (Bibri, 2018; Hong et al., 2017) strikingly reveals the importance of sustainable cities. Ensuring sustainable life routines of citizens can be possible by constructing adaptable, resilience and high-quality infrastructure that provides livable, accessible and safe urban areas (Sala Benites et al., 2022).

On the other hand, buildings which are the essential components of the city responsible for 40% of world energy consumption and 36% of energy-related greenhouse gas emissions (European Commission, 2021) because of the buildings' heating, cooling, ventilation, and lighting needs (Engelsgaard et al., 2020). The importance of resource optimization, planning, and control became a sine-qua-non especially in high-density parts of the cities (Akcin et al., 2016; Calvillo & Villar, 2016). Moreover, the high use of water and materials in buildings compared to other sectors shows the seriousness of the adverse environmental effects of buildings (Franco et al., 2021) and the inevitable necessity to design smart sustainable buildings. Smart sustainable building is a relatively new approach that combines the characteristics of ecological (sustainable, green, passive) buildings with the features of smart buildings in a single building (Radziejowska & Sobotka, 2021). This approach avoids conceptual confusion with smart buildings that ignore sustainability and sustainable buildings ignore ICT. "Smart" and "sustainable" concepts for "building" and "city" are inseparable parts like two sides of a coin, and the "smartness" provides effectiveness in achieving "sustainable goals" with methods and technologies.

2.2. Smart sustainable buildings

While the impact of buildings on environmental sustainability is obvious, the impact of buildings on human health and work efficiency is of considerable importance, as people spend 90% of their time in buildings (Stieninger, 2016). Installing smart systems for user comfort is the first step of a human-centered approach (Markoska et al., 2019). The parameters of various devices are collected by sensors with the help of the IoT, and the data are stored in real-time in the corresponding database (Yang et al., 2022). A smart building approach using control algorithms and IoT, one of the ICTs, can constantly monitor environmental data, offer a management approach to achieve minimum energy consumption and optimum interior comfort (Lin et al., 2020); manage various tasks such as surveillance, access and fire detection (Lam et al., 2023).

The potential for ICT to facilitate the design, construction, and operation of smart buildings has required a re-evaluate of the technologies used in current building production approaches (Apanaviciene et al. 2020a; Chiesa, 2020). The construction industry's cutting-edge technologies can facilitate real-time data collection, monitoring, and control, optimizing processes and adding economic value through online platforms (Piras et al., 2024): Data acquisition (IoTs, UAV (Unmanned Aerial Vehicles)/drones, Geographical Information Systems (GIS), Laser Imaging Detection and Ranging (LİDAR), Global Positioning Systems (GPS), Sensors, Radio-frequency identification (RFID), data analytics (Big data, artificial intelligence/machine learning), data visualization (BIM, 3D printing, Robotics, DFab (Digital fabrication)), sensing and digital technologies ((BIM), (GIS), (GPS), laser, satellite, light detection and ranging (LIDAR) (Sepasgozar et al., 2019). Gonçalves et al. (2020) developed a model for smart building energy management based on machine learning using smart control predictive control; Lin et al. (2020) developed a sun-powered smart window blind system with automatic control; Louis & Dunston (2018) simulated the preparation of a process model with IoT-enabled control and sensor information at the construction site for real-time and automatic decision-making in construction.

"Integrating digital technologies in construction facilitates urban planning and land cover management while supporting sustainable development efforts. Barrile et al. (2023) integrate BIM and GIS to combine physical-geographical (urban) information of the building (microscale) to the urban power systems (macro-scale) to offer an advanced methodology for building energy management in the Municipality of Reggio Calabria (Italy). On the other hand, Qian & Leng (2021) propose "Community intelligent modeling," which is a three-dimensional simulation platform that could act as a bridge between buildings and digital environment analysis software, collects data from BIM, GIS, IoT, and cutting-edge technologies to solve low comfort level, poor safety, and significant energy consumption problems. These and similar efforts point to smart sustainable cities, where buildings supported by digital technologies are integrated with city components for environmental sustainability and human comfort.

2.3. Smart sustainable cities

The idea of a sustainable city emerged in the late 1990s and does not have a single descriptive expression in the literature (Janik & Ryszko, 2020). "The city approach that can meet the needs of the present without compromising the needs of future generations." (Kaltenegger &Fink, 2016) is the most accepted description. On the other hand, the concept of "smart" is one of the components of the sustainability movement (Arditi et al., 2015). Re-evaluate how we build and manage our cities (Höjer, M. and Wangel, 2015) and introducing additional requirements to cities that are constrained to operate with limited resources to ensure that their citizens can live without compromising their level of well-being has revealed smart cities (Austin et al., 2020; Azevedo et al., 2018; Sladoljev et al., 2019) in the 1990s (Albino et al., 2015). However, the concept's origin goes even back; based on the Cybernetically Planned Cities of the 1960s, it had in urban development plans with a new name as Networked or Computable Cities since the 1980s (Gabrys, 2014). There is no universal and inclusive smart city definition yet (X. Li et al., 2019; Lima et al., 2020). However, a smart city is an approach that adopts modern ICTs in city planning, construction, operation, and management (Xia et al., 2022). In summary, the smart city is an interconnected system that focuses on people and the environment, aims for quality life, monitors and optimizes resources, management, security, mobility, and technology, and makes decisions by prioritizing smart ICT, data, and rationality. This view also supports the argument that smart city studies facilitate achieving sustainable city goals regarding method and technology.

Although the smart city aims for sustainability, the absence of sustainability in all smart city applications has revealed the concept of a smart sustainable city (Ahvenniemi et al., 2017; Bibri & Krogstie, 2017). Smart sustainable city is a new phenomenon that spread in the mid-2010s and is relatively less studied (Janik & Ryszko, 2020; Taveres-Cachat et al., 2019) means that cities should be sustainable (flexible and inclusive) and digitally competent (ITU, 2021), increasing the quality of life of city residents (Kutty et al., 2023).

Global examples show that integrated 3D geographical information of the ground and underground of Chongqing (China) facilitates urban planning, public facilities management, simulation technology in construction, emergency response, etc. (GIM International, 2017). On the other hand, Denmark's relatively easy access to open data facilitates cooperation between municipalities and the private sector, supporting decision-makers in smart city solutions (Snow et al., 2016). The top three smart sustainable city indicators showing Smart sustainable city rankings for Copenhagen (Denmark) are wastewater treatment, E-commerce, patent applications, and, for other European cities: Berlin; Bicycle network, Wastewater treatment, E-commerce, Paris; Wastewater treatment, Unemployment, GHG emissions; Rome; GHG emissions, Protected terrestrial area, PM10 concentration."

The lens of the state of the art technologies, while IoT-based sensor technology enables cost-effective approaches for continuous monitoring of city components (Tripathi et al., 2023); artificial intelligence and machine learning are effective in providing the necessary infrastructure to digitalize the daily operations of local governments (Siokas et al., 2021). While Ford et al. (2020) developed a conceptual smart city digital twin that facilitates disaster management, Austin et al. (2020) proposed a city digital twin architecture combined with a semantic model and machine learning approach and applied it to buildings in Chicago. Revelo Cáceres et al. (2023) integrated BIM, GIS, and LCA (Life Cycle Assessment) to analyze the urban densification of high-rise blocks in the city of Quito (Ecuador), highlighting that operational energy causes the most impact. These studies show that an integrated building-city approach is essential when equipping city infrastructure with the latest digital technologies to better serve building occupants.

2.4. The lens of smart sustainable building-city integration (SSB-CI)

Every new building design in cities must be compatible with existing development plans and urban texture. If a new energy-efficient building design causes the existing urban landscape to change radically, it may reduce the energy efficiency of the neighborhood (Futcher et al., 2017). In other words, the energy efficiency of the urban form may be less than the sum of the energy efficiency of isolated buildings (Futcher et al., 2017). Designing and operating smart sustainable physical and digital building systems, considering the cities' infrastructures, can potentially increase resource efficiency in areas where other environmental resources and city services are carried out, just like in the energy field. A more detailed look at the scope of a smart building's relationship with the city is as follows (Stieninger, 2016):

"Technically, a designed building is an island disconnected from people, environmental systems, and nature; it can have solar panels on top of the roof. Moreover, it can reuse gray water, black water, rainwater, and organic waste in the landscape, producing more energy than it consumes. It can be called "green" and "smart" if it includes all the technology and tools imaginable while meeting all the computational requirements; even though it is a fancy, net-zero-energy, repeatable building, nothing can go in or out except rainwater and solar radiation, it is a closed circuit. It is a fact that such a building cannot be smart because its functioning does not end at the entrance door. A smart building should interact with other sustainable city components while supporting reuse and recycling; it should use its inputs and outputs (what it takes from nature and what it can give back to nature) in a balanced exchange of giving and receiving. A smart city can operate in a healthy and environmentally friendly manner only if it benefits from constant change while providing feedback loops about all inputs and outputs".

With this approach, Stieninger (2016) argues that a building, even with smart systems with the latest technologies, cannot be called smart if designed separately from all sub-components of the urban system. This discourse emphasizes that integration is essential. The task of smart buildings in the functioning of the urban system is to establish a harmonious and environmentally friendly relationship with other connected buildings and infrastructures surrounding it. The delivery of resources required for the functioning of the building to the building, the management of building waste, the connection between the inside and outside of the building, and the entry and exit of people into the building Stieninger (2016) constitute the integration relationship of the building with the natural and built environment.

Through the latest digital construction technologies, smart buildings and smart cities can connect to physical, digital, and theoretical (Kim et al., 2021). Gao et al. (2024) integrated BIM, GIS, and LCA and used a Multi-information integration-based life cycle analysis technique to calculate the spatial distribution of GHG emissions during the production, transportation, and construction stages in Shenzhen (China). Mair et al. (2023) proposed a framework and the categorization system for recycling construction material through BIM, GIS, and LCA Technologies. Cinquepalmi et al. (2023) proposed a tool based on the systematization of various digital technologies for rapid automatic pre-evaluation of the potential conversion of an existing building stock into a residential space through integrated BIM and GIS technologies. Costantino et al. (2022) combined BIM, 3D GIS, LIDAR, and Grasshopper (Rhino), collected numerical cartography and geodata from Open Street Map and point clouds generated by airborne LIDAR sensors; analyzed and simulated to visualize projects from illustrations to photorealistic renderings for 3D Modelling of Buildings and Cities. The smart city data platform receives and shares all data from smart city components in the network (Apanaviciene et al., 2020a). In a smart city, some dynamic and self-learning control systems in which components interact and optimize their energy use ensure that buildings are integrated while powerfully operating the in-building energy management and the city's energy system (De Groote et al., 2017). The building can help manage local stormwater, and the microgrid provides drinking water to the building and treats and reuses wastewater from the building (Stieninger, 2016). However, not every city has the highest level of smart-ready environment in every area, so if the building has a higher ICT capacity, this functionality may remain underutilized for a while until the city uses it, or vice versa (Apanaviciene et al., 2020a) . Therefore, the first step is to evaluate the current level of building-city integration in order to identify potential smart sustainable intersection areas.

2.5. Smart sustainable building-city evaluation and integration evaluation approach

While sustainable/green buildings' certification systems such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), and WELL (performance-based evaluation system) are widely accepted, some academic research introduced new local tools (H. Kang et al., 2016). The certification systems of some countries such as Japan and Hong Kong provide smart and green building criteria together; some countries like Korea have entirely different (Amirhosein Ghaffarianhoseini et al., 2016). Since existing research generally focus on cities by using the system (Bibri & Krogstie, 2017; Janik & Ryszko, 2020; Kim et al., 2021; Palumbo et al., 2021; Pérez & Oltra-badenes, 2020) there are few publications on evaluating smart building (Buckman et al., 2014; Ghaffarianhoseini et al., 2018). Nevertheless, the Smart Readiness Indicator (SRI) (energy savings and operation, responding to users' and grids' needs) for buildings, supported by the European Commission, stands out in research (Fokaides et al., 2020; Markoska et al., 2019; Martínez et al., 2021; Ramezani et al., 2021), and the Building Intelligent Quotient (BiQ) and Honeywell Smart Building Score (HSBS) are other tools that we find traces of in the literature.

On the other hand, the issue of smart cities takes place in nations' strategies and action plans, and the number of cities equipped with smart city networks is increasing progressively. Evaluating the applications to provide a smart and sustainable quality to cities is necessary. The current literature focuses on evaluating and comparing (with the most accepted indicators) cities' sustainability and impact performance for approximately 30 years with various tools. In Giffinger's study, which is the most cited in the literature, smart city components are under six headings: smart mobility, smart living, smart environment, smart governance, smart people, and smart economy (Giffinger et al., 2007). However, the tools that evaluate smart or sustainable cities are insufficient in evaluating building-city integration with current criteria.

The latest research in the literature, propose a holistic multi-scale system-of-systems approach in which building and urban scale are considered together and there is an illustrative example of building-city integration to improve human health, comfort and reduce the energy consumption of buildings (Bi & Little, 2022). However, evaluating the integrated smart building-smart city is relatively new approach. Apanaviciene et al. (2020a) investigated the potential of buildings to benefit from the capacities of smart cities and become smarter in the fields of smart energy, smart mobility, smart living, and smart environment. This study also ensures the evaluation framework's reliability by testing the proposed indicators. Conte & Monno (2012) suggest a conceptual model by mentioning a cross-scale evaluation approach over building evaluation and they emphasize the necessity of applying the model in case studies involving stakeholders to ensure the reliability of the holistic indicators of the model. At the core of the evaluation approach of this study is building sustainability, and buildings are defined as a dynamic process, just like a living organism, within the ever-changing urban mechanism (Conte & Monno, 2012). This view is like Stieninger's (2016) idea that since a buildings operation will not end within its door thus it should be integrated with the city in order to be a really smart building. Since buildings and cities are still considered separate entities in the research mentioned above, this research defines a holistic and systematic evaluation approach toward integration.

3. Methods

3.1. Identifying research questions

Research questions (RQs) make understanding and summarizing researched concepts easy (Kim et al., 2021). This study's systematic quantitative literature review (SQLR) searches for articles to answer five RQs. The following RQs investigate smart and sustainable building-city evaluations and SSB-CI evaluation in terms of concepts, research trends, strengths, and weaknesses till January 2023. This way, the review defines SSB-CIE intersection areas to reach a systematic evaluation approach to SSB-CI, draws a concept diagram for SSB-CIEM, and defines SSB-CI maturity.

RQ1: What do smart/sustainable building-city concepts and integrated approaches mean? (The answer is given in section 2.

RQ2: What are the smart/sustainable building-city evaluation/ integration evaluation studies? (The answer is given in section 4). Articles found from queries are examined. Bibliometric analysis and keyword co-occurrence analysis are performed to determine the prominent concepts.

RQ3: What are the strengths and weakness in smart/ sustainable building-city evaluations? (The answer is given in section 5.2.) Strengths and weakness identified by authors are highlighted through in-depth content analysis.

RQ4: What are the smart sustainable building-city intersection areas? (The answer is given in section 5.2.). As a result of the content analysis, the intersection areas are defined.

RQ5: How to set up a systematic approach to SSB-CIEM? (The answer is given in section 5.3., 5.4.).

3.2. Database selection for research

Frequently, using an SQLR database such as Scopus and Web of Science (WoS), a systematic and holistic approach identifies studies in the research area (Pickering & Byrne, 2014). In this review, we use Scopus, the most comprehensive abstract and citation database of peer-reviewed literature (Harzing & Alakangas, 2016; Jin & Ji, 2018). Scopus uses Boolean Syntax and allows the combination of keywords for a precise search. Scopus is a well-established alternative to WoS, and it has appeared in many international universities' rankings, such as the Times Higher Education rankings (Harzing & Alakangas, 2016). On the other hand, Google Scholar's quality control process is weak and remains in the background as it simply scans all kinds of information found on academic-related websites. Another motivation for choosing the Scopus database was that it covers more than 29,200 active serial titles and that content from more than 7,000 publishers has been thoroughly reviewed and independently selected (Scopus Content, 2024). Therefore, it is possible to search for published articles on smart sustainable building-city evaluation almost without missing them with advanced search processes. In addition, the Scopus database has been preferred in literature review articles on similar topics, such as the management of construction projects and city services with smart technologies (Akindele et al., 2023; Akinlolu et al., 2022; Celeste et al., 2022; Rigillo et al., 2023; Sepasgozar et al., 2021; M. Wang et al., 2020).

3.3. Systematic literature review steps

The researchers adopted a four-step method to propose a systematic approach for SSB-CIEM (Smart sustainable Building-City Integration Evaluation Model). Figure 1. shows the review steps as: 1- Qualitative literature review, 2- Visualizing and interpretation of bibliometric analysis results, 3- Critical analysis of current evaluation tools, 4- A systematic approach to SSB-CIEM. Qualitative literature review (1. Step) examines the interrelationships between current concepts (sustainability, smart and sustainable building-city), focuses on the lens of SSB-CI (Smart sustainable

Building-City Integration), and discusses how the SSB-CI lens can be applied to buildings and cities.

Visualizing and interpretation of bibliometric analysis results (2. Step) includes planning, filtering, analysis, and reporting studies. In the planning (data collection phase), researchers select words that best describe their research questions and structure queries 1, 2, and 3. The reason for choosing the sampling method is to reach the integration areas through building and city evaluation tools with a bottom-up approach. Chosen query words are the most used in research in this field in recent years, as mentioned in the literature background section. A comprehensive literature search was carried out to reduce the number of articles that would be overlooked by typing all related concepts (e.g., smart building, sustainable building, evaluat*, assessment, rank) from the existing literature into the Scopus database/search engine. Although the sample can be expanded with other normative concepts in this field, as in many disciplines, this research is limited to the determined keywords; this also defines the sample size. In the filtering (data cleaning phase), queries were searched in the articles' titles, abstracts, and keywords. At this stage, the sampling includes all articles from the oldest to the newest provided by the Scopus search engine. Articles on new and existing smart or sustainable building-city evaluation tools are included in the results. The analysis sample is limited to articles in English found with the words searched for in Scopus. There is always a risk of finding articles that are not directly relevant to the research question, and these articles were excluded for the accuracy of the results. The analyzing stage includes visualizing (science mapping) valuable data. The Bibliometrix (Biblioshiny) is an open-source software tool that works with the R Studio package (Kim et al., 2021). This software tool can visualize much data, such as co-occurrence networks of keywords. The reporting stage includes focal points in smart and sustainable building-city evaluation studies.

Critical analysis of current evaluation tools (3. Step) covers the content analysis of the bibliometrically analyzed articles. Results highlight the strengths and weaknesses in the smart, sustainable building-city evaluation tools. The identified strengths and weaknesses offer a holistic approach to the SSB-CIEM intersection areas.

A systematic approach to SSB-CIEM (4. Step) includes a systematic approach using the information obtained from the analyses of the previous sections, a concept diagram, and a graph describing maturity in SSB-CIEM. The conceptual diagram shows the areas at the intersection as integration areas as a result of the content analysis of building and city evaluation articles. The working principle of the diagram is based on Stieninger's (2016) "a smart building system changes inputs and

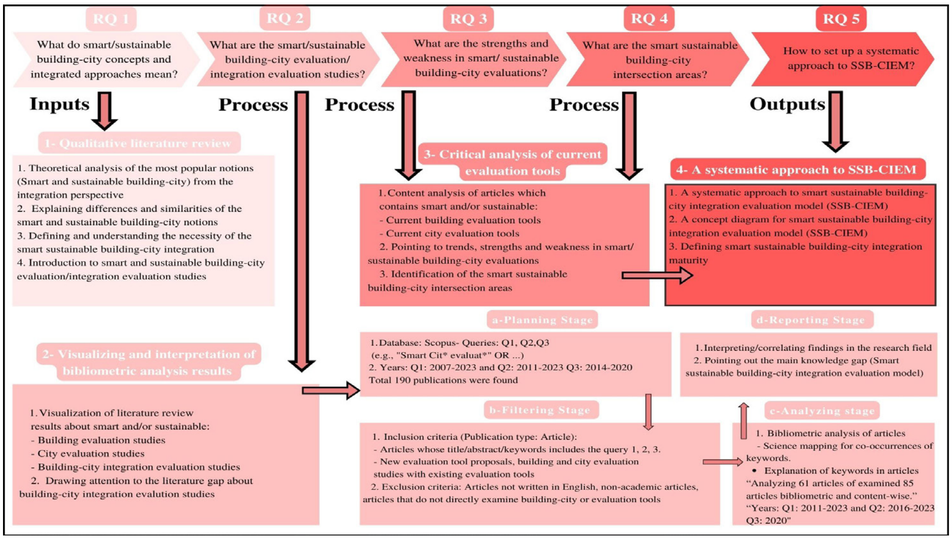

Figure 1. *Research methodology.*

outputs in balance with the city." it is based on the approach. The literature on integrating building and city data points to the latest digital technologies (BIM/GIS) in the diagram. The maturity graph expresses the potential of state-of-the-art digital technologies to increase cross-scale working levels throughout the building life cycle (see Figure 1).

4. Results

We search the concepts with detailed definitions in the previous sections through publications' titles, keywords, and abstract sections. The search results of the queries (1, 2, and 3) take place in the tables and maps (section 4. and section 5.). Queries progress from the building scale to the city scale and later to the integration scale. The total number of publications was 190 (q1:73, q2: 114, q3:3) (according to Scopus). The search engine found 85 articles (q1:47, q2:36, q3:2). 23 of these 85 articles were unrelated to the research area, so it was discarded. Finally, we selected and analyzed sixty-one relevant articles (q1: 29, q2:31, q3:2 (1 was an intersection article)) bibliometrically. The percentage distribution of the articles is as follows: 45,90% building, 50,81 city, 3,27% building-city integration area.

4.1. Query 1: Searching for publications containing smart and/or sustainable building evaluation

Query 1 searchs "Smart building* evaluat*" OR "Sustainable building* evaluat*" OR "Sustainable building* assessment" OR "Smart building* assessment" OR "Smart sustainable building* evaluat" OR "Sustainable smart building* evaluat *" query outputs (till January 2023). The search engine finds 77 publications, including articles (47) between 2007 and 2023. Others are conference papers (22), review (4), and book chapter (4). The distribution of query outputs is engineering (46), social sciences (23), energy (22), environmental science (17), computer science (14), others (less than 10). The possible reason for the overwork in engineering and energy is the realization that the building construction industry consumes the world's total energy, and the search for technical energy-efficient solutions in building projects has been effective. The fact that social sciences are second in smart city research shows the potential of smart and sustainable buildings to increase people's welfare.

4.2. Query 2: Searching for publications containing smart and/or sustainable city evaluation

Query 2 searchs "Smart Cit* evaluat*" OR " Smart cit* assessment" OR "Smart sustainable cit* evaluat" OR "Sustainable smart cit* evaluat*" (till January 2023). The search engine finds 93 publications, including articles (34) between 2016 and 2023. Others are conference papers (45), conference review (3), review (3), and book chapter (5). Publications are limited to the presence of the researched concepts in the title, abstract, and keywords sections. The distribution of query outputs is; computer science (49), engineering (42), social sciences (35), energy (20), environmental science (18), mathematics (16), business management and accounting (11), and others (less than 10). Results show that majority of the publications in the field focus on computer science. The development of ICT, which constitutes the infrastructure of smart cities, with computer science and engineering studies, and the integration of the opportunities it provides with other components of cities, makes the number of studies in these areas superior to others. Since the purpose of smart city studies is to increase citizens' welfare triggers studies in the field of social sciences.

4.3. Query 3: Searching for publications containing the concepts of sustainable and/or smart city, building, integration and evaluation

Query 3 searchs ("smart building* integration" OR "sustainable building* integration") AND ("smart cit*" OR "sustainable cit*") AND (Maturity OR "Maturity Level" OR Assessment OR Tool* OR "Assessment Tool*" OR "Assessment Model" OR Indicator* OR Standard* OR KPI* OR Certificate OR Evaluat* OR Performance OR Rank* OR Index OR Readiness OR Code*

Figure 2. Cluster distribution map for query 1.

OR "City IQ" OR "Key Performance Indicator*" OR "Decision Support System") OR "City Analysis" OR "Reference Model". The search engine finds 3 publications (3 articles) between 2014 and 2020.

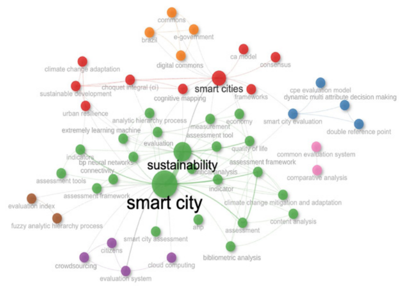

Figure 3. Cluster distribution map for query 2.

4.4. Keyword analysis

The co-occurrence analysis of the author's keywords obtained using Biblioshiny is presented in Figure 2. and Figure 3. A keyword and other keywords of the same color form a cluster. Lines that connect keywords represent links. The larger the node is, the more significant the usage frequency of the corresponding keyword is and the greater its relevance. The overuse of a keyword in publications shows that the topic is the focus of researchers. In Figure 2, the minimum number of co-occurrences of a keyword was set to 1. The fact is that the subject of sustainable building evaluation stands out the subject of smart building evaluation relatively. The sustainable building/s assessment concept strongly relates to assessment tools, AHP, fuzzy-ahp, rating systems, and multiple criteria analysis. Moreover, decision support systems, Delphi consensus, general consensus, data collection, and verification in determining sustainable building evaluation criteria stand out in research. Thus, widely accepted in the scientific literature, these techniques can be used to decide the sub-areas of the proposed SSB-CIEM. Finally, we see the first traces of the relationship between aesthetic criteria and sustainability for holistic SSB-CIEM (see Figure 2).

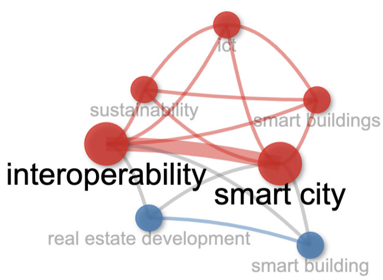

Figure 4. Cluster distribution map for query 3.

It is seen in Figure 3 that the concept of smart city evaluation is directly related to indicators such as economy, connectivity, and quality of life. The strong relationship between the concept of sustainability and smart city stands out. The common goals of these two concepts are improving the quality of life, urban resilience, climate change mitigation, and adaptation. The fuzzy AHP, Bp neural network, extremely learning machine, cloud computing, and frank operator are innovative approaches to preparing smart city evaluation tools (see Figure 3).

Figure 4 shows that at least 1 of the keywords in the articles were found together. According to the analysis result, smart buildings and smart city are mentioned with interoperability. ICT is the key to enabling interoperability between the building and the city. Real estate development is associated with the issue of building-city integration. Based on Figure 2, Figure 3, and Figure 4, the bibliometric analysis study shows that there are very few studies on integrating smart city with smart building, and all kinds of methods are open to exploration to ensure this integration (see Figure 4).

5. Discussion

5.1. Content analysis of current evaluation tools (Research trends)

This section contains the content analysis of the articles, which were bibliometric analyses made in the previous section. The review focuses on sixty-one articles regarding research direction, reference, research methodology, and achieved goals.

5.1.1. Content analysis of articles for query 1 (Research trends)

According to the results of Query 1, research on new sustainable building evaluation tools, dimensions of sustainability, comprehensive literature reviews, multi-criteria decision-making methods, and verification of evaluation criteria are listed in Table 1. The following article's topics fall outside the research: life cycle assessment (LCA), building energy performance models, thermal comfort methods, simulations, building envelope and facade, Ad-Hoc networks, users' perception of sustainable buildings, and sustainable buildings in higher education. So, the analysis includes twenty-nine articles (see Table 1).

Although the popularity of smart building studies is indisputable, there is still a great interest in sustainable/green building studies (Anshebo et al., 2022). Green smart building applications researched by (S. Xu & Sun, 2021) are also a relatively new approach. Alawneh et al. 2019; Díaz López et al., 2019; Efe et al., 2022) compare the most used sustainable building certificates (LEED, BREEAM, DGNB, and BEST). Del Rosario et al. (2021) compare DGNB and European framework Level(s) under the EPD criterion in the LCA title. Based on evaluation tools with a high impact on a global scale are generally used for preparing local features added tools (Mousavi, 2022; Mousavi et al., 2017).

In sustainable building evaluation, there are two types of parameters, endogenous (constants: global weights of criteria) and exogenous (variables: performance score of building for each criterion) (Bhatt & Macwan, 2016). Mostly, the survey method validates these parameters (categories and indicators) of the prepared evaluation tools through academia, construction industry experts, and sustainability experts (Al-Jebouri et al., 2017). Among the multi-criteria decision-making approaches, AHP is the most preferred sustainable building criteria selection method by researchers (Bhatt & Macwan, 2016; Gong et al., 2017; Medineckiene et al., 2015). (Díaz-López et al., 2019) analyze the indicators through eleven popular evaluation tools and find the inadequacy of the indicators representing the economic dimension while encountering comprehensive criteria for sustainability's environmental and social dimensions. (Grazuleviciute-Vileniske et al., 2021) explore the role of aesthetics through evaluation tools used in sustainable building evaluation.

5.1.2. Content analysis of articles for query 2 (Research trends)

According to query 2, articles are not about smart and sustainable city

Table 1. *Content analysis of articles related to smart and sustainable building evaluation.*

Research direction	Reference	Research Methodology
Sustainable hotel evaluation with local evaluation tool	(Mousavi, 2022; Mousavi et al., 2017)	Literature review, interviews and LEED evaluation
Local evaluation tool and ecological and socio-cultural sustainability	(Anshebo et al., 2022)	Expert panel, literature review, AHP
Selection and application of consensus methods	(Chan, 2022)	Comparison of Delphi and general consensus over case study
An exemplary criteria set of the university campus buildings evaluation	(Efe et al., 2022)	Comparison of B.E.S.T. with BREEAM and LEED over case study
Climate zone, building type, and accommodation characteristics for a new tailarmade tool	(Bahadiroğlu et al., 2022)	Case study
More life-cycle modules and more comprehensive scenarios for improving EPDs a data	(Del Rosario et al., 2021)	Comparison of certificates over case study
Green smart building	(S. Xu & Sun, 2021)	AHP-FCE over case analysis
Four theory: sustainability aesthetics, genius loci, biophilia, and a regenerative approach.	(Grazuleviciute-Vileniske et al., 2021)	Literature review, examine among the criteria of certificates
Materials & waste management, energy efficiency have highest weight in the technological aspect.	(Reddy et al., 2021)	Literature review, analysis current tools, expert panel, DELPHI
Adding technological advances in sustainable building evaluation tools	(Arukala & Pancharathi, 2020)	Literature review, expert opinion, Fuzzy-AHP
Integrated SDGs evaluation and management approach for sustainable non-residential buildings	(Alawneh et al., 2019)	Literature review, AHP, relative importance index, questionnaire, focus group discussion
A comprehensive view of the status quo and predicts the dynamic directions of future research	(Díaz-López et al., 2019)	Bibliometric analysis, systematic literature review
Sustainable building evaluation tools	(Díaz López et al., 2019)	Comparative analysis
Indicator usage in sustainable building evaluation	(Al-Qawasmi, 2019)	Context analysis
Urban planning indicators to indicate missing elements such as technology, cultural issues in local region and sustainability	(Stevanovic, 2018)	Literature review
Indoor environment quality, natural and human resources, social, and governance requirements for a local sustainable construction framework	(Al-Jebouri et al., 2017)	Literature review, analysis, survey,
Sustainable building evaluation tool and 3-layer development process framework for project decision makers	(H. Kang et al., 2016)	Mixed-method sequential design, including interviews, workshops, the Delphi survey technique, FD-AHP weight analysis, and scenario analysis
A new sustainable commercial building criteria	(Bhatt & Macwan, 2016)	Fuzzy logic and AHP
A new sustainable building assessment method: INVAR, utility degree and investment values of the projects under deliberation	(Kaklauskas, 2016)	The systems and the values and weights of the quantitative and qualitative criteria express these requirements, case studies
Credibility and applicability of evaluation tools, a new framework	(H. J. Kang, 2015)	Analysis, structural framework
Mobilising sustainable building evaluation models	(Faulconbridge, 2015; Faulconbridge & Yalciner, 2015)	Events along the way', empirical examine
Criteria selection for sustainable building evaluation	(Medineckiene et al., 2015)	AHP, Swedish certification system Miljöbyggnad, Saaty's judgement scale and new original scale, ARAS (Additive Ratio Assessment) method, MCDM, LEED
Resilience and sustainability for optimize system (e.g., civil infrastructure) considering structural design, utilized material, maintenance plans, management strategies, and impacts on the society	(Bocchini et al., 2014)	A numerical application dealing with the comparative analysis
Estonian regulations, sustainability evaluation tool indicators against LEED and BREEAM	(Seinre et al., 2014)	Comparison
Perceptions and preferences for India sustainable building evaluation tool	(Bhatt et al., 2012)	Interviews, statistical analysis
An integrated building-urban evaluation model based on the urban matrix	(Conte & Monno, 2012)	A cross-scale evaluation approach
AHP in sustainable building criteria: weights of parameters	(Bhatt & Macwan, 2011)	Thomas Saaty's rule of Consistency Ratio, comparison

Achieved Goals			
	Current sustainable building evaluation tools and criteria		
New local or universal evaluation tools	Suitable tool and method selection	Criteria selection, development of criteria, importance/weights of criteria	Current situation analysis and dynamic directions of future research
(Bhatt & Macwan, 2016; Bahadiroğlu et al., 2022; S. Xu & Sun, 2021; Arukala & Pancharathi, 2020; Alawneh et al., 2019; H. Kang et al., 2016; Kaklauskas, 2016; H. J. Kang, 2015; Mousavi, 2022; Mousavi et al., 2017; Anshebo et al., 2022; Conte & Monno, 2012)	(Mu et al., 2022; Chan, 2022; Díaz López et al., 2019a; Del Rosario et al., 2021)	(Medineckiene et al., 2015; Al-Qawasmi, 2019; Stevanovic, 2018; Reddy et al., 2021; Al-Jebouri et al., 2017; Seinre et al., 2014; Bocchini et al., 2014; Bhatt & Macwan, 2011)	(Faulconbridge, 2015; Faulconbridge & Yalciner, 2015; Díaz-López et al., 2019; Grazuleviciute-Vileniske et al., 2021)

evaluation fall outside the scope of this research. Thus, the analysis includes thirty-one articles listed in Table 2, which include city evaluation studies, a literature review, and new model proposals for smart and sustainable city evaluation tool (see Table 2).

Researchers evaluate the cities all over the world such as in China (Fang & Shan, 2022; Hsu et al., 2021; Z. Wu et al., 2021), Brazil al., 2022), India (Govindarajan & L.S., 2021), United Kingdom (Caird, 2018) Japan (Zou et al., 2022), and Indonesia (Qonita & Giyarsih, 2022). However, the current models are still not universal (Hajek et al., 2022) due to the uncertainty of evaluation processes, complexity, and the limitations of the evaluation tools. The lack of a universal model encourages the proposition of new models with local characteristics for different geographies.

The general typology of the smart city evaluation tools occurs smartness dimensions and indicators obtained from multiple stakeholder groups consisting of experts in the fields with multi-criteria decision-making methods (Castanho et al., 2021; De Genaro Chiroli et al., 2022; Hajek et al., 2022; Y. Wu et al., 2022; Zeng et al., 2023). Experts present alternative proposals to a finite set of criteria by assigning weights and evaluating and ranking criteria (Kaklauskas, 2016). Researchers usually prefer TOPSIS, AHP, and fuzzy-AHP methods to define smart city evaluation criteria. According to Sharifi & Allam (2022), the majority of indicators are under the headings of ICTs, economy, and governance. Some studies evaluate a city with only one dimension of smartness, such as transportation (Yan et al., 2020), governance (Mainka et al., 2016; Rotta et al., 2019), social and political dynamics (Valencia-Arias et al., 2021). According to Suliman et al. (2021), smart city evaluation tools can only ensure the multifaced development of cities when they expand their scope with sustainability, resilience, and connectivity. (Correia et al., 2020) suggested a new model that has evolved to combine sustainability, innovation, and quality of life. However, in (Sharifi & Allam, 2022)'s taxonomy, the limited compatibility of the smart city models on environmental sustainability and climate change is remarkable. The common view is that one-dimensional evaluation tools are insufficient and far from standardization (C. Li et al., 2020).

An evaluation model can measure the maturity level of smart or sustainable applications of local governments/municipalities with titles such as smart governance, smart environment, or smart economy (Castanho et al., 2021; Hsu et al., 2021; Rotta et al., 2019; Suliman et al., 2021). The smart readiness level of a city infrastructure evaluated in this way can determine the direction of smart city investment decisions. However, when it is discovered that a city's smart city physical infrastructure, such as wireless network and IoT, has not been established, that is, if it needs physical infrastructure before digital infrastructure (Yan et al., 2020), it will not be possible to prioritize data shar-

Table 2. *Content analysis of articles related to smart and sustainable city evaluation.*

Research Direction	Reference	Research Methodology
Measuring smart city performance	(Sotirelis et al., 2022)	Multiple Criteria Decision Analysis
Municipal waste management	(Jonek-Kowalska, 2022)	Multi-criteria analysis
Multi context evaluation	(De Genaro Chiroli et al., 2022)	AHP to support the process of weights definition and MACBAC.
Featured research/key themes	(Hajek et al., 2022)	Bibliometric analysis, content analysis
Policy implications and investments	(Fang & Shan, 2022)	Principal component and sensitivity analysis, k-means clustering, multi-linear regression
Connectivity to sustainability/resilience	(Sharifi & Allam, 2022)	Taxonomy
Hesitant information	(Y. Wu et al., 2022)	K-medoids clustering to classify experts, DEMATEL method to determine the weights of attributes, consensus-reaching process
The fuzzy comprehensive evaluation model on sustainable development of smart city construction	(J. Xu et al., 2022)	Fuzzy set theory and neural network model for indicators, AHP
ICT, and life quality	(Zou et al., 2022)	AHP
Governance evaluation	(Hsu et al., 2021)	Literature review, expert consensus, the fuzzy AHP
Smart agglomerations, City Intelligence Quotient (City IQ)	(Z. Wu et al., 2021)	Automated information scraping in leading social media platforms, semantic analysis
Sustainability	(Valencia-Arias et al., 2021)	Qualitative descriptive methodology
Renewable energy	(Govindarajan & L.S., 2021)	Climate Smart Cities Assessment Framework (CSCAF)
Impact, performance and sustainability potential	(Kourtzanidis et al., 2021)	Three complementary evaluation axes
Sustainability, technology	(Castanho et al., 2021)	Cognitive Mapping and the Choquet Integral
Development level	(Huang et al., 2021)	A double reference point decision making method
Connectivity, sustainability, resiliency	(Suliman et al., 2021)	Literature, case study
Perception	(Orlowski, 2021)	Comparing with rankings or ISO standards
Smart building-city integration for real estate development	(R. Apanaviciene et al., 2020)	Comparative case study
Common and sherable framework	(C. Li et al., 2020)	Horizontal comparisons and benchmarks
Comprehensive system framework for smart transportation	(Yan et al., 2020)	Secondary qualitative data analyses, self-organization theory, case study
To maximize smart city capacity	(Wang et al., 2020)	Theoretical exploration, indexes and smart city relationship
Scheme (tool) selection	(Sharifi, 2020) (Sharifi, 2019)	Literature review, analyzing
Sustainability, innovation, and quality of life	(Correia et al., 2020)	Literature review
Municipal e-Gov Platform Evaluation Model	(Rotta et al., 2019)	Investigating municipal websites
Sustainable development goals (SDG 11)	(Wendling et al., 2018)	Critically analysis
Smart technologies for cities and citizens: reporting practices, challenges and recommendations	(Caird, 2018)	Case-study, evaluation and reporting
Smart city construction (model accuracy and time cost)	(Shi et al., 2018)	AHP, experts' opinions AHP, AHP-BP and AHP-ELM
Local evaluation tool	(Rocon & de Alvarez, 2017)	Literature review, European Smart Cities evaluation tool
ICT, open innovation/decision-making processes/governance	(Mainka et al., 2016)	Best-practice examples and research frameworks

Achieved Goals				
New evaluation tools		Current smart city evaluation tools		
		Suitable tool and method selection, literature review and tool comparison	City Ranking	Current advances and future research directions, improving current tools
(Sotirelis et al., 2022; De Genaro Chiroli et al., 2022; Fang & Shan, 2022; Y. Wu et al., 2022; J. Xu et al., 2022; Zou et al., 2022; Hsu et al., 2021; Valencia-Arias et al., 2021; Z. Wu et al., 2021; Castanho et al., 2021; Kourtzanidis et al., 2021)	(H. Huang et al., 2021; Suliman et al., 2021; Orlowski, 2021; Apanaviciene et al., 2020a; C. Li et al., 2020; (Yan et al., 2020; Correia et al., 2020; Rotta et al., 2019; Wendling et al., 2018; (Shi et al., 2018)	(Sharifi & Allam, 2022; Sharifi, 2020; Sharifi, 2019; Shi et al., 2018; Wendling et al., 2018)	(Caird, 2018; Jonek-Kowalska, 2022)	(Hajek et al., 2022; C. Wang et al., 2020; (Rocon & de Alvarez, 2017; (Mainka et al., 2016; (Govindarajan & L.S., 2021; (Caird, 2018; (Rocon & de Alvarez, 2017; (Mainka et al., 2016)

Table 3. *Articles on smart building-city integration.*

Title	Reference	Keywords
Smart building integration into a smart city (SBISC): Development of a new evaluation framework	(Apanaviciene et al., 2020a)	Interoperability; Smart buildings; Smart city; Sustainability
Smart Building Integration into a Smart City : Comparative Study of Real Estate Development	(Apanaviciene et al., 2020b)	Interoperability; Real estate development; Smart building; Smart city

ing (Fang & Shan, 2022). In this case, a comprehensive ICT infrastructure must be established throughout the city.

5.1.3. Content Analysis of Articles for Query 3 (Research trends)

Query 3 results refer to the three articles and one of them is nor related shown in Table 3. The literature shows that only one study focuses on smart building-city integration evaluation. This study investigated the potential of buildings to benefit from the capacities of smart cities and become smarter in the areas of smart energy, smart mobility, smart living, and smart environment (Apanaviciene et al., 2020a). The authors conducted a case study covering nine office building projects that enabled smart materials and smart building services and proposed features of smart construction to serve the surrounding systems (Apanaviciene et al., 2020a). The other article does not propose a new evaluation tool (see Table 3).

5.2. Strengths and weaknesses

At the end of the content analysis, to respond RQ3 we identify six strengths for building-city intersection area and eight major weaknesses in building-city evaluation literature.

5.2.1. Strengths

As a result of our content analyses, strength areas at the intersection of building and city evaluations constitute holistic intersection areas. Contrary to existing literature, economy and technology areas are not included as separate areas in our model because they are pre-requirement for smart revolution of all areas. Therefore, we determined the six main intersection areas of the smart sustainable building-city to respond RQ4: Resilience, environment, management, aesthetics, mobility, and welfare and well-being.

5.2.2. Weaknesses

1. Adding local city features to building evaluation criteria is a requirement. Buildings are evaluated as closed boxes, and it is necessary to consider not only universal standards but also the topographic-climatic characteristics of cities and regions.

2. Studying more aesthetics, social and economic criteria in sustainable building evaluation tools is necessary. The criteria in existing evaluation tools are more focused on environmental sustainability.

3. Discussion of the necessary criteria in smart building evaluation needs to be improved. The literature is generally about developing sustainable building evaluation criteria.

4. Few studies evaluate the ICT infrastructure maturity of cities. ICT is indispensable to smart cities' infrastructure, and evaluations often need to measure the maturity of the technologies.

5. The smart city evaluation tools prepared by the multi-criteria decision-making method need to be more reliable. The tools must be validated with additional techniques and tests.

6. The smart city evaluations should have a holistic approach to all areas (e.g., mobility, living, governance). Current evaluation approaches need to evaluate some areas of city life.

7. The smart city evaluations often ignore the indicators of resilience, connectivity, and sustainability. This emerges as a higher understanding that covers the entire smart sustainable city approach.

8. Tools for evaluating smart city infrastructure and integrating smart buildings still need to be explored. Although there have been efforts to establish relationships between scales in a few studies in the literature, a common evaluation approach has yet to be seen.

5.3. A systematic approach to smart sustainable building-city integration evaluation model (SSB-CIEM)

After a comprehensive literature review, to respond to RQ5, we propose a new systematic approach for SSB-CIEM,

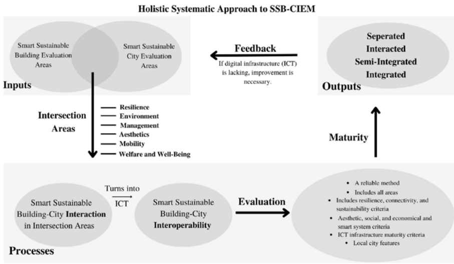

Figure 5. *A systematic approach to SSB-CIEM.*

as shown in Figure 5. SSB-CIEM is based on six main areas: resilience, environment, management, aesthetics, mobility, welfare and well-being. Some implementation examples from the literature in the six designated areas and future research recommendations are as follows:

5.3.1. Resilience

The integration of BIM and GIS can increase resilience in cities by providing information necessary for evacuation and intervention in fire situations and responding to fires in a short time (Isikdag et al., 2007) or by providing effective disaster management in assessing and monitoring the potential of flood risk to affect buildings (Lyu et al., 2016). Integrated use of digital technologies in disaster management can improve municipalities' urban services and help them achieve more resilient cities. Future research can focus on reducing possible risks of disasters (e.g., earthquake, flood, fire) with integrated BIM/GIS.

5.3.2. Environment

While GIS provides the integration of electrical data in a building system managed with BIM and data in the city management system, it enables data visualization, analysis, building performance analysis, and appropriate location selection with a bottom-up management approach with smart microgrids containing semantic information (Farooq et al., 2017). In the construction phase, practitioners can determine the nearest location to which the excavated soil will be transported through the BIM-GIS-IoT-based urban system (T. Huang et al., 2022). Recycling of construction, operation, and demolition waste of buildings to appropriate city facilities, in short, asset management throughout the building life cycle. Monitoring the data on the energy produced by buildings with PV panels and presenting the excess to the city grid; communicating with the city grid in real-time in case of an electrical malfunction and quickly carrying out the necessary maintenance and repair; and storing this data for later use could be focus points in the future research.

5.3.3. Management

BIM-GIS integration enables smart urban management practices, moving from traditional construction permit applications to fully integrated planning reviews in any municipality (automate model-based e-permitting (Shahi et al., 2019). The data required include 3D city models, BIMs, and regulations to be checked (Noardo et al., 2020). Moreover, integrated BIM-GIS enables versatile and flexible site layout planning (AlSaggaf & Jrade, 2023). Transform BIM information into a GIS map model for operation and maintenance management of mechanical, electrical, and plumbing, enabling integrated delivery (Hu et al., 2018). The interoperability of BIM-GIS technologies to integrate building and city management systems requires that future work focus primarily on resolving data format conflicts.

5.3.4. Aesthetics

The simulation of the city's and buildings' functioning in virtual environments and interactive BIMxD+BigData+Digital Twin is the new horizon (Redondo, 2023). Integrating BIM and environmental planning has only recently entered the agenda (Wilhelm et al., 2021). Recent studies show that integrating the BIM model of buildings into the GIS representing the urban scale system can facilitate design decisions in a 3D working environment, comply with zoning plans, and facilitate urban aesthetics.

5.3.5. Mobility

The proximity of public transport stops, and the frequency of travel indicate the accessibility of a building. Proximity to urban services and alternative means of transport (bicycle access and parking, car sharing, electric charging stations) are other sub-headings that fall within the scope of smart mobility (Seinre et al., 2014). Further studies can focus on making more accurate building and landscape layout decisions by correlating proximity to urban services, building landscape, and city plans with integrated BIM/GIS.

5.3.6. Welfare and Well-being

Converting point clouds obtained by scanning into geometry objects and then integrating them with geographical data such as air quality or noise information are positive developments in protecting human health and so well-being (Ellul et al., 2017). Moreover, benefiting human health by identifying and reducing aerobiological health risks in urban environments (Fernández-Alvarado & Fernández-Rodríguez, 2022) may be possible with integrated BIM/GIS in smart sustainable cities. On the other hand, integrating socio-cultural activities planned for occupants in affordable housing areas with the city through BIM/GIS integration and physical infrastructure systems may be a focus for future research, as it has the potential to increase human well-being with its smart sustainable features.

Even if a building project alone is at a sufficient level of development, integration into smart city networks, interoperability goals, and the ability to adapt to the strategic goals developed, identify integrated smart buildings (Apanaviciene et al., 2020a). A building equipped with smart, sustainable systems will integrate with the city if it can benefit the city's capacity at intersection areas. In "separated" environments, smart, sustainable buildings and cities do not interact with each other. In "interacted" environments, a human can interact with the building and the city via smart devices. In "semi-integrated" environments, buildings and cities start to work together but cannot interact in all areas. In "integrated" environments, building potential and city capacity interact in six main areas, and the interaction level can increase with ICT. When there is a lack of integration, decision-makers should improve the infrastructure of

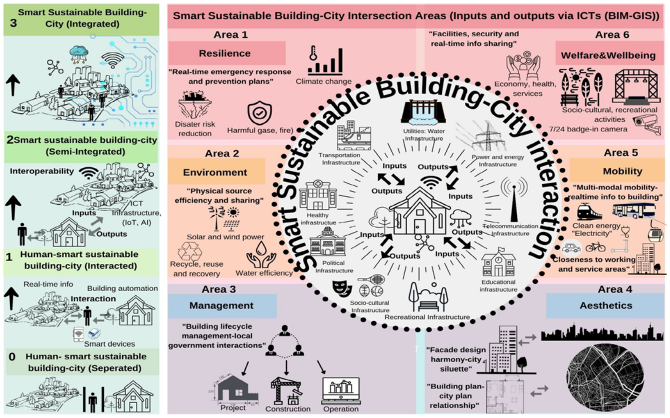

Figure 6. *Conceptual Diagram of SSB-CIEM*

the missing areas at the intersection by analyzing the building and city potential well (see Figure 5).

The conceptual diagram of SSB-CIEM in Figure 6. demonstrates the potential use of SSB-CIEM based on intersection areas. The building and the city constantly interact with each other through inputs and outputs in the six main intersection areas. Smart sustainable buildings can manage valuable data (e.g., energy and water) on all kinds of urban resources throughout their life cycle (planning, construction, operation, demolition) through a common digital platform with the city. Thanks to the latest developments in ICTs, management platforms that can effectively monitor inputs and outputs in real-time and make high integration possible can be considered BIM for buildings and GIS for cities.

Integration evaluation areas are limited by the dominant headings in existing evaluation tools at the building, city, and integration scales, and an overlooked heading (aesthetic). Every new smart technology and sustainability approach implementing area between the building and the city's building-related infrastructure has the potential to evaluate the existence and level of data integration technologies. Therefore, we discussed implications for future research and practice. Moreover, we showed that smart, sustainable building-city integration evaluation could be evaluated through BIM-GIS integration. BIM/GIS can provide smart sustainable building-city integration by integrating data into the city's design, construction, operation, and demolition activities. Since the

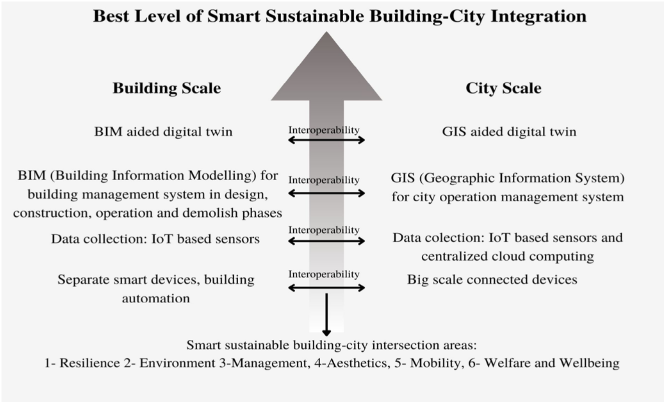

Figure 7. *SSB-CIEM maturity diagram.*

main areas included in the model cover many sub-application areas/titles, only the findings of the systematic literature review are compared with the existing literature, which is supported by some studies on BIM/GIS integration included in the articles searched in Scopus (see Figure 6).

5.4. Maturity in SSB-CIEM and Data Management

Grids, open data platforms, connected transport systems in smart cities, and the proliferation of technologies to automatically manage and monitor resources (González-vidal et al., 2019) allow smart buildings as a small-scale data management points interacting with these systems throughout their life cycle. Data management with ICT (monitoring, storage and interpretation-processing) and real-time information are critical in SSB-CI. Establishing a robust ICT infrastructure in intersection area could increase the maturity of integration. Figure 7 represents digital and physical infrastructures of building and city scales that increase the maturity level of integration.

While BIM is useful for 3D interior models with comprehensive meanings, GIS is useful for spatial analytical tools of open spaces (Jiang et al., 2022). BIM and GIS need to be combined for improving the availability and efficiency of information (Pauwels et al., 2017). Integration of BIM-GIS data in smart cities enables holistic perception of the building and its environment in the digital environment (Karan & Irizarry, 2015). In addition, the fact that data sharing is bidirectional between BIM and GIS is noteworthy in data integration as it minimizes the margin of error in analyzing systems belonging to resources in building-city management and reduces time loss (Farooq et al., 2017). Information models prepared with integrated BIM-GIS, real-time data sources, and other digital platforms can create digital twins (DTs) (Piras et al., 2024). When smart buildings and DTs of cities can work together, the level of integration increases (see Figure 7).

6. Conclusion

The literature review shows that the building's and city's smartness and sustainability evaluation efforts are prevalent. Despite this popularity, something is being overlooked: Smart sustainable building-city integration. Bibliometric analysis reveals that SSB-CI has been the subject of only a few studies, and SSB-CIEM is quite a new approach that is open to development. For this reason, this research defines the concept of SSB-CI. After conducting a bibliometric analysis of all articles obtained from Scopus, passing them through a certain filter, and making a content analysis of sixty-one, the areas of existing building-city evaluation tools were identified. The proposed SSB-CIEM includes six intersection areas: Resilience, environment, management, aesthetics, mobility, and welfare and well-being. Continuous interaction, interoperability, and information flow in the six designated intersection areas between building and city infrastructure in a smart sustainable city are prerequisites for full integration. The integration maturity is increasing with digital technological developments, namely the BIM-GIS-aided digital twin integration approach. Based on the findings, we proposed the following eight-item approach for a holistic SSB-CIEM:

1. We can evaluate integration maturity between building-scale and city-scale based on ICTs (Ubiquitous Computing, IoT, BIM, and GIS) data platforms.
2. The integration level of smart sustainable building-city physical and digital infrastructures can be increased depending on common data-sharing

(interaction turns to interoperability) levels via digital twins.

3. Taking experts' opinions for the intersection areas and sub-areas/criteria from the private and the public sector via multicriteria decision-making methods such as AHP and Delphi Technique can increase the reliability of the SSB-CIEM.

4. A holistic approach to all areas (i.e., mobility, living, governance) can increase integration and resource efficiency and improve citizens' quality of life.

5. The resilience, connectivity, and sustainability indicators should be indispensable in the intersection of sub-areas/criteria.

6. Evaluation sub-areas/criteria appropriate to the local characteristics of cities (such as geography (climate, topography) and cultural habits) can be added to SSB-CIEM.

7. SSB-CIEM criteria can be multi-dimensional if we add aesthetics, social, and economic-based criteria.

8. Among the sustainable building criteria, those that can be implemented with smart technologies should be called "smart sustainable criteria" for SSB-CIEM.

Using the SSB-CIEM can be helpful for city planners, architects, and engineers to set system integration starting from the planning stage and defining priorities in physical and digital infrastructure projects. At this point, we draw attention to expanding the use of digital tools necessary for building and city integration among practitioners. Moreover, the evaluation of building-city systematic integration in the identified areas with the proposed SSB-CIEM can be used by public authorities, especially in municipalities, in cooperation with technology developers, to improve the quality of services offered to citizens by producing new solutions based on publicly available data. Finally, the model supports that decision-makers consider the socio-economic and cultural benefits on a local and global scale of cross-scale communication established with the latest technologies from building to the city through steps such as reviewing national smart city action plans. Thus, SSB-CIEM can contribute to more than one area of sustainable development, particularly SDG11 "sustainable cities and communities." Future research could determine the sub-areas/criteria and criteria weights. Although the selected word sequences limit the study, researchers have reviewed many other articles related to the study for an in-depth literature analysis. There is always a risk that a significant article will not be noticed. The bibliometric and content analysis studies are limited to English articles in journals indexed in Scopus. Future studies may include other databases, such as the WoS, to support the outputs. Finally, the lens of integration can also be applied to other popular and normative city concepts.

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