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Smart Home Management for Modern Living

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Abstract

People increasingly prefer urbanisation for living, working, and playing. Nevertheless, living in a city environment can be detrimental due to pollution and the messiness of other chores, including transportation difficulties, household work, and caring for family. To overcome these challenges, smart home management (SHM) systems could be a good solution. A smart home is one in which services are automated and sensors, actuators, and devices are connected to a data system. Moreover, the smart home allows you to create customised scenarios to control your home and enables real-time monitoring of your home's condition. Five important phenomena emerge in SHM. It is essential to ensure the security and safety of the data first. Second, user-centred design, particularly in the context of the proliferation of wearables, enhances the user experience. Lastly, environmental sustainability is achieved through eco-friendly urban construction, in conjunction with innovative SHM algorithms and renewable energy alternatives. Fourth, a governance framework must be established for an open data protocol and privacy. In conclusion, the accessibility of SHM for low-income urban families is an important equity issue and a concern related to the digital divide.

Keywords: *Smart home management, data security, user-centred design, environmental sustainability, energy efficiency, IoT interoperability, privacy governance.*

1. Introduction

As homes become increasingly complex, with appliances, lighting, security, temperature control, energy use, and entertainment systems, there is considerable scope for automating these functions. Due to energy concerns, humans learned to reduce their footprint. Smart home management facilitates interactions among systems that may be forecasting or reacting to real-time information from sensors or other sources. SHM's capabilities also include managing and operating connected devices to enhance experience and optimally utilise natural or electrical resources. The proposed scope is primarily management rather than monitoring or control. It concerns the integration of capabilities for private networks, open standards, and user-friendly designs. Furthermore, it governs household comfort relative to long-term autonomous operation. We will examine the impact on the energy profile, occupant experience, and inter-device interoperability (Barsocchi et al., 2018). Work comprises ten subject areas capturing distinctive, but interlinked facets of contemporary SHM: fundamental architecture and universal regulatory pressures, enabling technologies shaping domestic enmeshment, sustainability and carbon footprint in a world grappling with climate change, quality of life enhancement complementing efficiency and stewardship, governance frameworks facilitating compliance, conformity, integration, and adoption of intelligent connectivity and other smart management strategies, execution challenges curtailing uptake of beneficial solutions, impact assessments based on defined performance metrics yielding actionable insight, exemplifications illustrating real-world deployments across diverse households, prospective research avenues fuelling SHM future (Shilin, 2022).

2. Foundations of Smart Home Management

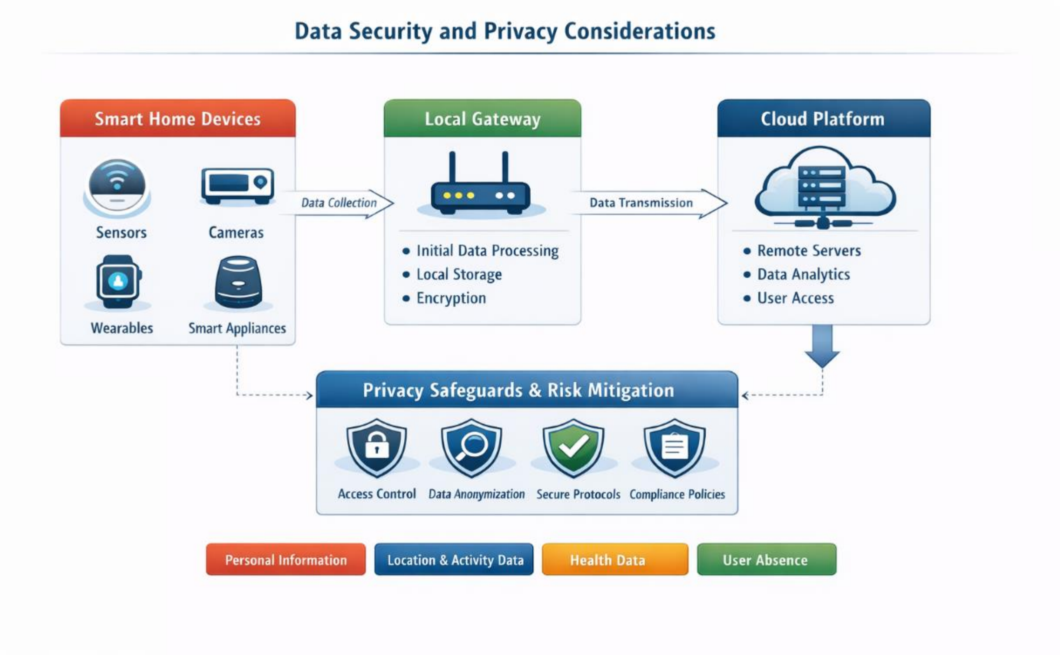
Most smart home management systems are based on consumer-grade commercial gear used largely in homes. This section outlines a framework for smart home management by describing the architecture and key technologies commonly used, with particular emphasis on their role in modern living. The aim is to identify foundational knowledge to improve the design and functionality of smart home management systems.

2.1. System Architecture and Interoperability

The quality of life for families in modern societies is improving due to the use of various technologies that enhance comfort and improve control. These devices may provide heating, lighting, and security surveillance, all of which can be controlled over the internet. While individual appliances can be portable and easy to configure, this is not the case for the smart devices in a whole-house system. This concerns the complexity and diversity of government, lighting, heating, and other electrical systems. As a result, it has become essential to categorise development into home appliances and home system devices. The development of home appliances typically includes the installation of a universal controller or remote control to facilitate user interaction. The home system functionality enhances communication and contributes additional intelligence to the overall control system. A standard for open system architecture can significantly advance intelligent building and home systems, enabling compatible devices to communicate easily, provide flexible functionality, and be readily extended (Zheng et al., 2017; Shilin, 2022).

2.2. Data Security and Privacy Considerations

Increasingly, smart devices are entering our everyday lives, providing intelligent services and enabling remote monitoring and control to meet consumer needs. The connected devices transmit data continuously. These devices can threaten your personal information, such as health data, occupation, and the absence of persons, through unsecured channels. The data flow is complex, as it can take multiple paths. Local gateways and platform services providers execute storage. There is no universal smart home architecture. Privacy issues are generally addressed with point solutions that combat a specific type of threat. A more structured method is needed to conduct a thorough privacy evaluation (Poh et al., 2021).



2.3. User-Centred Design and Accessibility

Homes and buildings can be made more intelligent through IoT technology. An intelligent home system consists of all electrical devices and their controllers. Smart Home Management refers to the integration of systems for the control and monitoring of connected devices. It ranges from managing a single smart device to managing an entire system. The distinctiveness of every device often gives rise to a fragmented ecosystem that drains resources and undermines the experience. In a cooperative network, Smart Home Management adopts a holistic strategy to preserve experience and enhance resilience. This supports a wide range of objectives through continuous data gathering and intelligence-enabled decision-making. Attention can shift from service parameters to household personal goals—enhanced understanding and meeting of user requirements.

The living arrangement has changed; it is currently experiencing a surge in demand for collaborative smart home systems. Smart Home Management remains limited to a single household context and focuses on a narrow user experience (Jeong Kim et al., 2020). Using both breadth and depth in the design approach will yield greater diversity. A broad understanding of the technologies surrounding smart homes can be achieved by examining household characteristics. By separating the dimensions of the user-need model and the ergonomic space for devices and services, we can identify context-use cases across homes. Differences in social attributes affect households' core expectations, values, and the ways they invest in smart devices. Smart homes can become instruments of social change, depending on the intensity of household types.

3. Core Technologies Driving Smart Homes

As people move into more multi-occupancy complexes, we are increasingly observing smart-home collaboration. According to Jeong Kim et al. (2020), Smart Home Management remains limited to household-specific conditions and functionality, with a focus on user-friendliness. By utilising a combination of depth and breadth, the diversity that will be addressed will be optimised. Understanding the technologies of social dynamics and household features helps understand the smart home system as a whole. The user-need model has separate dimensions, as do the ergonomic spaces for devices and the ergonomic spaces either conceptually or in practice for services. This helps in the interpretation of context-specific use cases across homes. Differences in social attributes affect households' basic aspirations, values, and attitudes toward investing in smart devices. Smart homes can be a driver of social change, with varying intensities depending on household type.

3.1. Sensing and Automation

Smart Home Management systems have provided our lifestyles with considerable comfort and convenience. Centralised, integrated energy-efficient equipment schedules (for lighting, temperature, and humidity) reduce energy consumption while ensuring convenience and comfort. Since most equipment can be programmed, energy use can be adjusted to changing consumer electricity rates. Smart Home Management systems that monitor device status can flag equipment failures via anomalous patterns. Stand-alone equipment, such as custom dynamic load-shedding controllers or standard equipment, can further enhance the user experience and savings. Mile et al. (2017) enable the integration of external factors to achieve home comfort, energy savings, and support utility Smart Grid initiatives.

Smart Home Management systems aim to keep users uninvolved, with feedback provided through simple reports and alarms. User preferences often evolve from psychological affinities among common household inhabitants, particularly through users' initial operational practices (Shilin, 2022).

3.2. Network Protocols and Connectivity

To connect smart home systems, multiple connectivity protocols can be used, such as Wi-Fi, Zigbee, Z-Wave, Bluetooth, LoRaWAN, and Thread (Shilin, 2022). Research has compared these protocols with respect to reliability, latency, scalability, and security. Most elements are already connected to the Ethernet network via mobile access points; therefore, Wi-Fi protocols are typically selected, as they enable monitoring and control of home appliances (Perumal et al., 2013). Zigbee is used to connect low-power devices over short distances. The internet uses a dedicated gateway. The Z-Wave protocol was designed to operate similarly to Firefly but is optimised for battery-powered applications. It also has limited multisensor support. Bluetooth is not designed for short-range communication, but it is used for local control via smartphones and for connecting a variety of actuators. Conversely, devices operating under LoRaWAN can control outdoor devices over long ranges without interfering with one another. The thread is optimised for the Internet of Things. It leverages wireless communication to reduce power consumption. Also, Thread runs on IPv6. It thus connects to other IPv6 networks effortlessly (Plantevin et al., 2017).

3.3. Artificial Intelligence and Decision Support.

A smart home can offer different solutions to improve the quality of life. However, in practice, these technologies are most often used for household chores that add no extra value. For instance, certain residences automatically pull the drapes or switch on the apparatus at specified hours, all without real utility; though perceived as merely for fun, this can be enjoyable. Consequently, it is essential to create a system that adds value to day-to-day living rather than systems that are replaced at intervals for an interchangeable task. Customers ultimately do not care about value, fun, and innovation; rather, it is these functions that we deliver. Currently, smart homes use AI to manage only major appliances. Consequently, the home will become more like an operations centre, where we will constantly have to monitor and manage our control over the AI.

Therefore, consumer problems, needs, and requirements should be well understood; on that basis, the decision-making process will change. This provides a sound basis for decision-making under uncertainty. Involving householders and family members will facilitate service provision and adaptation of service from one unit to another. Multiple devices emit valuable information, which we fuse to facilitate comprehensive interpretation at home. Predictive analysis of different data feeds can support decision-making at the household level and at finer operational parameters within each room.

There needs to be a more advanced form of explainable artificial intelligence (XAI) than simply explaining why; namely, what action should be taken next. Living in a smart home can, in some instances, also provide substantial additional household information. Although such data are typically made publicly available, they can be harvested more safely. According to Kopytko and others, smart homes can support decision-making.

4. Energy Efficiency and Environmental Impact

Modern life consumes much energy in homes. Home energy management aims to maximise comfort while minimising energy costs. Management systems for smart homes can help with this. Smart home technologies are those that enable monitoring and automated control of a home's energy use. Smart home appliances are therefore able to operate efficiently in response to dynamic electricity tariffs. This means that their load can be shifted to when electricity is cheapest and/or when it is renewable. They also enable on-site optimisation of renewable generation and storage (Nathali Silva et al., 2018). Energy-aware operation typically happens automatically, not requiring individual users to specify what to control (Reinhart et al., 2013).

4.1. Demand Response and Grid Interaction

Smart homes can participate in demand response (DR), a set of incentives and programs that shift energy use away from peak periods. Historically, demand response has been available only to businesses. For a household to participate, it must provide the same level of demand stability. Smart home energy management systems (SHEMS) enable demand-shifting strategies, including load shedding (rescheduling the operation of electrical loads) and load reduction (turning off or reducing appliance use), and promote on-site generation (e.g., solar power) and storage (batteries) to maintain stable demand. These methods enable domestic smart homes to achieve grid stability while utilising renewable energy. As the country mitigates the risk of future large-scale blackouts and promotes the use of renewable energy resources, energy service providers will increase their capacity to provide household-level DR (Mohammadi Rouzbahani et al., 2019).

4.2. Appliance-Level Optimisation

Smart appliances have advanced the concept of the smart home, enabling automated energy management and conservation (Nathali Silva et al., 2018). Energy consumption can be minimised through appliance scheduling, load balancing, and automated equipment shutdown. A scheduling algorithm that accounts for user comfort and a load-balancing scheme that manages household energy below prespecified thresholds achieve high cost and energy savings. These developments are in response to the growing need for energy efficiency in the home.

According to Zheng (2019), the major uses of energy at the household level in Finland are space heating (68%), water heating and saunas (15%), and electricity for appliances, cooking, and lighting (13%). Around 30% of all household electricity (23 TWh) is used for space heating and appliances. A wide variety of energy tasks in homes can operate flexibly to save energy and reduce greenhouse gas emissions when managed by home energy management systems. Microgrids are an alternative to central-station power systems because they use distributed energy resources that can reduce generation. When microgrids can share information at the household appliance level, customers become participants in energy reductions through active measures such as load shedding. Demand-side management (DSM) achieves energy savings of 10–30% through appliance optimisation, which involves scheduling water boilers, heaters, and dishwashers to operate efficiently. Home energy management systems provide real-time control and monitoring of household appliances, thereby improving energy efficiency and reducing customer bills by coordinating consumption with customer preferences. Using renewable generation at a smaller scale, such as solar photovoltaics and wind turbines.

4.3. Renewable Integration and Storage

Producing renewable energy on-site through solar photovoltaic (PV) reduces dependence on imported energy, thereby substantially lowering energy consumption costs. This is more attractive in states where the retail tariff exceeds the cost of producing electricity from renewable resources. Battery energy storage systems optimise the efficiency of local producers and users. Thus, charging and discharging schedules can be flexible, meaning that charging and discharging can occur when the storage systems can support them, elastically relative to the C storage capacity. The self-regulating automatic control functions optimise the process of generation-storage-consumption,
capable of controlling the autonomy of renewable energy (Ajao et al., 2017). Energy autonomy occurs when building energy use does not require the importation of external energy. It is important to note that energy autonomy may not entail entirely independent use of energy from the grid. (Qaryouti, 2014)

5. Living Experience and Comfort

The ability to formulate a more comprehensive set of monitoring processes, associated with actions across space and time, enables collaboration at the room level. (Barsocchi et al., 2018) The physical stimulus that elicits action is the recognition of at least one user or visitor. Reasoning models are especially adept at major benign events, like leaving a window open. In other words, achieving an objective in the presence of two individuals is complicated. One significant tenant is filtering at the appliance level. The ability to model user profiles using series-connected actuation enables occupancy-based security levels, thereby controlling the system's response to events to which the device is exposed.

5.1. Spatial Automation and Context Awareness

Room-level smart home management automation, enabled by presence detection, supports presence-aware automations and routine sequence execution. Completion of room-level automation requires completing the rooms and vertically mapping devices within them. Developers select the modality of presence-detection techniques based on the intended level of certainty. The situational context integrates the parameters that specify the current activities with the preferences that express the user's choices, thereby conditioning automations and productions.

Recent studies suggest solutions for home automation that improve comfort and enable energy management. An intelligent control mechanism with location awareness monitors room occupancy via Wi-Fi and adjusts the ambience and energy consumption. Systems that are aware of the environment collect sensing data from both external and internal sources. It also uses this information to select appliances that assist with everyday tasks and to adjust their functions via flexible feedback to the user. (Arefin Mozumder & S M Sharifuzzaman Sagar, 2022). A modular architecture that integrates actions to learn preferences and detect high-level activities addresses a wide range of occupant needs and daily disruption routines.

5.2. Health, Safety, and Well-Being Applications

The challenges facing contemporary society include caring for our ageing population, improving air quality, and the rise in stress and loneliness. Smart homes with health, safety, and well-being applications can better address such challenges.

According to a newspaper report, more and more older adults live alone, which aggravates their physical and mental problems. Sensors in smart home environments collect data on events, activities, and personal habits to enable coordinated monitoring of daily living and to generate automatic alerts (Majumder et al., 2017). Various environmental conditions, including weather, temperature, humidity, and air quality, affect people’s health. Smart homes equipped with appropriate detectors linked to an online database will monitor and control parameters to support your comfort and health.

5.3. Personalisation and Adaptation

The user seeks smart environments that respond to them, infer their preferences, and provide services tailored to their habits. A rising interest in research investigating behaviours and designing characteristics supporting household needs; advances like artificial intelligence could help. Furthermore, while there are many types of housing arrangements, every home requires attention, effort, and space (Jeong Kim et al., 2020). Understanding user traits is integral to intelligent spaces. Whether through explicit specification or implicit learning of user traits, when user characteristics change, the system or its behaviours must be modified. In addition, spatial and community settings shape preferences across environments; adaptation remains important across specific locations, including with respect to time (R. Reisinger et al., 2022).

Users select pre-specified settings within borders; everything else largely returns control to systems, thereby shortening personal free time, which is often used to gain control over housing. Changing class schedules or creating reusable templates is complicated by individual differences in personal spaces and routines. Teacher-device support enables the wide adoption of base conditions. The requirement of direct participation hampers learning, whereas parallel exposure facilitates it. Auto-selection is now in the limelight. More advanced technological processes make fuller use of the environment, thereby narrowing the set of items to be discriminated. Completion 4 underlines central control. Mass-market tools progressively improve service to a wide variety.

The adjustment measures pertain to income, consumption, timing, sitting presence, and the full-task economy. Initially, work may exceed results; feedback helps gauge performance, which aids the reinforcement cycle—learning from firsthand experience while providing corrective or fully instructive feedback.

6. Governance, Standards, and Compliance

Principles and mechanisms for interoperability, privacy, and ethical responsibility in smart home management. Full-Text available at IEEE Xplore

6.1. Standards for Interoperability

Multiple standards address smart home elements, from network routing (IPv6) and device discovery (mDNS) to data format serialisation (CBOR) and application-layer protocols (CoAP, LwM2M, MQTT). You can access the OpenThread/Thread stack and the Zephyr RTOS as open-source implementations of these standards, as the Matter protocol stack is based on them. The HCA open-source Matter implementation facilitates the integration of Matter devices with Lovefield-driven middleware, adapting to the diverse needs of users, including legacy home use.

Similarly, certification schemes that focus on Energy are now also being applied to platforms and products that do not generate but consume energy. Most major cloud providers offer smart home skills for Alexa or Google Home, enabling integration of a wide variety of devices through a single application. Insurance and privacy are the two key considerations for providers who conduct exhaustive tests to assess the extent of their exposure to external attacks. More and more companies are promoting their products with strong privacy-by-design principles to enhance data and user privacy—for example, Apple's local data processing.

6.2. Privacy by Design and Data Governance

The age-old privacy-by-design principles can address privacy and data security. An example of the data life cycle in a smart home, as well as the different governance roles that can be defined and assigned accountability for those roles. Four main categories of data permissions may be regulated with the user:

(i) who may see which data (access);

(ii) how long it may be kept (storage);

(iii) who may benefit from the data (rights); and

(iv) which data may be sold or used for advertising purposes (monetisation). Smart home systems may collect data on inhabitants' behaviours and habits to predict future actions.

Such home information can also be used to trigger adaptive notifications that suggest exchanging everyday activities during certain periods or proactively for the future.

Table 6.1: Data Permissions and Governance Roles in Smart Homes

Permission (i-iv)	**Description**	**Primary Governance Role**	**PbD Principle Applied**	**Example in Smart Home Context**
(i) Access	Who may see which data	Data Custodian	Access Minimization	Family vs. guests viewing camera feeds

Permission (i-iv)	**Description**	**Primary Governance Role**	**PbD Principle Applied**	**Example in Smart Home Context**
(ii) Storage	How long can data be kept	Data Steward	Data Minimization	Delete motion logs after 30 days
(iii) Rights	Who may benefit from the data	Data Controller	Purpose Binding	User owns insights; provider analyses aggregates
(iv) Monetisation	Data sold/used for advertising	Data User/Owner	Transparency & Consent	Opt out of, targeted ads from habit data

6.3. Regulatory and Ethical Considerations

From a regulatory perspective, the General Data Protection Regulation (GDPR) and the ePrivacy Directive are the two most relevant EU laws, and companies must comply with them. The direct applicability to the entire EU territory and the indirect applicability to other countries, e.g., the USA, through international cooperation policies under the GDPR, concern data protection and privacy. People should not view these regulations as limitations but as opportunities to develop their services. At the global level, the OECD has established principles for safeguarding the privacy of personal data and the transboundary flow of personal data.

7. Challenges, Risks, and Mitigation Strategies

An interconnected smart home offers numerous benefits, but is difficult to implement due to several challenges and risks. Among these, reliability, cybersecurity, equity and the challenge of ascertaining and communicating the additional value of smart-home technologies are critical.

Smart homes comprise several devices. When devices fail and maintenance is required, the average resident's frustration is evident. In shared flats and houses, device turnover can significantly affect circular processes designed to improve device accessibility (or affordability) through repeated installations and uninstallations. Time-to-repair rates and predicted maintenance windows are determined only by experts. However, postponing repairs or increasing re-brokering or retention rates is a strong signal of reliability concern (Sturgess et al., 2018).

It is still new, but cybersecurity attacks on a specific person, home, or property have started. As a result, devices that accept direct external access or provisioning connections in untrusted locations are at a higher risk. We are now seeing malware packaged as uninstallers across more product categories. Increasingly, consumers maintain multiple personal websites and other services; registrations are drivers of both online and offline fraud, which, in turn, fuel the proliferation of smart homes (Heartfield et al., 2018). Security-related insurance can enhance awareness of baseline resilience controls. In addition, the standards for incident response and recovery planning, as well as their wider lifecycle implications, encompass broader premises or even institution- or region-level domains.

7.1. Reliability, Maintenance, and Lifecycle

Home appliances are typically designed to last 10-20 years. In contrast, smart home electronics have a shorter lifespan, with IoT (Internet of Things) devices, wireless cameras, and related components becoming quickly outdated. Devices produced five or even 10 years ago may not be compatible with today's applications. As Shilin (2022) notes, you must assess the reliability and life of devices. Moreover, it is vital to plan maintenance schedules and upgrade paths. Most importantly, define the minimum reliability required for devices used continuously at home.

7.2. Cybersecurity Threats and Recovery

The smart home is gradually becoming an extension of the Internet of Things (IoT), enabling energy-efficient, comfortable, convenient, and safe living environments. Early academic work on home automation (Gonzalez et al., 2009), residential energy management (Bourguet et al., 2011) and smart buildings (Anzanpour et al., 2019; Atzori et al., 2010) took place prior to 2013, but it is only after 2013 that the term smart home became popularised with the growth of internet-connected smart technology in homes (Davis et al., 2020). Over the last decade, we have been inspired to develop the desired smart-home solutions using an open architecture that meets the relevant requirements, informed by multiple definitions of smart homes.

Smart homes in industry and academia are undergoing a renaissance due to advances in AI. Smart-home solutions for various applications are already on the market, while new sensing modalities (e.g., Radar) and decision-support approaches (e.g., psychology-based influence strategies) are also being researched.

The goal of this work is to shape the use of smart-home systems to influence future living styles. This work provides a comprehensive review of smart-home concepts, state-of-the-art solutions, and future directions for smart homes across industry, technology, and policy, paving the way for bidirectional understanding between academia and industry. Drawing on recent developments in industry and academia, several key messages about smart-home systems emerge: a common, industry-wide definition and architecture are lacking. The smart-home domain requires relevant open-source platforms, kits, and deployment case studies to facilitate proof-of-concept (PoC) demonstrations of new technologies and to support open research agendas. The innovative perspective of improving machine-human collaborations could alter the living styles of future people, families, and communities with continuous exploration of smart homes (Heartfield et al., 2018).

7.3. Equity and Digital Divide

The advantages of smart home technology are not evenly distributed. Some homes face challenges in technology adoption due to limited knowledge, low technical literacy, and rigid systems. By addressing income inequality and providing low-cost, flexible devices to families who need them, we can ensure everyone can live a modern life.

People with cognitive disabilities or cognitive decline have special needs. Smart-home functions can address this problem and prevent misclassification when tailored to specific situations. Through the implementation of co-creation, education, and sound design principles, bias can be minimised and equitable, inclusive use among diverse users facilitated.

Many people are unable to use smart-home technology due to their income or infrastructure constraints. After becoming aware of their options, many policy stakeholders survey the available alternatives before selecting a conventional option. According to these findings, the digital divide is just one of the many factors. According to Shilin (2022) and Vastardis et al. (2016), affordability and adaptability are essential for inclusion and the fulfilment of personal aspirations.

8. Evaluation and Metrics

Smart environment systems, such as smart homes, use network-connected sensors (presence detectors, cameras, energy monitors, etc.) to communicate with one another to optimise user behaviour and quality of life through information exchange. The most important part of making any decision or taking any action is the collection, corroboration, and interpretation of data. Low-cost, user-friendly, integrated solutions that minimise physical installation and economic impact are preferred. This does not compromise data processing or network interoperability.

A smart home can perform a range of actions (such as sending an alert, turning a device on or off, or adjusting an appliance, such as a thermostat) to ensure comfort, security, and surveillance. Performance indicators assess measurable parameters (e.g., internal temperature variation, response time in the dark, electricity consumption). In contrast, user satisfaction and comfort assess subjective parameters (e.g., user satisfaction rated on a 1-5 star scale). User experience (UX) is about a lot of things (besides usability), and it has a multi-dimensional touchpoint. For instance, visually inspecting spaces surrounding icons, multiple user interface objects, acceptance metrics, and system backups. Given the life cycle environmental impacts, carbon and economic footprint and embodied energy (Barsocchi et al., 2018)

8.1. Performance Metrics for Comfort and Efficiency

The thermal metrics of a building can be measured. This refers to the conditions experienced by users, as a function of air temperature, relative humidity, and other variables, such as air velocity. Another crucial performance criterion is the Transient Response, which measures the time required for the system to respond to and recover from perturbations (FABI et al., 2017). To make smart home systems commercially viable, energy and cost savings need to be demonstrated. Simulations of energy modelling – offline and in real-time – together with the continuous monitoring and logging of energy use during normal operation, are necessary to quantify these savings accurately.

8.2. User Experience Metrics

Because household management systems are complex and require substantial daily user intervention, user experience is important. The installation and interaction require considerable effort. As such, individuals would rather not have a domestic installation at home. Despite improvements in hardware and software (R. Reisinger et al., 2022), we still need to understand user experience metrics and relevant dependencies for end-user development systems.

User experience metrics can be defined by four broad criteria: satisfaction, usability, task success, and adoption. Satisfaction refers to the subjective evaluation of the overall quality of experience. In this way, it encompasses the aspects of enjoyment, comfort, safety, trust, anxiety, and frustration in the evaluation process. Usability refers to the 'learnability' and efficiency of the interaction in terms of time, effort, and number of actions or interrupts per unit of task completion. Task success can be defined as achieving the goal, which may involve speed, accuracy, or the need for assistance or rework. Adoption measures the uptake of functionality over time, including ease of use, frequency, and expected use. Satisfaction and usability are quality aspects, while task success and adoption concern the achievement of goals (Bissoli et al., 2019).

8.3. Sustainability Assessment

Systems for smart-home management facilitate communication among building technologies and enable functions that address users' diverse needs. Environmental sustainability is a growing global concern that affects policies and regulations, lifestyles and consumption patterns, product design, and household activities. Smart building technology helps to solve these issues. Similarly, research is underway on these technologies, their impact, and implications, particularly from an energy perspective. This leads to an evaluation framework of the sustainability of smart home management systems.

The methodology assesses total lifecycle environmental impacts, embodied energy, and CO_2 emissions associated with energy use throughout a system's life, and indicates the relative weight of these factors across systems. The analysis enables the development of energy-related policies and the selection of technologies and products for the design of smart home management systems. It contributes a critical perspective on energy to smart home management systems. The quantification of the sustainability assessment facilitates the analysis of the social and demographic effects of smart home management systems on behaviour, effect and significance at the household scale

(Barsocchi et al., 2018) ; (Aly & Elnokaly, 2015).

9. Case Studies and Applications

A smart home management system was developed for an elderly care home to monitor and provide health alerts without requiring explicit occupant interaction. (Vamsi Ilapakurthy, 2023). Through sensors placed on doors, light switches, and other relevant appliances, this device collects household activity data (e.g., wake-up, bathing, eating, cooking, medication). The software processes the raw signals, compares them with normal limits and disease-specific models, and indicates abnormality. Multi-Parameter Temporal Graphs Allow Monitoring of Multiple Persons. In the event of an abnormal situation, the physician is immediately alerted via the standard telephone, with voice guidance in the message, for assessment. More than one agent can observe the same premises. To facilitate user interface design, we adopted a multiple-criteria preference modelling approach, which supports conformity with the patient's everyday activities, flexibility, and awareness of prescribed situations. The model was completed using the control terminals of preferred appliances (Jeong Kim et al., 2020).

A multi-occupant dwelling incorporated a flexible home automation architecture to suit different arrangements. Users indicated that they would like to share important appliances and that several occupants would like to be notified when certain devices, such as the washing machine, are operated. A multi-user home automation architecture utilising prioritised rules, with functionality to add and delete other rules, supports personalisation. Common rules among users mean no extra configuration. A broad framework for automatic activity recognition has been implemented. The framework includes three types of models. These include a static one over annotated signals. They also include a second model that operates on users' daily routines. Safety and comfort are monitored through sensors in the system. In various cases, a user scenario design method was employed for different living arrangements, and human-centred design was used to identify the steps that raised concerns.

9.1. Residential Deployments in Different Climates

Across households, residential deployments in different climates employ a range of smart thermostats and home automation systems. Research has examined heating control in relation to occupancy, intentional manual controls, and predictive occupancy modelling. When combined with automated shades, smart Wi-Fi thermostats, and occupancy sensors, they can help reduce energy consumption. Research finds that explanations for system intelligibility play a role in understanding user behaviour. This facilitates the adoption of systems and improves their efficiency. The implementation strategy for automated security systems, lighting, and heating control measures is climate-specific (Kruusimagi et al., 2017).

A technology platform to check homes in a community energy scheme (CES), including indoor environmental conditions, electric power, thermal energy and heating. The technology system employs multiple technologies and protocols, including short-range wireless sensors that require local gateways, as well as low-power, long-range protocols such as LoRa, NB-IoT, and Wireless M-Bus. These technologies consume very little power and have a long range. Deployment encountered challenges with home connectivity, but cloud consolidation provided a consistent framework for subsequent services (Shipman & Gillott, 2019).

A home energy management scheme that incorporates load balancing and elastic peak-load shifting for scheduling household appliances is proposed. The optimisation problem is formulated as a mixed-integer linear program (MILP) that minimises overall energy consumption while respecting customers' demands and preferences. Nathali Silva et al. (2018) compare the proposed scheme to existing home energy management schemes. The proposed scheme has been proven to be superior. Thus, it reduces appliance energy consumption.

9.2. Multi-Occupant Homes and Shared Spaces

In recent decades, a growing interest in smart home technologies has stemmed from their capacity to enhance comfort and well-being and to increase efficiency. Initially, these technologies were designed for single-occupancy homes; however, as urbanisation accelerates, interest in multi-occupancy smart home environments is also increasing. You will usually find a shared apartment, a multi-family residence with relatives of different generations, and so on, where friends, work colleagues, and other social networks live together. When people settle into their homes, tensions can arise as the various occupants start competing for spaces and resources. The coordination, privacy, and conflict issues in co-occupancy systems thus deserve further study.

9.3. Smart Home as a Platform for Services

In the smart home context, home appliances and devices can provide a range of applications and services for home users. Following such a development, the home appliance or device may also be referred to as a service platform focused on determining, acquiring, deploying, and managing services. Accordingly, from a service perspective, the smart home ecosystem can provide new services through various combinations of services; therefore, it is important to clarify the service model for the smart home ecosystem (Zheng et al., 2017).

By combining appliances and services, new services can be offered at home through the respective appliances or devices. Smart appliances or devices can be viewed as service platforms that determine, acquire, deploy, and manage services.

In terms of services, a smart home ecosystem can offer value-added services by combining and orchestrating existing services; therefore, a clear service model for the smart home ecosystem is needed (Meis, 2006).

10. Future Directions and Research Opportunities

As new technologies continue to affect the domestic environment, major innovations (e.g., ESS, prosumerism) have already significantly altered living spaces, yet there remains room for improvement (R. Reisinger et al., 2022). Concerns are being raised about smart homes, with researchers examining the technology and its social impacts. The growing interest has led to the emergence of numerous technologies that enhance and integrate with smart homes, while many avenues remain open for researchers.

The emphasis on smart homes and AI indicates the evolution toward a smart home-as-a-service platform, in which data collected at home with the user's consent will benefit both parties (Kopytko et al., 2018). There has been considerable work on treating smart homes as an integrated system, assuming that well-specified algorithms and rules can address all features. Future research could examine smart home implementations that integrate diverse smart systems, cloud services, and open data, thereby adding value without encroaching on personal space.

11. Conclusion

Smart home management enables greater control over home environments by monitoring and automating home functions. It encompasses the fields of building automation, home automation, energy management and smart grids.

Smart home management systems are a hardware-software combination that enables real-time sensing of conditions, action automation, remote access, and user feedback. One can monitor and control household appliances even while away. Automation also aids users with disabilities in their work. Complex systems utilise predictive analytics and machine learning to predict user preferences and changes in occupancy and operating conditions. Smart home management makes life more convenient and comfortable. It also enhances security and safety, while enabling more efficient energy use and improved environmental quality.

Due to growing concerns about energy, health, and the quality of life in the home, smart home management has become increasingly relevant today. The COVID-19 pandemic brought attention to the importance of indoor air quality. When seeking environmental sustainability, prolonging the lifespan of current buildings and minimising the energy consumed are very important (Olayinka Zakariyya et al., 2017)

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