ABC2: Journal of Architecture, Building, Construction, and Cities

Empowering research for Sustainable Development Goals, ABC2: Architecture, Building, Construction, and Cities is a fundamental manifesto to address these pressing issues, fostering dialogue and knowledge exchange among researchers, practitioners, and policymakers. Exploring sustainable design, resilient infrastructure, advanced construction methods, and equitable urban development, ABC2 aims to empower the global community to create adaptive, inclusive, and sustainable environments. The ABC2 focus on cutting-edge research, technological advancements, and transformative strategies is essential for navigating the future of our cities and communities.

Research Article

From Integrated to Intelligent: A Typological Exploration of Global Smart Home Cases and User Needs

Azin Ehteshami[1*], Burak Pak[1], Mirjana Lozanovska[1], Richard Tucker[1]

[1*] School of Architecture and Built Environment, Deakin University, Geelong, VIC, Australia

DOI: https://doi.org/10.66408/abc2.2025.19

Correspondence: a.ehteshami@deakin.edu.au

Received: 16/05/2025
Revised: 08/09/2025
Accepted: 27/12/2025
Published: 31/12/2025

Volume: 2025
Issue: 02
Pages: 73-89

Abstract

This study addresses a critical research gap in smart home literature by providing a comprehensive typological analysis of global implementations. Utilising a multiple case study methodology with purposive sampling across six dimensions (target users, technology focus, implementation scale, intended purpose, geographical location, and user status), we systematically examined diverse smart home applications. Data collection followed a structured four-phase process incorporating academic databases, industry reports, technology publications, and manufacturer repositories. Through rigorous cross-case analysis, we developed a novel typological framework categorising smart homes as Integrated, Supportive, Defensive, Lifestyle, Efficient, and Intelligent. Our findings reveal that smart homes are non-monolithic, with most implementations embodying multiple typological categories simultaneously. The analysis demonstrates how technologies adapt to specific user needs—from security systems for vulnerable households to health monitoring for elderly residents and efficiency features for environmentally conscious users. Geographical patterns emerged, with European implementations emphasising healthcare applications while North American cases focus more on lifestyle enhancements. This typological framework enables a structured understanding of smart home complexity and provides valuable insights into technological integration trends. The research advances smart home scholarship beyond isolated technological examinations toward a comprehensive understanding of how these systems address diverse human needs across global contexts, offering significant implications for researchers, industry stakeholders, and policymakers navigating this rapidly evolving field.

Keywords: Smart homes, Smart home typologies, Technology adoption, Intelligent smart homes

Highlights

- Smart homes are not uniform; a new typology reveals diverse, blended functions like supportive care and lifestyle luxury.
- e design of smart homes is driven by specific user needs, from safety for the elderly to efficiency for homeowners.
- The field is dynamically balanced between mainstream adoption in inhabited homes and innovation in research environments.

1 Introduction

The swift rise of smart home technology marks a pivotal shift in the way individuals engage with their home environments. Beyond basic automation, modern smart homes now incorporate internet-connected devices that facilitate advanced monitoring, control, and data exchange within the household (Al-Ali, Zualkernan, Rashid, Gupta, & Alikarar, 2017; Al-Turjman, Zahmatkesh, & Shahroze, 2022; Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014). This pervasive integration, driven by the expanding Internet of Things (IoT), underscores the transformative potential of these technologies in daily life (Atzori, Iera, & Morabito, 2010). The theoretical framework underpinning this study is structured around three interrelated dimensions: the situated conceptualisation of smart homes, their capacity to respond to diverse and evolving user needs, and the extent to which they incorporate adaptive intelligence through learning and responsiveness. The first dimension concerns how smart homes are understood and defined across contexts. Gram-Hanssen and Darby (2018) delineate smart home studies into four categories: conceptual, technical, prospective, and evaluative (Harvey et al., 2020). They emphasise that 'smartness' is not an inherent attribute but is given meaning through specific configurations and interactions within each unique case. Building on this claim, understanding how smart homes are conceptualised across different contexts is paramount to studying them.

The way smart homes are conceptualised profoundly influences their design, market adoption, and public acceptance (Madakam & Ramaswamy, 2014). A comprehensive exploration of these diverse conceptualisations, therefore, allows us to trace the variegated ways smart homes are realised across different geographies, enabling a more nuanced and accurate categorisation of this fluid technological landscape. The second dimension investigated in this study is the capacity to address a diversity of user needs, where the true value of smart home technology lies. Wilson, Hargreaves, and Hauxwell-Baldwin (2015) provide a systematic analysis of smart homes and their users, highlighting the socio-technical nature of smart home systems and revealing the cross-cutting relationships between different understandings of smart homes and their users (Wilson, Hargreaves, & Hauxwell-Baldwin, 2015). Beyond mere technological capability, the success of these systems hinges on their ability to enhance convenience, security, and quality of life, or to provide specialised support for vulnerable populations (Zanella et al., 2014). Finally, the third dimension emphasises the presence of intelligence within smart home systems. Advancing beyond mere pre-programmed automation, intelligent smart homes utilise breakthroughs in Artificial Intelligence (AI) and Machine Learning (ML) to learn, adapt, and proactively respond to environmental cues and user behaviours (Alzoubi, 2022; Batool et al., 2024; Lai et al., 2019). Examining the extent and nature of this intelligence is key to understanding the next generation of smart home functionalities and their potential to transform living spaces into more adaptive and supportive ecosystems.

Building on this theoretical foundation, the study seeks to unpack how smart homes are framed and differentiated in practice by focusing on the following research questions:

- How are smart homes understood and defined across their real-world global implementations?
- What specific user needs do these smart homes address?
- To what extent do these smart home typologies demonstrate intelligence (e.g., learning and adaptation)?

To answer these questions, this research employs a qualitative, multiple-case study methodology. It involves a systematic process of identifying, categorising, and analysing real-world examples documented in academic literature and industry reports. This analysis culminates in a novel typological framework for categorising smart homes based on their primary functions and user needs.

2 Background and Historical Context

The evolution of smart home technology, though rooted in early 20th-century visions of automation (Bradbury, 2012; Nye, 1992) gained tangible momentum through key technological developments and shifting market dynamics. Nikola Tesla's 1898 demonstration of wireless remote control (Nikola, 1898), foreshadowed the wireless connectivity crucial in modern smart homes. The introduction of basic home appliances in the early 1900s (Cowan, 2023) laid the groundwork for task automation. The Smart Home industry has rapidly transformed worldwide, influenced by technological progress and shifting consumer habits. Each global region has its unique set of circumstances that affect the Smart Home market. In North America, the market is highly competitive with a wide range of products and services available to consumers. In Europe, data privacy concerns and regulations play a significant role in shaping the market dynamics. In the Asia Pacific, the market is fragmented with local and international players competing for market share.

The market for smart homes has rapidly transformed since the early 2000s, driven by technological progress and shifting consumer habits. The introduction of the first smartphones circa 2007 (Norman, 2013) fundamentally altered consumer expectations and habits, laying the groundwork for the modern smart home market. Since 2018, the number of smart homes has increased by 672.54 million users (Figure 1), with continued upward trends projected for the coming years (Figure 2). The market is segmented into key areas including Control & Connectivity, Security, Home Entertainment, Energy Management, Smart Appliances, and Comfort & Lighting (Statista Market Insights) (Figure 3). Customers worldwide are progressively looking for convenience, efficiency, and connectivity within their residences, with a growing demand for smart home gadgets that provide automation, security, and energy-saving features (Figure 4).

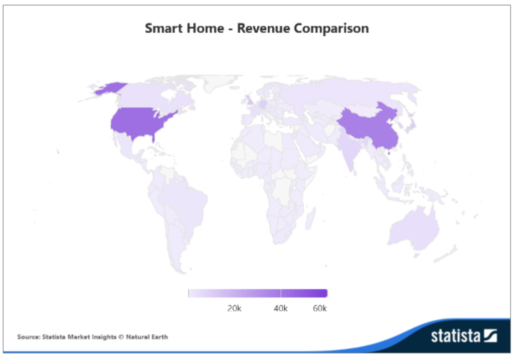

Figure 1: Smart Home Global Revenue Comparison, most recent update: Oct 2024. (Source: Statista Market Insights).

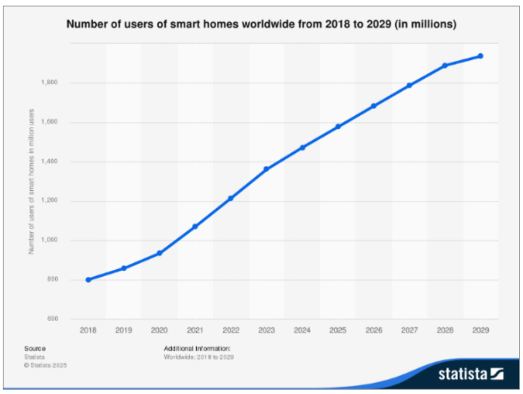

Figure 2: Number of users of smart homes worldwide from 2018 to 2029, published by Statista Research Department, Aug 21, 2025.

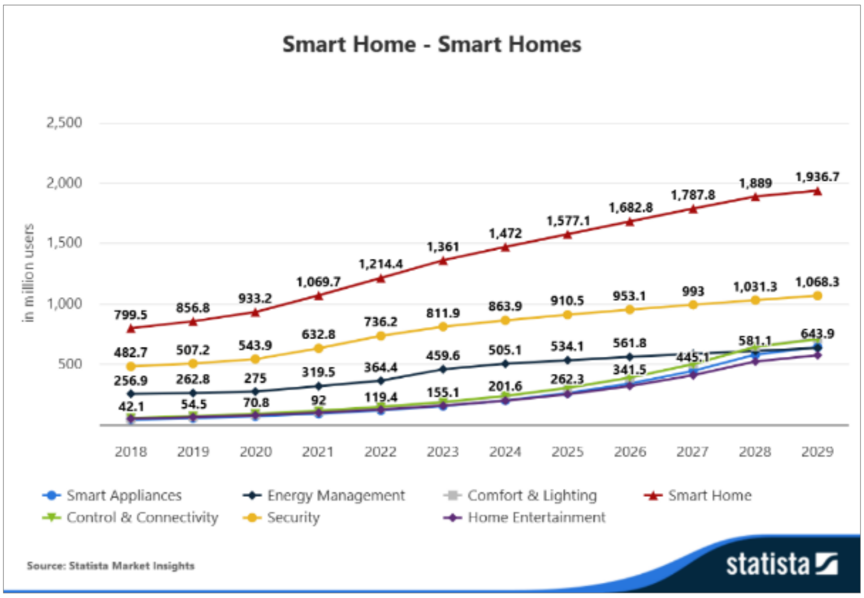

Figure 3: Smart Home Product Types and Forecast of Users' Growth. (Source: Statista Market Insights).

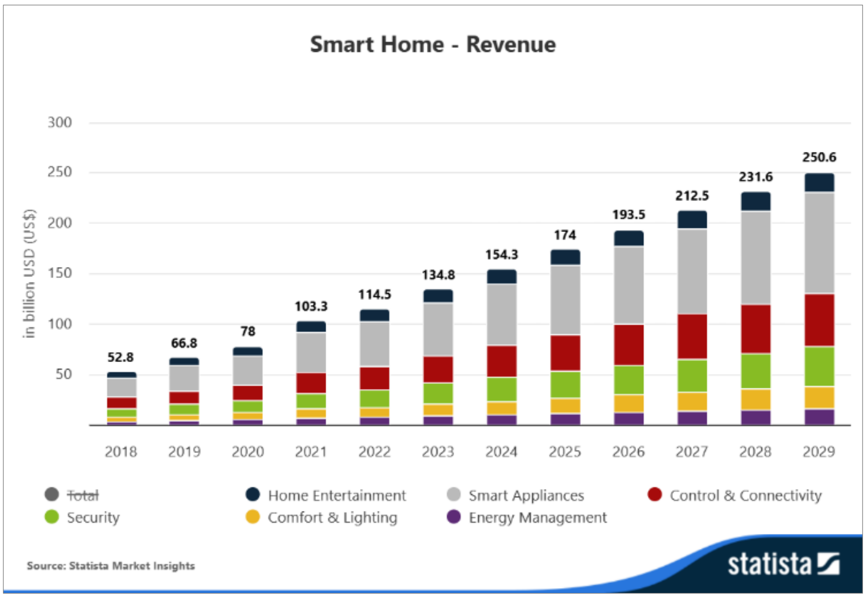

Figure 4: Market revenue data were converted from local currencies using the average exchange rates for the respective year. (Source: Statista Market Insights).

A significant step towards integrated control came with the 1966 ECHO IV (Katre & Rojatkar, 2017), the first recognised integrated smart home system capable of managing tasks and controlling devices, mirroring the integrated nature of contemporary systems. The 1975 development of X10 (Burroughs, 2010; Withanage, Ashok, Yuen, & Otto, 2014), the first widely adopted home automation protocol enabled remote control of appliances, a core functionality in many current smart home applications. The emergence of early smart thermostats in the 2000s (Wittje, 2013) highlighted the focus on energy efficiency seen in some case studies. Finally, the 2010s witnessed the rise of voice-controlled systems like Nest and Echo (Norman, 2013), alongside the prevalence of wireless standards (Jadhav, Chaudhari, & Vavale, 2014), representing the dominant user interface and connectivity methods in many modern smart homes and research projects. These milestones directly paved the way for the diverse applications and technologies observed in the analysed case studies (Table 1).

Table 1: Historical Milestones in Smart Home Technology.

Year	Milestone/Development	Description
1898	Invention of the Remote Control	Nikola Tesla demonstrates wireless control of a model ship using radio waves, showcasing the foundational principle of remote device management.
Early 1900s	Proliferation of Early Home Appliances	Introduction of household appliances like vacuum cleaners, washing machines, and refrigerators marked the early stages of domestic automation and reduced manual labour.
1939	"The Electric House of the Future" Concept	Popular Mechanics article envisions a fully automated home featuring automatic doors, intercoms, and customisable lighting, illustrating early aspirations for integrated smart living.
1966	ECHO IV - Integrated Smart Home System	James Sutherland designs and builds the ECHO IV, a pioneering integrated system capable of managing shopping lists, controlling home temperature, and operating appliances; it represents an early attempt at comprehensive home automation.
1975	Development of X10	The first widely adopted home automation protocol, X10, enabled the remote control of lights and appliances via existing electrical wiring, marking a significant step towards standardised home automation.
2000s	Emergence of Early Smart Thermostats	Introduction of early smart thermostats allowed remote control of heating and cooling systems, focusing on energy efficiency and user convenience.
2010s	Voice-Controlled Home Automation	Rise of voice-controlled systems with products like Nest Thermostat and Amazon Echo, revolutionising user interaction with smart homes and popularising voice command interfaces, along with the growing prevalence of Wi-Fi, Zigbee, and Z-Wave wireless protocols.

2.1 Key Catalysts in Smart Home Evolution

i. **Mid-20th Century:** Companies like General Motors (through Frigidaire) and Philco release promotional films showcasing visions of the futuristic home, heavily featuring home automation, often centred around the kitchen. These visions included pervasive computing and refrigerators suggesting menus, although the idea of discrete systems working seamlessly together remained a future goal.

ii. **Late 1990s:** Dial-up internet support becomes common, with older generations requiring assistance with basic computer tasks like email. This highlights an early challenge in adopting technology among less tech-savvy demographics.

iii. **Circa 2007**: The first smartphones are introduced, representing a significant upgrade over traditional cell phones and beginning to transform consumer expectations and habits. This period marks a shift towards "smart" technology becoming mainstream.

iv. **2009:** Forrester notes that nearly all cellular phones are becoming "smart," indicating a rapid and widespread adoption of smartphone technology (Figure 5).

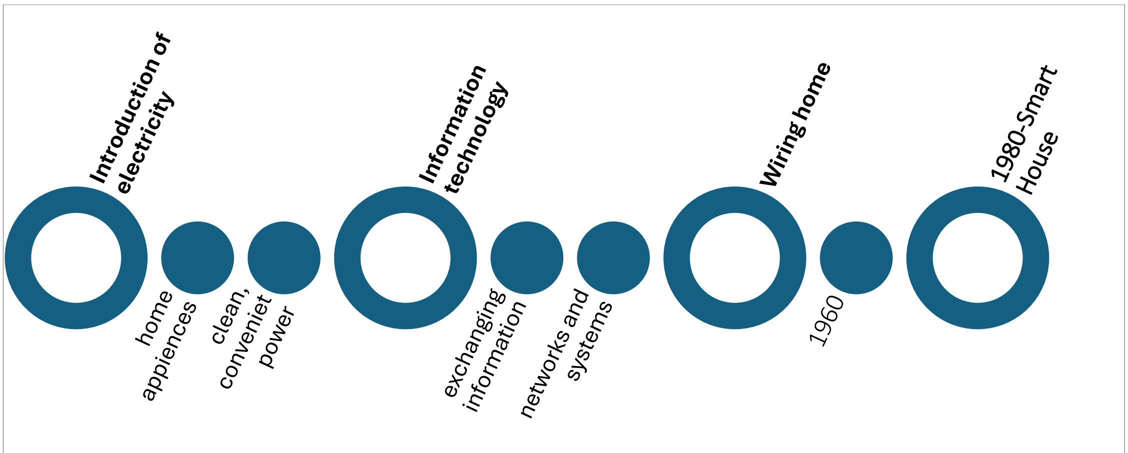

Figure 5: Timeline of key catalysts in Smart Home evolution..

3 Methodology

This study employed a multiple desk-based case study methodology to examine the global smart home landscape. This approach, well-suited for this rapidly evolving field, facilitates exploratory rather than hypothesis-driven analysis (Randall, 2003). The methodology addresses scenarios with numerous variables and ambiguous boundaries between the phenomenon and its real-world context, leveraging data triangulation through the integration of multiple sources (Yin & Campbell, 2018).

3.1 The case study approach

According to Yin (2018), the case study research method is widely used in social science; however, it is sometimes regarded as lacking scientific legitimacy in certain academic circles. This method is often described as having an absence of a consistent set of methods, rationales, and protocols.

Yin articulates a two-dimensional framework for case study research, encompassing both its scope and inherent characteristics:

Scope: Case study research is an empirical methodology for conducting a thorough investigation of contemporary phenomena in real-world contexts. This approach is particularly pertinent when the distinction between the phenomenon and its context is ambiguous.

Features: The methodology addresses technically unique scenarios characterised by a greater number of variables of interest than available data points. Specifically, it is applicable in situations where:

Existing theoretical frameworks inform and shape the progression of study design, data collection, and analytical processes. There is a necessity for data triangulation, facilitated by the integration of multiple evidence sources (Yin & Campbell, 2018). Case study research is frequently categorised alongside qualitative methodologies, including ethnography, anecdotal evidence, participant observation, and process tracing, among others. There is ongoing discourse regarding the inclusion of quantitative data in case study research, with some scholars advocating for a mixed-methods approach that synthesises both qualitative and quantitative insights (Rini, 2019).

3.2 Data extraction process

A systematic data extraction protocol was developed to ensure consistency across all cases. For each identified study, we extracted the following data points: the primary functional category, geographical location, historical context, key characteristics and technologies, and user status. The extracted data was then subjected to a cross-case analysis to identify recurring themes and patterns. This iterative process led to the development of a novel typological framework for categorising smart homes based on their primary functions and user needs.

4 Results

4.1 Experimental Projects and Research Initiatives

Beyond commercial implementations, a significant body of research explores the potential of smart home technology through dedicated experimental projects. These initiatives often serve as "living laboratories" to test advanced concepts and address specific human-centric challenges.

4.1.1 The Adaptive House (University of Colorado)

This adaptive house in Boulder, Colorado, contains over 75 sensors to track things like room temperature, light, sound, motion, and door and window positions, along with outside weather. Actuators control heating, hot water, lighting, and ventilation. The control system in this house is called ACHE, short for Adaptive Control of Home Environments. This experiment investigates a self-programming home that adapts to its inhabitants' needs. This smart home was designed without complicated user controls. It uses standard home features rather than touchpads, voice commands, or other advanced interfaces. The smart home's ability to understand and respond to its inhabitants comes from watching their habits over time. The focus is on improving comfort through air temperature control, water temperature control, and lighting. Instead of having to program the home, it learns and adapts by observing how people use their space. It notices actions like turning lights on or adjusting the thermostat and learns from patterns, allowing it to predict future needs. This system means residents can enjoy a comfortable living environment without manually adjusting settings. If the home makes an incorrect prediction, inhabitants can simply use standard controls like light switches or thermostats. Here are a few examples of how the system works: On a rainy weekday at 8 a.m., if a person typically returns home by 7 p.m. for the last three days, the home may predict a return by 6:30 p.m. and begin heating the space to a comfortable temperature. When the person arrives, the kitchen and living room lights turn on brightly while they make dinner. If they then relax and watch TV, the lights behind the TV turn off, and other lights might dim. On weekends, if a person leaves at 4 p.m. and plans to return after midnight, the house does not heat up until they arrive. If they come home at 1 a.m., the system expects they will stay in the master bedroom for the next seven hours. Instead of heating the whole house, it uses space heaters to warm that room and adjusts the water heater since hot water won't be needed for several hours. Home comfort systems were chosen because if a prediction is wrong, fixing it is simple. If the home doesn't expect the residents to return, it can turn on the heat or air conditioning when they arrive. If a light fails to turn on, residents can turn it on themselves. The home predicts needs based on patterns it recognises in residents' behaviours. Using only the day or time may not offer accurate predictions. Instead, it considers many factors, like recent room usage, the weather outside, and when residents commonly leave and come back, allowing for better predictions. (Mozer et al., 2005).

4.1.1.1 House-n (Massachusetts Institute of Technology)

At MIT, a multidisciplinary team of researchers is exploring the creation of pervasive computing environments for the home. The focus is on developing technologies and design strategies that utilise context-aware sensing to deliver information to individuals at the right time and in the right place. This research advocates for an educational use of technology rather than relying primarily on automated control. The team is in the process of establishing a "living laboratory," which will provide a flexible infrastructure for scientifically studying the potential of pervasive computing to enhance learning and encourage behaviour change within the home. This facility, referred to as the MIT-TIAX PlaceLab, will be dedicated to investigating technologies that foster supportive home environments (Larson, 2003).

4.1.2 The Aware Home (Georgia Institute of Technology)

The Aware Home Research Initiative (AHRI) addresses various health and environmental challenges through a sophisticated framework comprising a dedicated residential facility, a collection of managed eldercare environments, and a laboratory focused on child development. The initiative utilises an integrated system of sensors—including motion detectors, light sensors, temperature and humidity monitors, as well as door and window sensors—and control mechanisms such as lighting systems, lamppost and appliance modules, and smart door locks. These technologies facilitate research across several domains, including health and well-being, entertainment, and sustainability. A significant achievement of the Aware Home group lies in its efforts to design and implement Ambient Assisted Living (AAL) systems tailored specifically for individuals with autism, contributing valuable insights to both practical applications and theoretical frameworks in this area (Fausset et al., 2013; Kientz et al., 2008).

4.1.3 European Network of Living Labs

The European Network of Living Labs (ENoLL) serves as a robust consortium of Active and Assisted Living (AAL) research groups throughout Europe. With nearly 400 historically recognised Living Labs and over 170 active members, ENoLL exemplifies the extensive and diverse landscape of AAL research.

These research entities focus on a wide range of subjects related to AAL smart homes, alongside various dimensions of technology integration within human environments. The establishment and achievements of ENoLL highlight the significant breadth and depth of ongoing AAL research initiatives across the continent (Mirijamdotter, Ståhlbröst, Sällström, Niitamo, & Kulkki, 2006).

4.1.4 Smart medical home—University of Rochester

The University of Rochester's Smart Medical Home initiative leverages Ambient Assisted Living (AAL) technologies to meet diverse healthcare requirements. This program emphasises patient education, gait analysis, cognitive support tools, and in-home biosensing capabilities. Ongoing research efforts are centred around the development of mobile applications utilising Apple's Research Kit framework, specifically tailored for cognitive assistance, in collaboration with various commercial partners (Bastaki, Sedky, Campion, & Atkins, 2023).

4.1.5 Distributed Systems Group—ETH Zurich

The Distributed Systems Group (DSG) at ETH Zurich engages in various facets of ubiquitous computing, particularly within the framework of Ambient Assisted Living (AAL) in smart home environments. Key areas of research encompass sensor networks, energy efficiency mechanisms, the Internet of Things (IoT), user experience design in smart environments, as well as the security and privacy ramifications associated with AAL systems. Additionally, DSG actively participates in commercial partnerships, exemplified by their collaboration with M-Lab (Stuecklberger, Dimitrova, Liagouris, & Roscoe)

4.1.6 Smart Environments Research Centre—Washington State University

The Smart Environments Research Centre (SERC) is a comprehensive research entity focusing on all dimensions of AAL technologies. The group's areas of expertise include machine learning, cognitive analytics, engineering of smart home systems, development of wearable biosensors, and the establishment of clinical metrics. Within SERC lies the Centre for Advanced Studies in Adaptive Systems (CASAS), a renowned research group dedicated to AAL in smart homes. CASAS is notable for curating publicly available datasets derived from various AAL environments, fostering broader research efforts (Cook, 2009).

4.1.7 POSEiDON Project—Middlesex University

The POSEiDON Project represents a significant AAL initiative tailored for individuals with Down Syndrome, aiming to enhance their autonomy in everyday life. Research focuses on the development of augmented reality tools for daily tasks, addressing ethical considerations in the design of AAL systems, and personalising environments to better serve individuals with Down Syndrome.

4.1.8 ORCATECH—Oregon Health and Science University

ORCATECH Living Labs at OHSU stands out as a prominent contributor to health-oriented AAL smart home research. Spanning more than 480 residences over eight years of longitudinal data collection, ORCATECH's findings have significantly influenced ecological validity studies on health metrics and therapeutic interventions utilising AAL technologies. Their publications address critical infrastructure aspects related to sensors and systems, user experience considerations, clinical metrics, mobility within AAL settings, and cognitive function assessments (Mathews et al.).

4.1.9 Intelligent Assistive Technology and Systems Lab—University of Toronto

The Intelligent Assistive Technology and Systems Lab (IATSL) is dedicated to developing zero-effort technologies within adaptive AAL systems, primarily targeting domains such as occupational therapy and gerontology. The lab has achieved substantial success through large-scale, inter-institutional collaborative research projects, leading to impactful contributions across diverse healthcare areas employing AAL technologies. Focus areas include Alzheimer's disease, ageing in place, ambient healthcare solutions, rehabilitation strategies, and various other technology-driven AAL initiatives (Taati, Snoek, & Mihailidis, 2011).

4.2 Case Study Analysis and Findings

The analysis of the selected smart home case studies reveals a multifaceted landscape characterised by diverse approaches and priorities. Our examination through the lens of the proposed typological framework—Integrated, Supportive, Defensive, Lifestyle, Efficient, and Intelligent—underscores the non-monolithic nature of smart home implementations, with many cases exhibiting characteristics across multiple categories.

4.2.1 Manifestations of Smart Home Typologies

The Lifestyle Smart Home category emerges as significant, often intertwined with luxury and convenience. Bill Gates' Xanadu 2.0 Mansion and Mark Zuckerberg's "Jarvis" Smart Home are prominent examples, showcasing features aimed at enhancing comfort, entertainment, and personalised experiences for affluent users (Cao, 2020; Mudgerikar & Bertino, 2020). The En-Suite Sky Porches at the Hamilton Scott further illustrate this with luxury amenities and unique features like car elevators, enhancing a high-end lifestyle (Mudgerikar & Bertino, 2020). In contrast, the Efficient Smart Home is driven by the optimisation of resource use. Jonathan Dixon's Energy Efficient Smart Home (UK), a Passivhaus retrofit, exemplifies this by integrating smart technology to minimise energy consumption. The Supportive Smart Home addresses the critical needs of specific user groups, particularly the elderly. The Howz Sensors for Older Adults (UK) actively monitors daily activities for well-being, while the ADU for Ageing Parents (US) provides independent living spaces with tailored safety and convenience features. The RADAR-AD Dementia Prediction Project, a European research initiative, pushes the boundaries of this category by using smart home labs to monitor for subtle changes for early dementia detection (Hall, Wong, Rogerson, Stimpson, & Ochieng, 2023). Many of these cases also function as Integrated Smart Homes, characterised by the seamless orchestration of multiple systems. This is powerfully demonstrated by the extensive, interconnected systems in Bill Gates' Xanadu 2.0 Mansion and Mark Zuckerberg's "Jarvis" Smart Home. The conceptual Near Future Smart Home by Murata Manufacturing further illustrates this vision of comprehensive integration across diverse functions. Finally, the emerging Intelligent Smart Home category, leveraging AI and machine learning for adaptive and personalised experiences, is most prominently featured in Mark Zuckerberg's "Jarvis," which utilises AI-powered natural language processing. The research-focused RADAR-AD Dementia Prediction Project also incorporates intelligence through data analysis and predictive algorithms. The Near Future Smart Home by Murata Manufacturing concept strongly emphasises intelligent adaptation, suggesting a future direction for the field.

4.3 Summary of Findings

Across these typologies, our analysis reveals several key findings:

- User-Centric Design: The primary function of a smart home is strongly correlated with its target user. Lifestyle-oriented homes cater to those seeking luxury, while Supportive technologies are tailored to the needs of vulnerable populations.
- Geographical Patterns: The case studies present a global distribution of innovation. While luxury residential cases are concentrated in North America (US) and Asia (Singapore, Japan), the European context is particularly prominent for Supportive smart homes, as seen with the RADAR-AD project and the Howz Sensors for Older Adults. The Near Future Smart Home by Murata Manufacturing highlights Japan's contribution to conceptual and Intelligent advancements.
- Technological Characteristics: Key technological components include security systems, environmental controls, various sensors, and evolving control interfaces like mobile apps and voice assistants. The trend is toward comprehensive, integrated systems that move beyond managing individual devices.

- Adoption vs. Experimentation: The analysis distinguishes between inhabited residences, such as Jonathan Dixon's Energy Efficient Smart Home, which demonstrates mainstream adoption, and research environments, such as the RADAR-AD Smart Home Lab, which serve as platforms for ongoing innovation and future-oriented development.

This diversity suggests a field that is maturing beyond singular applications towards more tailored and integrated solutions.

4.3.1 Diversity in Smart Home Applications and Purpose

Analysing the smart home cases reveals a broad spectrum of applications, extending well beyond general consumer convenience, and aligning with our typological framework. Lifestyle Smart Homes primarily enhance daily living, offering convenience, comfort, and entertainment. Examples include Bill Gates' Xanadu 2.0 Mansion and Mark Zuckerberg's "Jarvis" Smart Home, showcasing highly personalised and automated environments for affluent users. The En-Suite Sky Porches at the Hamilton Scott also highlight luxury amenities and unique features that elevate the lifestyle. Efficient Smart Homes prioritise resource optimisation. Jonathan Dixon's Energy Efficient Smart Home (UK), a Passivhaus retrofit, exemplifies this by integrating smart technology for minimal energy consumption. Supportive Smart Homes address the critical needs of specific user groups, particularly the elderly. The Howz Sensors for Older Adults (UK) actively monitors daily activities for well-being, while the ADU for Ageing Parents (US) provides independent living spaces with tailored safety and convenience features. The RADAR-AD Dementia Prediction Project (Europe) further demonstrates this, using smart home labs for early cognitive decline detection. Many cases also function as Integrated Smart Homes, seamlessly orchestrating multiple digital and physical systems for a holistic experience. This is evident in complex residences like Bill Gates' Xanadu 2.0 Mansion and Mark Zuckerberg's "Jarvis" Smart Home, as well as conceptual designs like The Near Future Smart Home by Murata Manufacturing. Finally, the emerging Intelligent Smart Home category, leveraging AI and machine learning for adaptive experiences, is seen in Mark Zuckerberg's "Jarvis" with its AI-powered voice control, and the research-focused RADAR-AD Dementia Prediction Project, which uses data analysis for predictive insights. The Near Future Smart Home by Murata Manufacturing further emphasises intelligent adaptation, suggesting a future direction for the field. The purpose behind these implementations varies: many serve as primary personal residences (e.g., Jonathan Dixon's home, Bill Gates' mansion), indicating widespread adoption for everyday benefits. Others function as dedicated research environments (e.g., RADAR-AD Smart Home Lab, Howz pilot study) or platforms for demonstrating integrated technological capabilities (e.g., Murata's concept home), reflecting ongoing innovation.

4.3.2 Geographical Distribution and Regional Focus

While the sample reflects cases primarily from North America and Europe, the analysis highlights distinct regional focuses within this scope. North American cases (US) showcased diverse applications, including energy efficiency (Business Owner), specialised housing solutions like ADUs tailored for elder care (ADU for Ageing Parents) or sustainable rentals (Sustainable Rental ADU), indicating motivations spanning personal care, sustainability, and potential income generation. European case studies (Greece, UK) demonstrated a strong emphasis on research and healthcare applications, particularly focused on assisted living and monitoring solutions for the elderly (RADAR-AD, UK Pilot Study). Energy efficiency and integrated home automation for personal residences were also evident (Jonathan Dixon's home, UK). Although specific case studies from Asia were limited in this selection, secondary information associated with some sources pointed towards regional priorities there, such as a strong interest in security features in Malaysia and broader trends towards AI/ML integration and sustainability across the Asia Pacific region. While the sample reflects cases primarily from North America and Europe, the analysis highlights distinct regional focuses within this scope. North American cases (US) showcased diverse applications, including energy efficiency (Business Owner), specialised housing solutions like ADUs tailored for elder care (ADU for Ageing Parents) or sustainable rentals (Sustainable

Rental ADU), indicating motivations spanning personal care, sustainability, and potential income generation. European case studies (Greece, UK) demonstrated a strong emphasis on research and healthcare applications, particularly focused on assisted living and monitoring solutions for the elderly (RADAR-AD, UK Pilot Study). Energy efficiency and integrated home automation for personal residences were also evident (Jonathan Dixon's home, UK). Although specific case studies from Asia were limited in this selection, secondary information associated with some sources pointed towards regional priorities there, such as a strong interest in security features in Malaysia and broader trends towards AI/ML integration and sustainability across the Asia Pacific region.

4.3.3 Key Technological Characteristics and Integration

The real-world case studies reveal several common characteristics and features of contemporary smart homes. These homes typically integrate a variety of smart devices and systems, including security systems such as smart locks, cameras, motion sensors, and alarms. Smart thermostats are commonly used for automated temperature control and energy efficiency. Smart lighting systems offer remote control and scheduling capabilities. Voice-activated assistants are increasingly integrated to provide hands-free control over various smart devices. While not always explicitly detailed, smart appliances are also part of many smart home ecosystems. Sensors play a crucial role in monitoring environmental factors such as motion, temperature, humidity, and carbon dioxide levels. Some smart homes also incorporate smart power strips to manage appliance energy consumption, solar panels for energy generation, and smart water management systems. Entertainment systems like smart TVs and speakers are also frequently integrated. These diverse systems are controlled and interact with each other through various means. Centralised control via mobile applications on smartphones and tablets is a common feature. Voice control through smart assistants provides a convenient and increasingly popular interface. Smart hubs often serve as central connection points, integrating devices that use different communication protocols. Automation based on triggers from sensors or pre-set schedules allows for proactive and context-aware operation. The potential for AI-powered intelligent orchestration and recommendations is also emerging, promising more sophisticated and personalised smart home experiences. This trend towards unified and intelligent control systems signifies a move beyond managing individual devices to creating a truly integrated and responsive home environment. Users and researchers have reported numerous benefits and challenges associated with smart homes. The benefits include enhanced comfort and convenience, significant energy cost savings, improved security and safety, increased independence for elderly or disabled individuals, and greater peace of mind for caregivers. However, challenges also exist, particularly concerning the potential for digital risks and harms such as hacking, privacy breaches, and technology-enabled abuse. The initial cost of ownership and setup complexity can also be a barrier. Early systems sometimes suffered from inflexibility and poor manageability. Ensuring ease of use and fostering user understanding of data privacy remain critical factors for the continued adoption and positive perception of smart home technology. Addressing these challenges through robust security measures and user-friendly designs is essential for realising the full potential of smart homes. Across the diverse applications and regions, several key technological characteristics emerged consistently. Common components include:

- <u>Security Systems:</u> Smart locks, cameras, motion/door sensors, alarms.
- <u>Environmental Controls:</u> Smart thermostats and lighting systems offering automation and remote access.
- <u>Sensors:</u> Various types for monitoring motion, occupancy, appliance usage, and environmental parameters (temperature, humidity).
- <u>Control Interfaces:</u> Mobile applications, voice-activated assistants (increasingly prevalent), and sometimes centralised smart hubs.
- <u>Energy Management:</u> Devices like smart power strips, integration with solar panels, and smart water management systems were noted in cases focused on efficiency or sustainability.

A notable finding relates to the level of integration. While some implementations focus on specific functions (e.g., primarily security), many demonstrate a move towards comprehensive, integrated systems where multiple devices and subsystems interact (e.g., Loxone system in Jonathan Dixon's home, integrated features in the ADUs). Control methods are evolving from individual device management towards unified control via apps, voice commands, and automated routines triggered by sensor data or schedules, suggesting a trend towards more cohesive and responsive home environments.

4.3.4 User Status: Prevalence of Inhabited and Experimental Homes

Our analysis examined whether smart homes primarily function as lived-in residences or as experimental setups. Many of the case studies reviewed depict inhabited smart homes, including notable examples such as Bill Gates' Xanadu 2.0 Mansion and Mark Zuckerberg's "Jarvis" Smart Home, as well as the En-Suite Sky Porches at Hamilton Scott, Jonathan Dixon's Energy Efficient Smart Home, and the ADU designed for Ageing Parents. These instances reflect the active adoption and use of smart home technology in real-world, everyday environments by diverse user groups, moving beyond mere theoretical or laboratory frameworks. At the same time, it is important to recognise the existence of dedicated experimental and research-focused initiatives. Projects like the RADAR-AD Dementia Prediction Project and the Howz Sensors for Older Adults, which involve research conducted within participants' homes, underscore the ongoing exploration of smart home capabilities. Additionally, the conceptual Near Future Smart Home devised by Murata Manufacturing exemplifies the continuous innovation and research into future possibilities. This dual presence indicates that the smart home landscape is simultaneously maturing into mainstream applications while also serving as a platform for groundbreaking innovation.

4.3.5 Smart Homes Typologies based on analysis

During our analysis, patterns emerged across various cases. Through iterative clustering, the research identified five typologies of smart homes (Figure 6), each characterised by:

- Integrated Smart Home: Focuses on the seamless orchestration of digital and physical ecosystems within the home.
- Supportive Smart Home: Primarily designed to facilitate care, address vulnerabilities, and promote well-being.
- Defensive Smart Home: Emphasises security-oriented implementations to protect residents and property.
- Lifestyle Smart Home: Centres on convenience-driven automated environments to enhance daily living.
- Efficient Smart Home: Prioritises the optimisation of resource use and sustainability within the home.
- Intelligent Smart Home: Characterised by adaptive systems leveraging AI and machine learning for personalised experiences.

5 Discussion

This study aimed to provide a structured and comprehensive overview of the global landscape of smart home case studies, addressing the gap often present in research that tends to focus on isolated aspects of this rapidly evolving domain. Our findings, derived from a qualitative analysis of diverse real-world implementations, corroborate the dynamic and multifaceted nature of contemporary smart home technology, representing a significant departure from earlier, more rudimentary automation concepts such as the ECHO IV (Katre & Rojatkar, 2017). By synthesising information on applications, geographical distribution, key features, and user considerations, this research offers a holistic perspective through the lens of our developed typological framework.

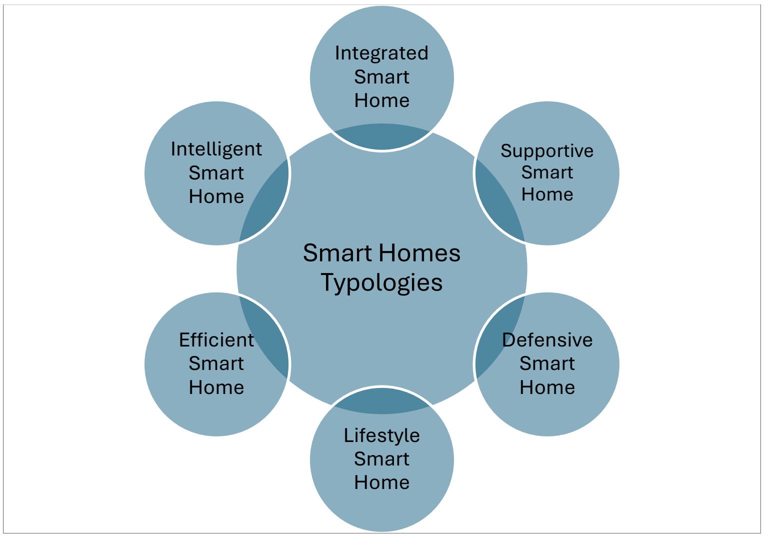

Figure 6: Smart Home Typologies.

5.1 Defining and Operationalising Key Concepts

A central challenge in smart home research is the lack of a consistent definition across disciplines. While terms like "home automation" and "smart home" are often used interchangeably, our research aligns with the distinction that a smart home inherently implies Internet of Things (IoT) connectivity, which enables a broader range of functionalities, remote access, and data exchange. This operational definition is consistent with recent literature in computer science and engineering (Al-Ali et al., 2017; Atzori et al., 2010), which views the smart home as a connected ecosystem rather than a purely automated one.

Furthermore, the concept of "smartness" itself is not uniform. In architecture and design, "smart" often relates to a home's ability to adapt its physical environment, whereas in computer science, it is defined by a system's capacity for learning and prediction (Madakam & Ramaswamy, 2014; Mozer et al., 2005). Our research bridges these disciplinary views by operationalising "smartness" across a spectrum of typologies. For instance, the Adaptive House at the University of Colorado exemplifies a computer science-driven definition of smartness, as its system learns resident behaviours to predict needs. In contrast, Jonathan Dixon's Energy Efficient Smart Home operationalises a more architectural view of smartness, where technology enhances a building's performance and sustainability goals.

Our typological framework serves as the core operational tool for this study. By defining categories such as Supportive and Lifestyle, we move beyond generic definitions to provide a structured way of understanding how these concepts manifest in real-world contexts. A smart home is not just a collection of devices; it is a system designed with a specific purpose, whether for health monitoring (e.g., Howz Sensors for Older Adults) or for enhancing a high-end lifestyle (e.g., Bill Gates' Xanadu 2.0 Mansion). This structured approach allows for a more nuanced analysis of the field than is possible with a single, all-encompassing definition.

5.2 Interpreting the Findings

Our analysis reveals that smart homes are not monolithic but are conceptualised and realised in various ways, often embodying a blend of functionalities. For instance, Bill Gates' Xanadu 2.0 Mansion exemplifies an integrated system orchestrating a multitude of features that define a Lifestyle of luxury and convenience. The RADAR-AD Dementia Prediction Project, in contrast, showcases a Supportive smart home in a research context, integrating various sensors and data analysis with the potential for Intelligent early disease detection. The inherent multifunctionality of smart homes, where single implementations like the ADU for Ageing Parents serve Supportive, Defensive, and Lifestyle functions, underscores their evolving complexity. This blending of typologies within single cases is consistent with existing research on the diverse nature of smart homes. Our findings on the key drivers for smart home adoption—security, convenience, efficiency, and support—are also largely consistent with existing literature on consumer motivations and the role of technology in sustainability and assistive living. We observed distinct geographical variations, with a notable European concentration in Supportive homes for the elderly, as reflected in the Howz Sensors for Older Adults pilot in the UK and the RADAR-AD Dementia Prediction Project. North America's emphasis on Lifestyle is evident in high-end residences like Bill Gates' and Mark Zuckerberg's homes. Asia's emerging focus on Intelligent automation is hinted at by the sophisticated En-Suite Sky Porches at the Hamilton Scott and the conceptual The Near Future Smart Home by Murata Manufacturing from Japan. However, the limited availability of detailed academic case studies from all regions represents a potential inconclusive aspect of our analysis regarding definitive global trends. The distinction between inhabited residences and research-driven settings supports the idea of a move towards mainstream adoption alongside continued innovation. This is consistent with increasing market penetration reports. The technological integration trends observed in cases like Xanadu 2.0 and "Jarvis," with unified control and AI, represent a significant advancement beyond the basic on/off functionality of early systems like the ECHO IV, highlighting the increasing sophistication and user-centric design of contemporary smart homes, which aligns with future trend predictions.

5.3 Recommendations

Based on our analysis, several key recommendations can be made for stakeholders in the smart home ecosystem.

- For Researchers: The proposed typological framework offers a structured approach for future studies. The identified trends in functional integration and user-specific applications can guide research into the socio-technical factors driving smart home evolution. This study extends previous research by offering a global, comparative analysis grounded in a novel framework. The specific examples analysed provide concrete illustrations of the abstract categories, enriching the understanding of smart home diversity beyond theoretical discussions.
- For Industry: The typological framework can assist in tailoring products to specific market segments identified in our case analysis. Industry should focus on developing secure and interoperable smart home ecosystems, prioritising user-centric design principles, and addressing the affordability barrier to wider adoption. Further research and development in AI-driven intelligent and adaptive smart home systems should be encouraged.
- For Policymakers: Our findings highlight critical challenges like security and privacy. Policymakers should develop clear guidelines and regulations to address these digital risks in smart home environments. They should also promote interoperability standards and support research into accessible and user-friendly solutions for vulnerable populations.
- For Users: It's important for users to prioritise security and privacy when selecting smart devices. They should choose systems that align with their primary needs, recognising the diverse functionalities demonstrated in the analysed examples, and stay informed about the evolving capabilities and potential risks of smart home technologies.

5.4 Research Limitations

While this study provides a comprehensive overview of the global smart home landscape based on available case studies, several limitations inherent in the methodology and scope should be acknowledged. The research is entirely dependent on publicly available case studies, academic literature, industry reports, and online publications. This reliance introduces potential limitations:

- Publication Bias: Published case studies may disproportionately represent successful, innovative, or commercially promoted projects, potentially underrepresenting failures, more mundane implementations, or homes experiencing significant issues.
- Information Gaps and Variability: The level of detail, focus, and quality varies significantly across sources. Many case studies lacked comprehensive data on specific user experiences, long-term usability, costs, or technical challenges, constraining the depth of analysis on certain aspects.
- Geographical and Language Bias: While efforts were made to achieve geographical diversity, the availability of detailed case studies is likely skewed towards regions with high publication rates, major technology markets (like North America, Europe, parts of Asia), and documentation primarily in English. This may lead to an underrepresentation of smart home developments in other regions or non-English-speaking countries.
- Provider Influence: Some case studies sourced from technology providers (e.g., Loxone examples) may naturally emphasise the positive aspects and successful integration of their specific products.
- Lack of Primary Data: This study did not involve primary data collection, such as direct interviews with homeowners, ethnographic observation, or technical performance testing. Consequently, the understanding of user perspectives, lived experiences, day-to-day challenges, and unreported issues is limited to what was documented in the secondary sources.
- Depth vs. Breadth Trade-off: The aim of providing a broad, global overview necessitated a trade-off with the depth of analysis for individual case studies. The focus was on identifying patterns and characteristics across multiple cases rather than conducting an exhaustive investigation of any single implementation.
- Temporal Limitations: The smart home technology field evolves rapidly. This study provides a snapshot based on sources available up to the time of research. Newer trends, technologies, or market shifts emerging after data collection may not be captured.
- Defining "Smart Home": The definition and scope of what constitutes a "smart home" can vary. This study relied on the interpretations presented within the source materials, which may not be perfectly uniform across all cases.

Despite these limitations, the systematic approach to identifying, selecting, and analysing diverse case studies provides a valuable synthesis and structured understanding of the current global smart home landscape, fulfilling the study's primary objective.

6 Conclusions

This study has provided a comprehensive analysis of the global smart home landscape through the examination of diverse real-world and conceptual case studies, structured by a novel typological framework encompassing Integrated, Supportive, Defensive, Lifestyle, Efficient, and Intelligent smart homes. Our findings underscore the inherently multifaceted and non-monolithic nature of this evolving technology, demonstrating its adaptation to a wide array of user needs and functional priorities across different geographical contexts. The analysis reveals key trends, including the increasing integration of diverse technologies, a growing emphasis on user-centric design tailored to specific demographics like the elderly and environmentally conscious consumers, and regional variations in adoption and focus. While North America and Europe have been prominent in early adoption and specialised residential applications, Asia is emerging as a significant force in shaping future intelligent automation. The distinction between inhabited homes showcasing current adoption and research settings exploring future potential highlights a field in dynamic transition. The proposed typological framework has proven to be a valuable tool for dissecting the complex landscape of smart homes, offering a structured approach to understanding their diverse conceptualisations and implementations. By categorising cases based on their primary ifunctions and user needs, this study provides a clearer understanding of the underlying drivers and potential of smart home technology beyond simple automation. However, the limitations of relying on secondary data and the potential for publication and geographical biases necessitate caution in generalising these findings. Future research would benefit from primary data collection and a more extensive representation of case studies from underrepresented regions to provide an even more nuanced global perspective. Ultimately, this study contributes to a more holistic understanding of the global smart home landscape, offering a framework for future analysis and highlighting the key trends and challenges that will shape its continued evolution. The insights gained have implications for researchers, industry stakeholders, policymakers, and the general public, providing a foundation for informed innovation, regulation, and adoption of smart home technologies that effectively address diverse human needs and aspirations for the future of living.

Acknowledgements

The authors would like to acknowledge the support of Deakin University, which provided the necessary resources and intellectual environment for this research. This work forms part of a PhD study by the first author.

Funding

This research did not receive any external funding. It was conducted as part of a PhD program, supported by Deakin University.

Ethical Approval Declaration

NA

Informed Consent Statement

NA

Data Availability Statement

The data that support the findings of this study were derived from secondary sources available in the public domain. A comprehensive list of these sources is provided in the references section of this manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

Al-Ali, A.-R., Zualkernan, I. A., Rashid, M., Gupta, R., & Alikarar, M. (2017). A smart home energy management system using IoT and big data analytics approach. *IEEE Transactions on Consumer Electronics, 63*(4), 426-434.

Al-Turjman, F., Zahmatkesh, H., & Shahroze, R. (2022). An overview of security and privacy in smart cities' IoT communications. *Transactions on Emerging Telecommunications Technologies, 33*(3), e3677.

Alzoubi, A. (2022). Machine learning for intelligent energy consumption in smart homes. *International Journal of Computations, Information and Manufacturing (IJCIM), 2*(1).

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer networks, 54*(15), 2787-2805.

Bastaki, B. B., Sedky, M., Campion, R. C., & Atkins, A. (2023). Application of artificial intelligence in ambient assisted living to support elderly people in smart homes. In *IoT Enabled Computer-Aided Systems for Smart Buildings* (pp. 145-163): Springer.

Batool, S., Abid, M. K., Salahuddin, M. A., Aziz, Y., Naeem, A., & Aslam, N. (2024). Integrating IoT and Machine Learning to Provide Intelligent Security in Smart Homes. *Journal of Computing & Biomedical Informatics, 7*(01), 224-238.

Bradbury, R. (2012). *The martian chronicles*: Simon and Schuster.

Burroughs, J. (2010). X-10 home automation using the PIC16F877A. *Lamp, 10*(10).

Cao, Y. (2020). Digital ethnography research on the state of the art of smart home experience.

Cook, D. J. (2009). IGERT: Integrative Training in Health-Assistive Smart Environments. *NSF Award Number 0900781. Directorate for STEM Education, 9*(900781), 781.

Cowan, R. S. (2023). *More work for mother: The ironies of household technology from the open hearth to the microwave*: Plunkett Lake Press.

Fausset, C. B., Mitzner, T. L., Price, C. E., Jones, B. D., Fain, B. W., & Rogers, W. A. (2013). *Older adults' use of and attitudes toward activity monitoring technologies.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Hall, V., Wong, R., Rogerson, L., Stimpson, P., & Ochieng, B. (2023). THE HOWZ (SMART METER) PROJECT.

Harvey, J., Poorrezaei, M., Woodall, T., Nica-Avram, G., Smith, G., Ajiboye, T., . . . Zhu, K. (2020). The Smart Home: How Consumers Craft New Service Networks by Combining Heterogeneous Smart Domestic Products. *Journal of Service Research, 23*(4), 504-526. doi:10.1177/1094670520929095

Jadhav, P., Chaudhari, A., & Vavale, S. (2014). Home automation using ZigBee protocol. *International Journal of Computer Science and Information Technologies, 5*(2), 1778-1780.

Katre, S. R., & Rojatkar, D. V. (2017). Home automation: past, present and future. *International research journal of engineering and technology, 4*(10), 343-346.

Kientz, J. A., Patel, S. N., Jones, B., Price, E., Mynatt, E. D., & Abowd, G. D. (2008). The georgia tech aware home. In *CHI'08 extended abstracts on Human factors in computing systems* (pp. 3675-3680).

Lai, P. Y., Kim, M., Choi, M., Lee, C.-S., Porcellini, V., Yi, T., & Lee, J.-H. (2019). *Framework of judgment system for smart home assistant utilizing collective intelligence case-based reasoning.* Paper presented at the 24th International Conference on Computer-Aided Architectural Design Research in Asia: Intelligent and Informed, CAADRIA 2019.

Larson, S. S. I. K. (2003). Designing and evaluating supportive technology for homes.

Madakam, S., & Ramaswamy, R. (2014). *Smart homes (conceptual views).* Paper presented at the 2014 2nd International Symposium on Computational and Business Intelligence.

Mathews, J. J., Mulavelil, R., Rodrigues, N., Kautz, T. F., Cosgrove, K., Wang, C.-P., . . . Sharma, N. Feasibility and Acceptability of an In-Home Digital Device Health and Activity Assessment Platform in a Diverse South Texas Cohort: A Pilot Study. *Frontiers in Digital Health, 7*, 1603062.

Mirijamdotter, A., Ståhlbröst, A., Sällström, A., Niitamo, V.-P., & Kulkki, S. (2006). The European Network of Living Labs for CWE-user-centric co-creation and innovation. *Exploiting the Knowledge Economy: Issues, Applications, Case Studies. IOS Press, Amsterdam*.

Mozer, M., Dodier, R., Miller, D., Anderson, M., Anderson, J., Bertini, D., Daugherty, B. (2005). *The adaptive house.* Paper presented at the IEE Seminar on Intelligent Building Environments.

Mudgerikar, A., & Bertino, E. (2020). *Jarvis: Moving towards a smarter internet of things.* Paper presented at the 2020 IEEE 40th International Conference on Distributed Computing Systems (ICDCS).

Nikola, T. (1898). Method of and apparatus for controlling mechanism of moving vessels or vehicles. In: Google Patents.

Norman, D. (2013). TheDesignofEverydayThings: RevisedandExpanded Edition. New York.

Nye, D. (1992). Electrifying America: Social meanings of a new technology.

Randall, D. (2003). Living Inside a Smart Home: A Case Study. In (pp. 227-246).

Rini, J. (2019). WP2 Conceptual framework for comparative multiple case study analysis. *Maastricht University: Maastricht, The Netherlands*.

Stuecklberger, C., Dimitrova, D., Liagouris, I., & Roscoe, T. Systems Group, Department of Computer Science, ETH Zurich.

Taati, B., Snoek, J., & Mihailidis, A. (2011). *Towards aging-in-place: Automatic assessment of product usability for older adults with dementia.* Paper presented at the 2011 IEEE First International Conference on Healthcare Informatics, Imaging and Systems Biology.

Wilson, C., Hargreaves, T., & Hauxwell-Baldwin, R. (2015). Smart homes and their users: a systematic analysis and key challenges. *Personal and Ubiquitous Computing, 19*, 463-476.

Withanage, C., Ashok, R., Yuen, C., & Otto, K. (2014). *A comparison of the popular home automation technologies.* Paper presented at the 2014 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA).

Wittje, R. (2013). The Electrical Imagination: Sound analogies, equivalent circuits, and the rise of electroacoustics, 1863–1939. *Osiris, 28*(1), 40-63.

Yin, R. K. a., & Campbell, D. T. (2018). Case study research and applications: design and methods / Robert K. Yin. In (Sixth edition. ed.): SAGE Publications, Inc.

Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2014). Internet of things for smart cities. *IEEE Internet of Things journal, 1*(1), 22-32.