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Smart technologies in the construction technology of sustainable housing projects for low-cost housing, Focusing on the Greater Khartoum Region

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Abstract:

The advancement of Internet of Things (IoT) technological innovations and Machine Learning (ML) presents novel prospects for the creation of novel solutions across several industrial sectors. It encourages the development of a fresh wave of very trustworthy, accessible, secure, safe, and effective smart apps. These technologies have previously been partially or fully utilized to create applications that offer a number of advantages, including increased safety and logistics and safety in work environments. Although intelligent apps have as other industrial sectors have previously shown, there is a widespread perception that the building industry is falling behind. A preliminary analysis of the literature revealed a persistent deficiency in research that combines IoT and ML technologies. Therefore, this study present a comprehensive review that covered an adequate number of articles on smart building construction technologies published in different venues between 2013- 2023. The major objectives of this study is to review the current research in smart construction technological solutions and infrastructure with goal to identify the current research trends, potentials, and limitations associated with creating and utilizing smart apps in the construction industry. Additionally the work present thorough summary of research areas application demonstrate efficacy for these technologies. Section 2 present material and methods. Section 2 covers various aspect of smart technologies enable in construction. While Section 3 highlights some new research directions for smart construction applications that are quite interesting when developing smart applications. The article is concluded in Section 4, which addresses the problems and difficulties encountered.

Material and Method

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2.Material and Methods

A systematic review is a type of research methodology created to collect, assess, and analyze all the data relevant to a given research issue or area of interest. The study chose a systematic review as an approach to carry out the analysis since its goal is to provide an unbiased evaluation of a research issue in a trustworthy, rigorous, and methodical manner. It is important to note that, the strategy recommended by Kitchenham[1] is employed. The process involved several phases and activities (see Figure 1).

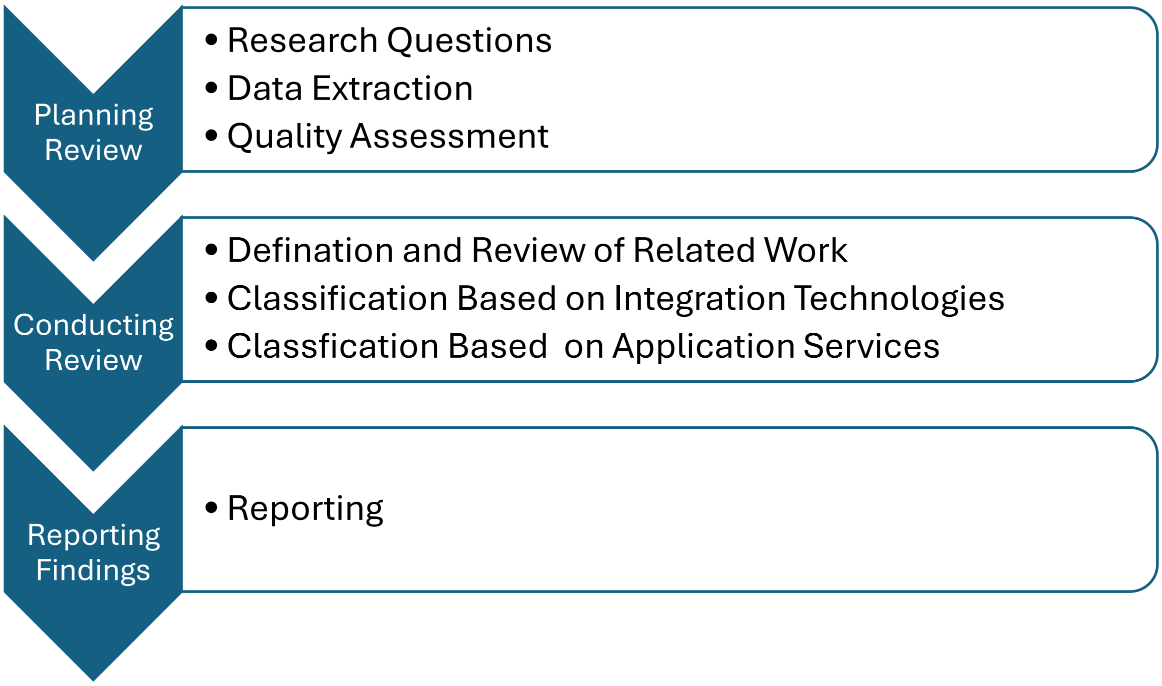

Figure 1. Processes and activity diagram of the literature review

3. Planning Phase

The goal of this review is to gather and evaluate the proposed smart technologies for building construction solutions from different perspectives. The analysis will reveal research gaps and suggest new areas for exploration. For this reason, the study developed five research questions (RQ).

3.1 Research Questions

The research questions represent the foundation for the search strategy for literature extraction. Most of the proposed systematic literature review in smart homes focused on evaluating the effectiveness of existing smart home solutions, and quality attributes. However, this study offered an analysis of various aspects of smart technologies in building construction which

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consist of technological integration, and applications and services. Following are the three research questions formulated for this study:

RQ1: What are the quality levels of smart building construction technologies research?
The goal is to identify possible technologies that make it possible for smart building construction open to reality.

RQ2: What are the existing technologies for smart building construction?
The goal is to identify possible technologies that make it possible for smart building construction open to reality.

RQ3: What are the existing smart building construction applications and services?
The goal is to identify and classify available smart building construction applications and services currently available in the market or in the development phase.

3.3. Data Extraction
The review process starts by conducting systematic searches on five different electronic databases based on designed search terms. The study considered "smart building construction technologies" to serve as the basis for the keyword selection. The keyword choice was supported by the need to address the whole range of smart home areas. The formulation of keywords covered from the broader and then narrowed to specific terms. The goal is to review the findings based on a formulated keyword search.
This study limited the extraction results on journals (article and review), conferences, book chapters, reports and online repositories from 2013 to 2023. In the search strategy, three primary keywords, “smart construction”, “smart technologies in construction,” ” and “smart construction application”. Each of these main keywords has a sub-keyword search.

3.3.1 The search process
The research search process starts with using “smart construction”, which results in 34 related literatures. As can be seen in Figure 2, there are more papers related “Internet of Things” followed by “human”, “air conditioning” and so forth. This indicates researchers are putting more emphasis on IoT to enable smart construction design in built environments to ensure building sustainability, which also plays a major role in reducing carbon emissions.

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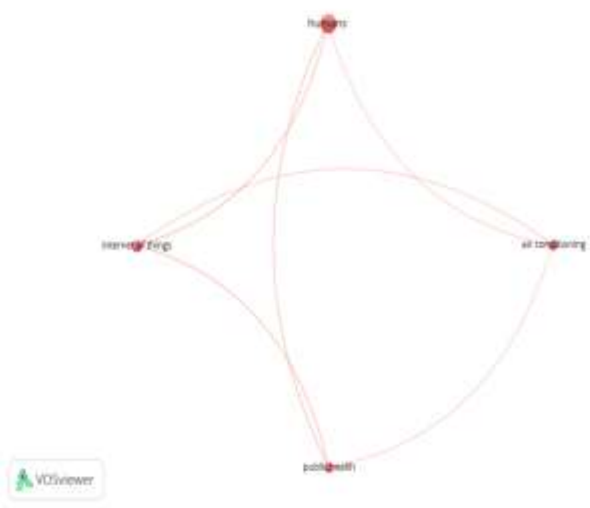

Figure 2. smart construction

The research also used “smart technologies in construction” as a major keyword for searching related literature across five different databases, which resulted in the retrieval of 88 related literatures. It is shown in Figure 3 that papers related to “temperature control”, wearable sensor”, “machine learning”, Internet of Things”, “nano structure” and “bio sensing technologies” have a higher percentage among the literature discovered in this search.

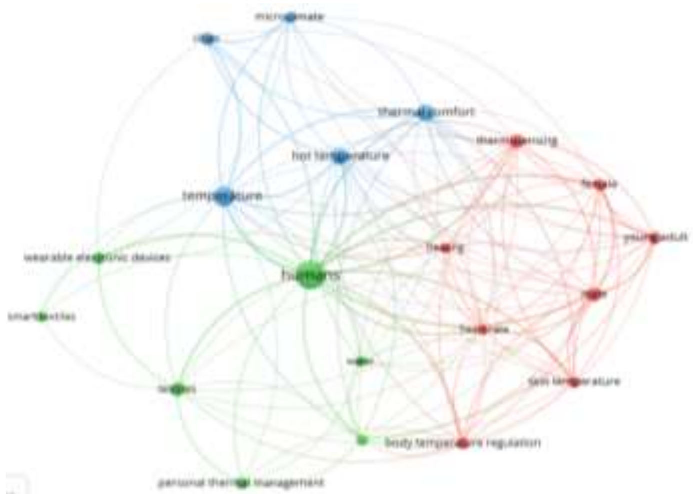

Fig 3. smart technologies in construction

The search moved to “smart construction application” as the main keyword. The search was done across five different databases, which resulted in 87 existing literature. A large portion of the literature discovered on this search is related to “smart home” followed by “internet of things”, “machine learning and so forth, as seen in Figure 4. This shows that research in

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building energy sectors is utilizing the Internet of Things technology alongside machine learning to transform buildings into energy-aware environments.

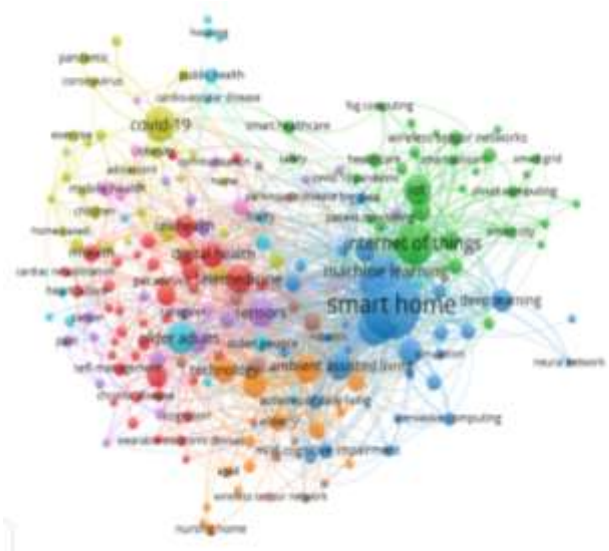

Figure 4. smart construction application

3.3.2. Sorting of the related literature
After the search was done, the entire literature during the search process resulted in 209 literatures. The research team removed similar publications that appeared in several queries by using a Google document page coupled with an Excel spreadsheet. This procedure helps track and remove 76 identical publications and a reduction in the total number of publications from 209 to 133 researches. Substantial duplicates were discovered across the search outcomes received during the second, third, and fifth stages of the query, with only a few duplicates discovered during the fourth phase of the query.

3.4 Quality assessment

This study considered 133 existing related literature with the goal of identifying current trends and future research opportunities in the area of smart homes. The study ensured only high-quality research literature was used for the final evaluation In this regard, the study adopted quality assessment parameters and guidelines used in [2]. In addition to the adopted parameters, the study added Journal indexing (A6) as one of the parameters for this study evaluation, resulting in six quality assessment parameters as described (A1-A6).

Assessment 1(A1): Is the article present in English? This is essential to ensure that all authors comprehend what has been written and can arrive at certain conclusions.

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Assessment 2(A2): Is the study related or relevant to the keywords used in searching the related study? This is essential to ensure that only relevant literature is considered for the final evaluations.
Assessment 3 (A3): do the search activities cover reputable databases? The objective is to ascertain if at least five (5) digital libraries have been searched, a search strategy has been introduced, or if all journals relevant to the topic have been discovered and cited by the authors.
Assessment 4 (A4): Has the relevant literature been sufficiently described? The objective is to ascertain the specific information offered in the literature.
Assessment 5 (A5): Can the authors evaluate the quality and validity of the study? The objective is to ascertain if the quality criteria taken into account are precisely defined and followed, and also the results of the findings are extensively discussed.
Assessment 6 (A6): is the journal currently active in at least three databases considered for the literature search process? This is essential to ensure that the potential results presented at the end of the study are significant.
It is important to note that after applying the quality assessment factors, the study reached 54 related literatures. The study further evaluated the literature analytically based on the authors experience and understanding of the field.
The following are used to express the assessment: (yes) indicates data is clearly presented, P (partially) indicates data can somehow be inferred, and (no) indicates data is not defined and can be inferred. Similarly, yes= 1, P = 0.5 no=0 are used as rating factors accordingly.
Upon evaluating research using quality evaluation requirements, it was discovered that 35 out of 24 studies received a 6/6 grade, 18 studies received a 5.5 out of 6. Similarly, 8 studies out of 54 receive 5 out of 6 and 4 studies receive 4 out of 6.
Research with a rating of 6 corresponds to the two topics the smart building construction technologies offer an innovative approach along with testing evaluation and analysis using a specific metric, or they critically examine and analytically present a compressible review of the suggested approach. Such with a score of 5.5 are those who do not have thorough research or an appropriate technique of assessment.
The research with a score of 6 to 5.5 is journal articles. Similarly, those with 4 scores simply presented proof of theory or concept and presented in the form of conferences. In short, the data in Table 5 (see Index A) show that the greatest number of relevant research evaluated has answered quality evaluation questions with no addition.

3.4.1 Trend of publication

The data presented in Figure 5 shows the total number of publications, which consist of a review and research articles, with respect to the year of publication from 2013 to2023.

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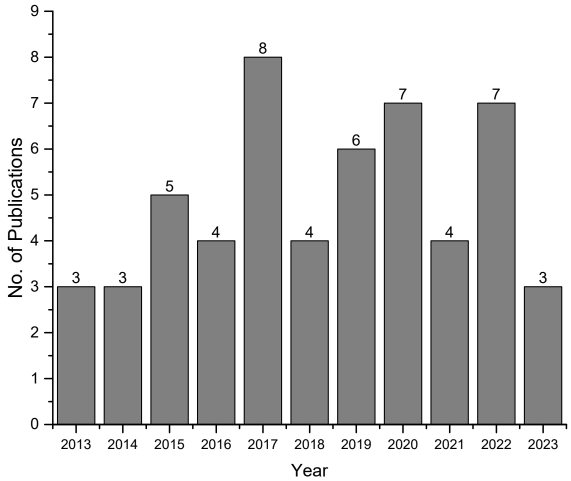

Figure 5 .Literature publication trend

Figure 5 shows that the year 2013 and 2014 has the lowest number of research publications, and it also shows that the year 2017, 2019, 2020 and 2022 has the highest number of publications. It also shows that only a few researchers (16.4%) proposed review work consisting of survey and comparative review analysis. The majority of these review works often focus on pinpointing flaws in how technology sensors or devices are implemented, neglecting the research restraints that improve the architectural design, algorithm platform, or model for smart technologies. This shows that smart home research is eager to look for academic and commercial recommendations to enhance the functionality and performance of smart building construction technologies.

3.0 Definition and related work

Various definitions have been used to conceptualize and define smart. Among the different approaches, the definitions by[3]and [4] covered the nature of smart homes in a pervasive way. The study defined a smart home as “a residence equipped with computing and information technology, which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security, and entertainment through the management of technology within the home and connections to the world beyond” They included the technology aspect of the phenomena, the features and services it offers, and the different user demands that smart homes try to satisfy in their definition. In the same vein study in [5]viewssmart homes as “the integration of different services within a home by employing a common communication system. It assures an economic, secure and comfortable operation of the home and includes a high degree of intelligent functionality and flexibility”. The following section providesa summary review of current smart home methods and approaches.

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Study in a proposed smart home solution that automates the management of HVAC operation based on dynamic indoor weather conditions or occupancy data[3]. The study uses an explicit control system modeled with different parameters to meet demand response design criteria. The authors in came up with a smart home solution that relies on external signals in advance to activate demand control[6]. One of the advantages of predictive control is that changes to the occupancy calendar or schedule cannot affect the performance of the controller. Studies in designed an algorithm that needs control values like cost, heat demand, or photovoltaics generation to fulfill demand as cheaply as possible. This indicates controllers must be aware of the proper input and analyze it to determine the ideal moment to use energy. A smart home framework is proposed in [7] that uses a more advanced controller that uses inference rules and classifiers to make decisions on best time to use home appliances during peak energy consumption hours.

Studies in [8-11] use real-time occupancy through various installed sensors within the perimeter of interest to detect and predict occupancy in the space. The approaches attempt to minimize the false results in occupancy prediction from the previous literature and improve appliance energy consumption. However, these approaches face challenges in predicting actual human occupancy to avoid false negatives triggered by stationary objects such as cats, dogs and others. Similarly, predicting the total number of occupancies presently in the building to adjust thermal comfort in according to the occupant number becomes another challenge.

A study in [12] designed HVAC controller that uses a carbon dioxide (CO2) and passive infrared sensors to detect the occupancy presence and send signal to actuator to regulate temperature turning depending on the occupants' number in the building. Even though, these sensors are widely used in previous literature, however, their application in commercial is not practical as suggested by [2]. Similar approach applied CO2-based in conjunction with ML algorithms. The result evaluation indicates solid performance even with the sudden change of temperature in the perimeter of interest as when space has been occupied.

A study in [10, 13, 14] proposed controller for occupancy detection using audio to effectively identify human occupancy and used a Gaussian Mixture Model to estimate the total number of occupancy in space. The proposed method achieved a certain level of accuracy with high false results caused by nearby external sound. Similarly, the approach requires all indoor occupancies to speak simultaneously to perform occupancy estimation for HVAC ventilation control.

To enhance the accuracy performance of controller in [15] study in [13] introduces a background cancelation procedure to deal with noise inference from undesirable sources by ignoring the sound frequency level of the desired sound frequency threshold defined. The idea relies on the strength of the sound frequency received by the background cancelation algorithm, which reduces the false alarm of occupancy prediction by 11–12% and saves 3.54% energy consumption by HVAC equipment. Despite the background cancelation algorithm applied, the study suffers from a false occupancy prediction.

A controller is proposed in [16] that combined camera-based image and video processing with help of Computer Vision (CV) libraries and estimate total occupancy numbers through

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headcount or indoor object tracking. Similar approach is used in [17] hat used single-camera occupancy detection to control ventilation in the lecture theater through a headcount occupancy estimation procedure. The experimental result analysis shows high performance in occupancy prediction. However, the false result in the report is as result of poor coverage of camera when students randomly entered or exited from the perimeter of interest. The major challenge of this study is poor detection of occupancy during occupancy overlapping in the period of an entrance and exit from the perimeter of interest.

An adaptive controller is proposed in [18-21] that uses a collaboration of optical and passive infrared cameras to detect human occupancy in space. The idea is to reduce the potential false alarm by using a single camera and ensure the reliability of detection which in turn increase HVAC energy saving and improve thermal comfort.

A controller that implements non-predictive control is proposed in [22]that heavily relies on occupancy fixed timetables. It uses such data to create a model that predicts the likelihood that a building will be filled and uses that information to regulate HVAC operation. In this typeof setting where occupation activities are carefully adhered to daily by a predetermined scheduling policy, this sort of control strategy may be useful. Commercial structures like offices, labs, and corporate environments are fantastic illustration that fully utilizes literature [23-27]. This strategy, meanwhile, would not be effective at a place where occupancy can skip or does not adhere to a set timetable.

Most of the non-predictive controllers such as [18, 28] employed binary algorithms demonstrating that frequent OFF and ON tend to shorten the lifespan of electrical appliances. As such more advanced in [29] that use decision-control algorithms, such as fuzzy logic were designed as improvements to binary algorithms with sets of values other than Zeros and Ones, giving context to allow dealing with additional choices for control to select. Research in [30] proposed a controller that controls HVAC energy usage based on demand. At the same time the controller can respond and postpone the demand whenever the electricity price is at its highest. A similar approach in [31] uses a schedule strategy to determine the control signal to activate energy consumption demand. This strategy uses rule-based technique to quick access power grid voltage or rate stabilization is an excellent example of schedule control employing model-based control.

The schedule-based controller previously used [31-35] to reduce energy costs and prevent the usage of appliances during times of high demand. For instance, it is possible to schedule an accessible standby equipment to utilize energy when energy costs are lower so that other appliances in the house may use the energy that is kept within this appliance. Both a runtime and a static technique may be used to provide this control.

4.2Smart Home Integration Technologies

In a smart home system, similar tasks can be achieved with different system integrations. For example, various studies have conveniently demonstrated smart light control via web and mobile applications. In an attempt to answer RQ2, previous survey studies did not examine smart home solutions in view to assess smart home integration technologies which is important

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to identify trends and issues related to quality attributes such as security, privacy, and efficiency. This study classified smart home integration technologies into (i) Mobile applications(ii) Web service applications (iii) Wearables (iv)

4.2.1Mobile application

In most cases, a native mobile application is necessary to communicate with home appliances through microcontrollers with or without the internet. Depending on the manufacturer or designer, mobile applications are built based on specific platforms, for example, Android and iOS. Smart home research with the aid of mobile applications is currently gaining momentum with the vast majority of research prototypes being made publicly available in the market. This research linked various devices to simplify the deployment of Internet of Things (IoT) interfaces[36, 37]. Currently, the products enable user’s remotely access home appliances through mobile application interfaces. Additionally, some of the products for example, solutions in [38-43] have the potential to greatly facilitate users' centralization of the usage of their appliances and schedule energy usage. Alternatively, few studies allow visually inspired users to access the interface of numerous gadgets, objects, and appliances at home using screen readers, which are present in the majority of Smartphones and tablets, utilizing a more accessible virtual interface available in such programs.

4.2.2Web application

In most cases, the user can access smart home appliances through a web application (web browser) without worrying about platform dependency. However, an internet connection is necessary to establish successful communication. The popularity of web application research is quite similar to that of mobile web applications. The overall goal is to ease the management of home appliances through automation and remote control. The ability to manage the gadget from a Smartphone or computer via this web application benefits people with difficulties or disabilities the most.

Current research [44-46]indicates the movement of traditional web application strategies towards a simpler strategy for designing and exposing web services andAPIs. Current Web APIs completely rely on the interaction primitives offered by the HTTP protocol, with data payloads transferred directly as part of the HTTP protocol, rather than on the standard stack[47].Additionally, solutions utilized client and server communication in a more organized and limited manner to enforce new emerging concept in web service development that enables a modular approach to system construction by realizing several small, highly decoupled services that are focused on performing a specific small task. As a result, numerous little, autonomous, reusable microservices can be combined to form complex applications.

4.2.3Wearable devices

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Wearable devices, commonly referred to as "wearables," are a class of electronic devices that may be implanted in the body of the user, worn as accessories, or even tattooed on the skin. Such devices have practical purposes, are hands-free, are powered by microprocessors, and have the added capability of sending and receiving data via the Internet.The popularity of wearable research is quite similar tothe mobile and web applications. Studies in [48-51] utilized wearable technologies to communicate with smart hub controllers at home to help occupants schedule energy usageand recommendations for best time to consume energy at a lower cost.Studies in [26, 52-54] addressed key problems in wearable technologies in multi-residential buildings. It is quite challenging to classify sensor events in multi-residential smart homes without revealing any details about the identification of the person who activates them. Individual localization in several locations might be a viable solution to this problem.

4.2.4Smart home appliance

A master home automation controller, also known as a smart home hub, controls lighting, security systems, thermostats, and other household equipment using sensors. The hub is a physical component that serves as the brain of the smart home system and can perceive, analyze and wirelessly communicate. It unites all the many smart home applications into a single app that users can operate from a distance. Amazon Echo, Google Home, and Wink Hub are a few examples of smart home hubs. While many smart home items connect to the smart home network via Wi-Fi and Bluetooth, others rely on wireless protocols such as Zigbee or Z-Wave.Smart home devices embedded with microcontrollersproposed in[6, 25, 55-57]automatically manage home appliance energy consumption or control patterns of appliance energy usage from the grid through interaction with utilities to receive energy tariff prices to lower or timing appliance energy usage. Research in this area is trending in both academia and industry more than ever. More than 42% of the total literature considered in this study focused on the design and development of smart home devices with mostly targeting HVAC systems, light, kitchen appliances, washing machines, and others.

4.2.5Tactile interfaces

Tactile interface refers to the sense of touch that encompasses vibratory sensations, changes in temperature, and sensitivity to applied pressure. For the purpose of research and comprehending the sensation of touch, several research teams have created prototypes. However, the designs and actuator technologies employed cannot support mass manufacturing, since the assembly of various elements at the level of these micro actuators, which have a size in the millimeter range, becomes time-consuming and nearly impossible. Study in[33] proposed five main sensory modalities to interact with the physical and virtual worlds. The proposed approach used technologies that completely rely on voice, vision, and touch-sensing modalities. When it comes to physical interaction, the latter is the dominant modality. Study [58] argues that sensory feedback alone is insufficient for any successful interaction since two-way tactile communication from the contact site to the controlling unit is crucial [10, 22]. In

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response, the study in [59]proposed an interactive system that allows usersto senddata using touch sensors and receiveresponses viaa variety of modalities, such as haptic, visual, aural, and others.

4.3Smart home application and service

In an attempt to answer RQ3, the study explored the smart home area, which covered the subsequent intelligent application and service that improved building energy efficiency. A smart home uses Internet of Things technology to convert traditional buildings into energy-aware environments, allowing programmed building management and processes that offer high energy savings potential and improve indoor occupant comfort levels. The summary of this classification is presented in Table 1.

4.3.1Smart HVAC System

Smart HVAC systems use various sensors to track and control the interior airflow. In the 1970s, Fanger created the predictive mean vote (PMV) and predicted percentage dissatisfaction (PPD) models to assess occupant thermal feeling [6]. The PMV model, on the other hand, was created by surveying anactual number of occupants. The model does not take into account individual variations and factors, making it ineffective for customized control[24]. As a result, numerous researchers have created customized thermal comfort models [60] that can be used to control the indoor climate [61] and achieve greater accuracy with more specific parameters. These customized models [60]have linked numerous physiologic factors with an individual's level of thermal comfort. Skin temperature[7], blood pressure [16], heart rate [62], facial temperature [10], and sweat rate [7]were the physiological variables most commonly utilized to assess thermal feeling. These customized thermal comfort models have a high degree of accuracy in predicting how warm an environment would feel.

Numerous investigations also discovered that the occupants' skin temperature, blood pressure and heart rate displayed a distinctly different pattern when they were feeling uncomfortable in a transient thermal environment. As a result, there is a link between the physiological factors and the occupants' thermal perception and behavior. This correlation can be used to regulate HVAC systems for thermal comfort.The finding shows that using physiological input data, such as skin temperature, a machine learning model can accurately forecast room occupancy as an input parameter to an HVAC controller that adjusts the room's temperature. In multi-occupant offices, the wristband control system has the potential to increase overall thermal comfort.

4.3.2Smart lighting

Through demand-response programs, wireless controls, and schedule control systems, smart lighting uses complex controls that combine occupancy with lighting and sophisticated

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dimming features to decrease overweighting and prevent lighting of spaces. The most apparent benefit of smart lighting is greater energy savings, but there are many other potential advantages as well. As a result, the majority of research in this young field of study is now concentrated on maximizing energy savings when coupled with LEDs that operate efficiently [48]. In fact, based on occupant behavior, systems with incorporated energy-saving lighting control often show energy savings of 17–60% over standard lighting control [63]. Due to their high potential for reducing power usage and ease of retrofit, commercial buildings typically have such energy efficient smart lighting deployed [5]. Besides that, smart lighting can be utilized to improve light quality and adopt lighting that is centered on people. Therefore, it can be stated that the development of smart lighting systems will benefit commercial applications and scientific research in the fields of horticulture, architecture, building management, light quality control, and human physiology. Research and applications related to smart lighting are particularly interested in the development of high brightness LEDs for general illumination. LEDs have strong dimming capabilities and narrow peak bandwidths, which provide them significant control over the spectral power distribution of the produced light. Furthermore, they are the perfect primary emitters for a multi-channel lighting system due to their low power consumption, rapid switching speeds, and extended lifespan. A new era in lighting control technology has arrived with the advent of the LED lighting revolution[64].

4.3.3Smart plugs

This includes many forms of auxiliary and portable office and home equipment in buildings using smart plug loads[32]. The vast majority of smart plug loads in commercial buildings are controlled by non-predictive autocontrol that depends on timely scheduling. Residential building predictive appliance control, in contrast, uses load detection or technology that detects motion to alternately stop the energy flow to an appliance that is not in use. Study in[65] proposed solution that switches plug-in devices off when not in use. Although it is uncommon, replaced traditional methods of monitoring home appliance completely with smart outlets that allow building owners and managers to monitor, track, and operate plug-in equipment using either their own cloud services or specific building automation system platforms. The authors in [32, 66]contend that modern technology and occupancy activities cause unnecessary energy waste yet go unnoticed by the energy data providers. As a result, there is a critical requirement to measure, examine, and identify the precise sources of waste at the appliance level in each area that uses energy. In response, the idea of hybrid appliance load monitoring which links the electrical grid and smart meter to guarantee proper energy usage was proposed. The study in [67]presented plugs that are similar to smart meters used for energy monitoring but lack the ability to control specific devices. The majority of the existing smart meters employ disaggregation algorithms to examine the smart meter reading in order to measure device level consumption, in contrast to smart plugs, which provide real-time insights with greater precision at the device level. The insights supplied by smart meters are primarily passive and call for a longer cycle of observation and analysis, but smart plugs may include extra functions to manage energy consumption on a daily basis.

4.3.4Smart window

Control the quantity of sunlight and solar heat that enters the building using smart window systems. The regulating systems Smart windows include active and passive window glazing

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that adjusts to changes in temperature or sunshine as well as automatic shade management that regulates light levels throughout the day[68]. With further study now looking at its use in flexible substrates for better efficiencies at low cost and longer-lasting devices a technique employed in [69] displays a maximum efficiency of 22.3% manufactured in lightweight construction material products. A method employs cutting-edge thin-film technology in smart windows, which are akin to smart meters, to react to natural ventilation.
According to earlier modeling studies, smart windows can save a building's energy requirements by up to 40% when compared to static windows. Study in [70]indicates underlying functioning principles of smart windows can be divided into three primary categories. While photochromic and thermochromic windows respond to environmental stimuli by changing their transmittance with changes in light intensity and temperature, respectively, electrochromic windows change transmittance when applied voltages are applied[71]. Study in suggested a smart window that reversibly switches between a transparent state and a blocking state to dynamically manage the transmittance of solar radiation into buildings [72]. This is one of the newest and most promising technological solutions that can lower HVAC energy use in buildings while also reducing glare, obstructing views, and increasing natural daylighting[73]

5 .0 Reporting and Potential Research Area

Today smart building construction is equipped with technological innovations and smart devices to achieve several tasks in the building to promote building sustainability. Such innovations and devices are featured with intelligent control techniques with strong design into practice to react or respond to environmental events. Several technologies are available to seamlessly and constantly minimize house energy usage while keeping an acceptable degree of indoor comfort. A survey of the most relevant literature is given in this work. It determines publishing trends based on the quantity of research that is published each year, taking into account both articles from journals and conference papers. The research also uses the set procedure for review to assess the quality of literature and classify the literature based on integration technology and its application.

6.1. Reporting Finding

According to the research, the majority of the published work in the SBEMS field focuses on systems that make utilize of an implicit microcontroller that asks for responses from an individual or construction administrator in the event that the grid offers a benefit to program request or reduce building electricity usage. Sophisticated algorithms for learning must be included into intelligent construction equipment in order for individuals to act upon incentives in the event that they are preoccupied or fail to notice them. The research highlights the demand for intelligent energy control options in all types of buildings by demonstrating whether energy use in commercial buildings is often managed differently than in residential ones.

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Achieving adequate thermal comfort is one of the main objectives of HVAC systems. Unfortunately, a preset temperature point is used by a large number of HVAC systems installed in workplaces, which can result in unfavorable interior thermal conditions whenever there is an unforeseen change in occupant or meteorological circumstances. Thus, it is recommended that demand control ventilation should be put in place which can modify the system's threshold temperature according various indoor and outdoor parameters.

Energy cost reactive controllers are necessary to regulate HVAC systems utilizing a 5-minute period and the price of power from the electricity supply. When electric bills spike, the self-response mechanism can stop an occupant from running the HVAC system more frequently. In order to give tenants the ability to plan ahead for utilizing power-intensive equipment, it is imperative to incorporate a standard pricing scheme that provides tenants with a predicted electricity price estimate per day. An occupier could precisely plan energy-intensive equipment to take advantage of the low-tariff periods by turning on this option.

Enhance the occupant sensing and estimation algorithms used in smart buildings today. In order to optimize energy usage, CO_2, surveillance, and movement sensors are widely employed in smart building structure to detect and anticipate occupant. At the moment, these innovations are unable to distinguish between human and non-human occupancy. Thus, in order to prevent HVAC load in empty spaces, a presence detection system that can differentiate among human and non-human occupancy is crucial.

Enhance the methodology are used to measure thermal comfort in the building to preserve an occupant's prefers comfort. The majority of the research that has been done on thermal comfort evaluation involves third-party equipment, such as a device that is worn to measure skin temperature. Numerous devices from third parties are able to exchange data and interact with online services or suppliers. Thus, in order to ensure the privacy of individuals, researchers must focus on greater responsive thermal comfort investigation, which will lead to a broader adoption of smart building construction technologies.

The advancement of smart building construction solutions requires a significant contribution from academia and industry on smart indoor lighting technologies. Modern lumens, dimmers, and LEDs are used in smart buildings today. Unfortunately, due to inadequate lighting management methods and problems with architectural layout, current lighting systems generate a large portion of building energy usage. To enhance lighting management, lights can be synchronized with partner software and controlled via a remote. Activity and illumination detectors greatly contribute to lowering lighting energy consumption [67]. Dimmers, proper skylight placement, and well-insulated windows can reduce illumination energy use by about 40%.

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The smart plug that is currently in use is necessary to turn off an appliance. It is possible to enhance the intelligence of smart plug technology to enable scheduling capabilities for the use of moveable appliances. Additionally, interoperability capabilities can improve communication across various SBEM products and allow voice-controlled AI, intelligent thermostats, and AI assistants to impart knowledge.

Deep learning integration enables smart plugs to acquire knowledge from and adjust to the patterns of users in response to requests on the gadget. For instance, if the residents schedule an activity at the fitness center, the smart plug-connected dishwasher ought to activate the cycle for cleaning clothing as soon as the resident gets home. This is a crucial method of energy conservation, particularly for a common device such as virtual assistant.

Including resident habits in smart window systems can improve the overall energy usage of buildings. This can be accomplished by teaching occupant habits methods for opening windows [6–8]. In order to get daily data, research must thus concentrate on comprehending and modeling tenant window-opening activity using AI approaches.

In order for other intelligent power optimisation technologies [76, 80] to work in advance of an occupant's arrival and drastically cut the use of energy, portable or outside devices have to monitor the occupant's present position. The privacy of the occupants is threatened by these methods. Consequently, a self-learning and reactive smart energy savings system that can forecast occupant locations with greater accuracy and reliability is required. In comparison to setting the HVAC system at a harsh thermostat setpoint, this can assist with start HVAC system at lower temperatures either heating or cooling operations before arriving inside the house to maintain the indoor temperature to the ideal level, saving more energy. Better demand response technologies that enable residents to produce their own energy locally using renewable sources can help reduce the electricity mismatch in the smart grid.

Since the beginning of smart buildings, security has proved a significant concern, becoming even more crucial when it comes to data exchange and transfer. Because of an absence of facilities and safety measures, intelligent CCTV systems, digital voice assistants, and thermostats are increasingly becoming popular targets for attacks that cause problems including denial of service and invasion of privacy. Only few research that use security techniques are generally limited to secure certain communication or applications domains and require generality. Research in the field of smart building construction does not presently focus on safety standards. To reduce attacks and create a system for quickly identifying and reporting security breaches, further research on this topic is required in the future.

Privacy presents another difficulty. For instance, a smart meter and a sophisticated appliance that monitors occupant routines and vital signs including arterial pressure, pulse, temperatures,

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drug use, endurance, bedtime schedule, and medicinal products are likely to compromise privacy. This data must be constantly obtained and shared with energy suppliers, other pertinent suppliers, or cloud-based data analytics platforms. Existing procedures immediately revealed sensitive resident data without protecting privacy.

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