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SMART HOMES AND WASTE REDUCTION

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ABSTRACT

The concept of smart homes includes smart technologies, systems, and devices to facilitate efficiency, security, comfort, and overall management of the home environment. This paper presents the concept of smart homes and discusses how it relates to waste reduction, especially energy waste. As waste reduction is one of the key lean principles, the notion of a "smart home" and " waste reduction" can be connected to optimising efficiency and increasing the functionality of the home. An experiment was carried out in the Huddersfield smart house research facility for the optimisation of energy usage through smart home technologies and efficient appliances, resulting in lifecycle waste reduction. The investigation highlights the connection between Smart Home' and 'Lean Waste Principles' indicating how energy use in the building lifecycle is hidden in lean waste. This suggests a need for future empirical research to better understand how to reduce waste using smart home technology and provide solutions to resolve energy waste on a wider scale.

KEYWORDS

Smart Home, energy efficiency, waste reduction, comfort, lean waste

INTRODUCTION

In today's world, the rapid development of 'The Internet of Things' has led to the gradual integration of the concept of a 'Smart Home' into people's daily lives. Meanwhile, there is a worldwide increase in energy demand, resulting in negative environmental impacts. Buildings are one of the major contributors to rising energy consumption (Chenari et al., 2016). There are 29 million homes in the UK which use 14% of the UK's energy consumption (Pérez-Lombard et al., 2008) and the UK government aims to reduce 60% of these emissions by 2050 (Zala et al., 2017). This highlights the critical need for more effective strategies to manage energy consumption (Hakawati et al., 2024).

Efficient waste elimination is crucial to address the stated problem (Nižetić et al., 2019). One of the key Lean principles is waste reduction (Koskela et al., 2013). Seven types of waste are found in lean literature i.e. transport, inventory, motion, waiting, overprocessing, overproduction, and defects, and the eighth waste, making-do (Koskela et al., 2013). This paper will focus on waste in use, as opposed to production waste, i.e. wasted energy due to the

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inefficiency of buildings; and defects- appliance inefficiency in the home during a building's lifecycle, emphasising energy-efficient living environments. In a lifecycle analysis, five stages are typically recognised in the life cycle of infrastructure: material manufacturing, construction, maintenance, operation, and end-of-life (Liljenström et al., 2022). This study focuses on the operation stage of the building lifecycle.

Andrade et al., (2022) highlights that the integration of smart technologies expedited by the Internet of Things (IoT) has a pivotal role in reducing energy usage and enhancing user comfort. Monitoring energy consumption and improving efficiency through computational solutions can be achieved through smart homes, equipped with technologies for customised services.

The notion of Smart home technology and energy usage in the built environment is not novel. However, fewer evidence is found on waste reduction through energy efficiency from a lean construction lens. This paper discusses the concept of a 'Smart Home' and waste reduction from a lean construction perspective, for instance, energy optimisation using energy management systems, appliance efficiency, home automation, scheduling thermostats to reduce energy usage, and renewable energy integration. The main aim of the paper is to link smart homes to Lean from the context of lifecycle waste reduction. An experiment in the smart house research facility (Huddersfield Smart House Research Facility-HSHRF; see link here: Smart House - University of Huddersfield) is presented to support the findings.

RESEARCH METHOD

The research method included three steps; (i) a bibliometric analysis of Scopus-indexed papers; (ii) a review of relevant topics, and (iii) an experimental case study in the Smart House research facility at the University of Huddersfield.

The bibliographic analysis was conducted to understand the connection among Smart homes/ intelligent buildings, energy utilisation, and waste reduction. The following keywords are used: {smart AND home AND waste AND management AND energy AND efficiency} (See Figure 1). 36 Scopus-indexed journals were used as a database to generate the co-occurrence of topics and create a network of visualisation.

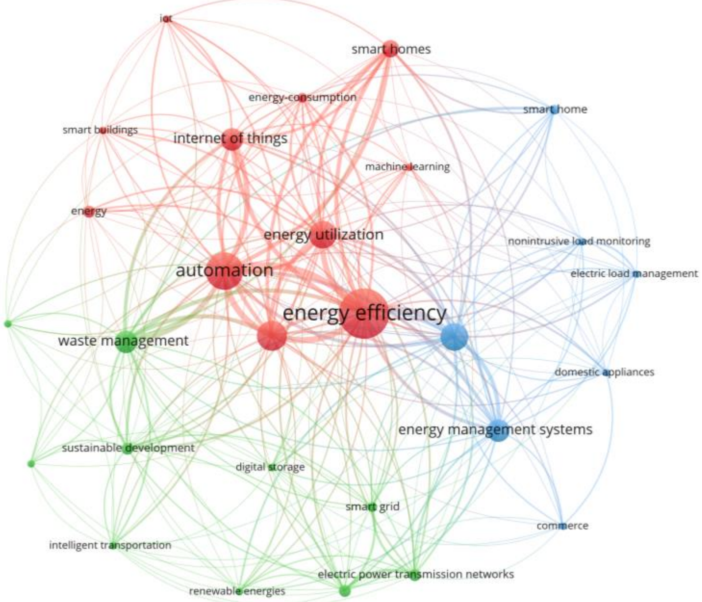

Figure 1 Bibliographic Analysis- Network visualisation of papers' keywords

It is observed in Figure 1 that effective energy efficiency is intrinsically connected to certain keywords, such as energy management, waste reduction, smart home, IoT, renewable energies, and energy consumption. After identifying keywords from the co-occurrence network, a related relevant topic is selected for the review of the literature.

A case study experiment conducted at Huddersfield Smart House Research Facility (HSHRF) is presented to support the findings. The HSHRF is a house built within a building, which has a number of sensors, as well as a digital twin, and it's used for testing is used for various physical testing purposes. The experiment explored a smart radiator in the HSHRF to observe the energy usage through a period of 24 hours and evaluate optimisation of energy in smart home environments.

LITERATURE REVIEW

CONCEPT OF SMART HOME

A smart home is supplied with a high-tech network connecting sensors and home devices, which can be remotely accessed, monitored or controlled (Wu et al., 2023). The 'original' concept of a smart home is an integrated home with various services interconnected by a single communication system (Lutolf, 1992; Aldrich, 2003). In a regular home environment (i.e., not smart), residents operate home appliances and devices individually and separately. Appliances and lighting are individually controlled by occupants rather than a centralised control system. However, network devices have proliferated in the environment of ubiquitous computer technology. As a result, in the last decade, the "smart home" concept has received considerable attention in the built environment (Yang et al., 2017). There are various definitions of a Smart Home in the literature, as shown in Table 1.

Table 1 Definition of Smart Home

Author	Year	Description of Smart Home
American Association of House Builders	1984	In the early 1960s, the concept of smart homes was called 'Wired Homes', built by hobbyists.
(Lutolf, 1992)	1992	A Smart Home is known as a network of home electronic devices and attributes linked to the internet.
(Aldrich, 2003)	2003	A "smart home" is a residence installed with computing and information technology that senses and reacts to the needs of the residents, aiming to enhance comfort, security, and entertainment through technology management.
(Lertlakkhanakul et al., 2008)	2008	smart home can be regarded as a 'smarter' version of home automation with integrated technological systems
(Albany et al., 2022)	2022	A smart home is a group of connected IoT devices that can be controlled remotely using a smartphone or computer.
(Munirathinam, 2020)	2020	Smart home technology, is defined as home automation, providing homeowners security, comfort, convenience, and energy efficiency by allowing them to control smart devices.
(Basarir-Ozel et al., 2023)	2023	A smart home represents smart devices and sensors, integrated into an intelligent home network, offering control, monitoring, and support services to satisfy user needs.

Smart home technology can be used primarily in two ways: (i) to ensure the occupants safety, health and comfort and (ii) to facilitate household operations, especially reduce energy costs (Schieweck et al., 2018). A smart home is connected with cutting-edge technologies for automation of functionalities, household appliances, and electronics for communication and entertainment (Lertlakkhanakul et al., 2008; Schieweck et al., 2018; Albany et al., 2022). In summary, the concept of the 'Smart Home' has been proposed to increase the building's efficiency and performance, enabled through the rapid development of artificial intelligence (Zhang et al., 2023); and integrated smart systems play a role through IoT technology (Huang et al., 2018).

CONCEPT OF WASTE IN LEAN

A core principle of Lean is to eliminate waste with the aim to increase performance (Aisyah et al., 2023) and as a driver for improvement (Tzortzopoulos et al., 2020). Seven lean waste types are:1. Transport: redundant and unproductive flow of information or materials; 2. Inventory: information or materials waiting to be processed; 3. Motion: Employee performed activities associated in the workflow; 4. Waiting: waiting for information or inputs; 5. Overprocessing: Associated with the processor (conversion) operation, which can possibly be prevented; 6. Overproduction: Producing more than is needed for immediate use; 7. Defects: accusation, untrustworthy or miscoded data, documentation and transcription errors, unauthorised procedures (Koskela et al., 2013; Owais et al., 2023; Sutherland & Bennett, 2007). Energy usage reduction is often concealed in lean wastes. EPA, (2007) highlight energy impacts associated with wastes targeted by lean. Table 2 provides an overview of lean waste types, lean waste in production, and energy use hidden in lean waste by (EPA, 2007; Owais et al., 2023; Sutherland & Bennett, 2007).

Table 2 Lean Waste in production and energy use hidden in lean wastes

Waste Type	Lean Waste in production	Energy Usage
Overproduction	Connected to a larger volume of production than requested or desired	Unnecessary energy used in operating equipment
Inventory	Pertaining to material waste caused by overstocks or unused stockpiles	Additional energy required to heat, cool, and light inventory storage and warehouse
Transport	Avoidable movement of products, materials, or information.	Additional energy used for transport
Defects	It occurs when the result fails to fulfil the quality standards.	Energy consumed in making defective products-, increasing lighting, heating, and cooling demand and energy consumption
Motion	Unnecessary movement of people, such as walking, reaching and stretching	Deals with activities performed by users
Over-processing	Associated with the processor (conversion) operation, which can possibly be prevented	More energy consumed in operating equipment due to unnecessary processing
Waiting/Delays	Any delay between the end of one process and the start of the next activity	Wasted energy during production downtime from heating, cooling, and lighting

In addition to the above wastes, the eighth category of waste is conceptualised by (Koskela, 2004). Making-do occurs where a task is initiated without all standard inputs, especially in production where there are multiple uncertain inflows to the tasks. The inputs can be materials, machinery, tools, personnel, external conditions, instructions, etc. Waste by making do can occur in different ways, for example, efficiency syndrome- the urge to maximise resource utilisation; pressure for an immediate response- situation of incomplete inputs and unreliable inflows of the production system (Koskela, 2004).

Buildings contribute significantly to the depletion of natural resources and emissions to the environment during its lifecycle. Buildings generate manufacturing waste, transportation of materials waste, construction waste, operation/use waste, and deconstruction/end-of-life waste. As the building industry is shifting its focus to sustainable development, the consideration of these waste factors is crucial to ensure waste reduction (Hossain & Thomas, 2019). The following section discusses the notion of smart home technology in waste reduction from the building use/operation point, especially in energy waste.

WASTE REDUCTION THROUGH SMART HOME

The evolution of smart home is transitioning from the initial emphasis on occupants' comfort to the development of innovative solutions aimed at effective and efficient control of the infrastructure (Murty & Kumar, 2020). A smart home can significantly influence waste reduction through the integration of multiple technologies and smart systems, resulting in reducing environmental pollution, and thus increasing the degree of environmental health (Škulj et al., 2019). The deployment of smart meters and controls, and the emergence of smart appliances and their inclusion in home networks allow energy consumers to benefit from a more comfortable, and healthier living environment, while consuming less energy thus reducing waste (European Commission et al., 2017).

There are multiple aspects connecting the smart home with energy waste reduction among which the paper reviews the following topics: (i) Energy monitoring and optimisation; (ii) Smart appliance efficiency; (iii) Home automation; and (iv) Renewable energy integration and smart home energy storage.

Energy Monitoring and optimisation

Smart monitoring systems can play a crucial role in integrating energy management and monitoring control systems through IoT technology (Huang et al., 2018). ‘Smart Sensors’ can be defined as sensors using semiconductor technology to join output power devices with control circuitry (Naidu, 1998). The smart home comprises of sensors that are wirelessly connected and dedicated to measuring physical quantities, such as various environmental characteristics-temperature, sound, light intensity, humidity, force, and pressure (Chakraborty et al., 2023; Chauhan et al., 2022). Additionally, smart home wireless sensors can detect smoke, gas, and temperature and alarm early fire in a smart home environment.

Optimisation of energy can be achieved through a smart energy management system for residential buildings (Essa, 2019). The energy management system prioritises energy conservation, expenditure reduction, safety improvement, and easy maintenance (Li et al., 2020). Efficient energy management systems reduce energy consumption, waste, and costs, help conserve fossil fuel resources, and increase occupant comfort. For instance, if Matsui, (2018)’s home energy management systems (HEMS) are installed in smart homes, they can predict the indoor comfort level, reduce 5.15% electricity consumption, and increase the comfort level by 16.4% for occupants. Another example is IoT-based smart sensors through energy-applied load monitoring (ALM) systems can be explored to predict energy consumption through smart data collection. Users are then informed by the total energy usage from several sensors connected to home devices; and take corrective actions to optimise consumption (Oudat et al., 2019).

Appliance Efficiency

Smart home appliances constitute multiple devices and applications such as smart washing machines, smart kettles, smart dishwashers, stoves, and smart refrigerators among others. Smart appliances can be remotely accessed, controlled, and monitored by the occupants (Balta-Ozkan et al., 2013). In a smart home environment, various devices can be remotely controlled through mobile terminals such as smartphones (Ma et al., 2023). One of the essential benefits of smart home appliances is the potential for energy reduction by both smart appliances themselves and (in)direct feedback options to the user (Du et al., 2023). For instance, smart lighting integration contributes to energy efficiency when combined the required lighting with natural lighting. User requirements are calculated and the lighting system can be adjusted using automation or task/user-based lighting to reduce the waste of energy (Vijayan et al., 2020).On the other hand Paul et al., (2022) argue, that the older version of the same appliance consumes more energy, than the newer ones. It is better to determine the economic and energetic replacement time of the appliances for the customer thus impacting the overall economic impact. In summary, smart appliances when appropriately installed and replaced in a timely manner, can optimise resources more efficiently, improving equipment utilisation and reducing waste.

Home Automation

Automation is defined as the capacity of technology to carry out functions in an autonomous mode with the least possible human interaction (Wong et al., 2017). An automation system is at the core of the concept of a Smart home, consisting of multiple systems in a home, for instance, control of HVAC systems, lighting control, energy management, security systems, and entertainment in home environments (Asadullah & Raza, 2016), designed for user comfort and energy efficiency. Automation allows better utilisation of advanced technologies and conservation of energy to be prioritised through smart homes that are inbuilt with communicative and innovative technologies (Vijayan et al., 2020). The development of automation can act as a key factor in resolving the issues of energy poverty (Niu et al., 2024). Specifically, automated processes improve to streamline operations, minimise energy wastage, and optimise resource utilisation, resulting in energy supply increase (Farzaneh et al., 2021)

Renewable Energy Integration and Storage

To support a cleaner environment, there is a shift toward the integration of smart meters, renewable energy resources (RERs), smart sensors, and energy storage systems (Nie et al., 2023). Renewable systems are equipped with a fully automated energy system, photovoltaic panels, and battery-electric storage systems (Nakıp et al., 2023). For instance, Nezhad et al., (2022)'s paper discusses the smart home with solar power generation through a rooftop PV panel. The solar power generation is forecasted and scheduling can be organised to minimising the operational cost, for example using the energy for a home appliance load. Essa (2019) presents a home energy management strategy that adjusts electricity generation and consumption based on the operating parameters of photovoltaic battery systems and thermostatically controlled loads. Battery energy storage and renewable generation in Smart homes will therefore optimise energy and further contribute to emission waste reduction.

DISCUSSION

Building components consisting of individual autonomous behaviours, to be controlled by a level of central control is considered smart and lean (Chien, 2013). From the theoretical point, there is not enough existing empirical evidence to consider smart house waste reduction from a lean point of view, especially, how the energy use in the building lifecycle hidden in lean waste relates to lean waste principles. From a practical point of view, it is observed that there is a gap in the interoperability of smart home technologies within the lean construction framework. Albeit both concepts prioritise efficiency and optimisation, integrating smart home systems without standard protocol requires careful consideration. The data exchange poses a threat to safeguarding information resulting in resistance to smart home technology installation (Yang et al., 2017). Furthermore, there is a gap in knowledge and expertise within the construction industry (Pavlou et al., 2007) to implement smart home technologies which will require a collaborative approach among construction firms, technology providers, and regulatory bodies to overcome these challenges.

CASE STUDY EXPERIMENT

EXPERIMENT DESIGN AT THE HUDDERSFIELD SMART HOUSE

An experiment was carried out in the Huddersfield Smart House research facility (HSHRF), which is a physical house providing a collaborative hub to accelerate research and development for energy efficiency in the built environment.

The HSHRF is a fully monitored physical smart house with real-time data over 48 wireless sensors to analyse temperature, humidity, CO2, and particulate matter. All the sensors are connected to a cloud-based system, called ‘iMonnit’. iMonnit refers to a cloud-based mobile internet platform and a central hub to manage iMonnit and ALTA products. All data is secured on dedicated servers operating Microsoft SQL Server (See Figure 3). The sensors installed in the smart house are constantly collecting real-time data, and they can be analysed and optimised through a digital simulation of the building.

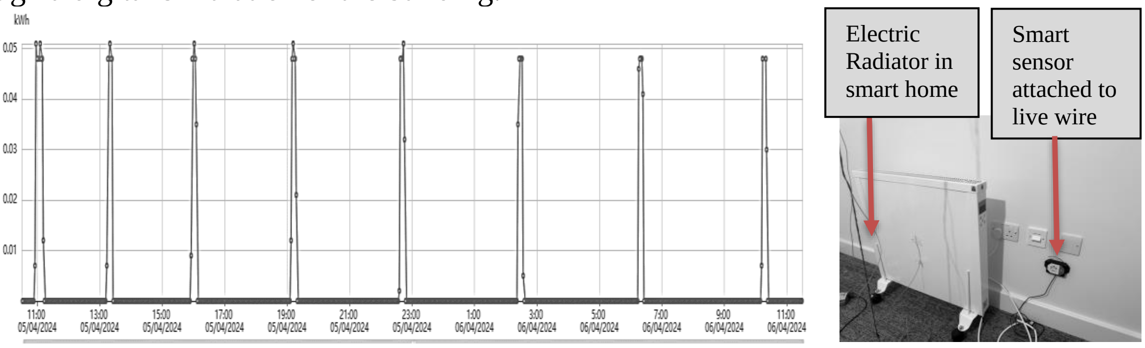

Figure 2 Experiment of Optimisation in Energy Consumption; Left: The usage of energy; Right: The experiment set up in HSHRF

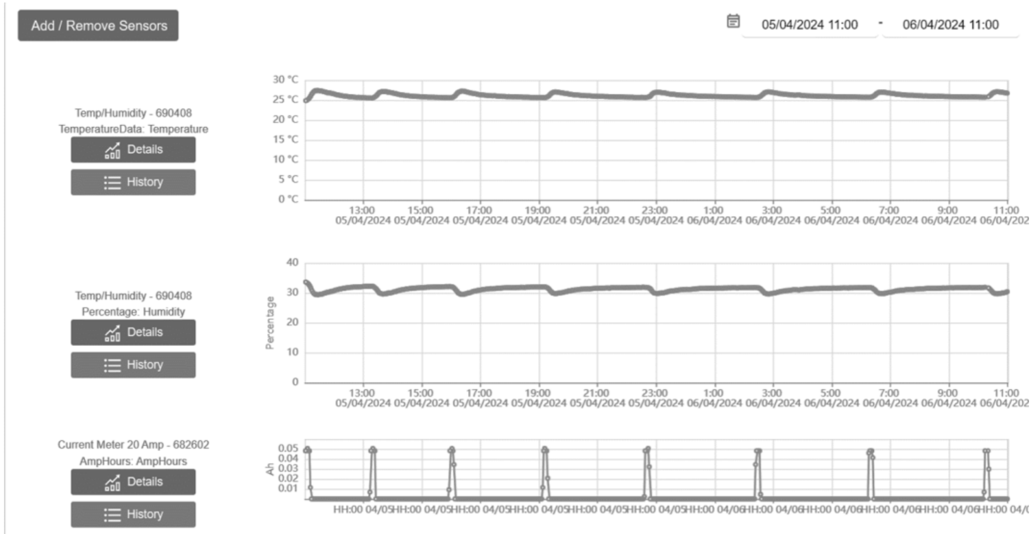

Figure 3 iMonnit chart- Monitors in Huddersfield Smart House research facility

The experiment was set up to validate energy optimisation through smart appliances, and smart sensors in a smart home environment (See Figure 2). The experiment was conducted to evaluate energy optimisation through a smart sensor and an electric radiator and generate an optimal temperature and humidity for the users. Electric radiators are becoming popular due to the government's green schemes for new-build housing (Zala et al., 2017). The data collection sensor is attached to the live wire, sending real-time data through the iMonnit cloud-based database system. The smart radiator was used to observe the energy usage over a period of 24 hours and evaluate optimisation. It should be noted the Smart house has installed external insulation properties such as external cavity walls and triple-glazed windows and acts as an energy-efficient experimental testbed.

RESULTS

The American society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has established guidelines for thermal comfort, recommending a range of 20 °C to 23.88 °C for temperature and 30-60 % for relative humidity. At the start of the experiment, the base temperature for the experiment room was 24°C. The smart house is built within a building and not exposed to outdoor environmental parameters, which is a limitation. However, this provides accurate data due to the repeatability of the testbed; results are consistent.

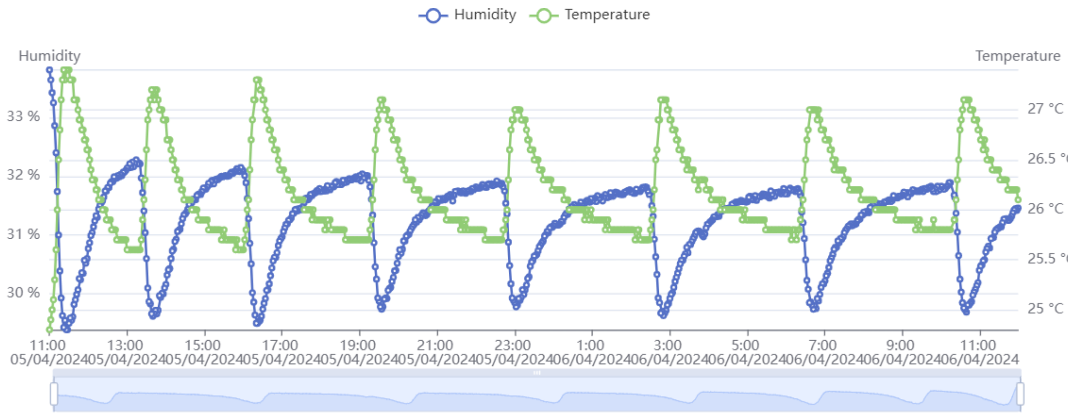

Figure 4 iMonnit chart- Temperature and Humidity graph

It is observed that this electric radiator consumed 1.90 kWh during a 24-hour test period (See Figure 3). After achieving the desired temperature, the radiator remained switched on for 1 hour and 20 minutes out of 24 hours, accounting for 8.3 % of the total time, indicating its ability to maintain room temperature effectively without constant energy consumption. This indicates that the appliance can maintain the optimal room temperature and minimise energy usage in an insulated smart home (See Figure 3). It effectively raised the room temperature from 24 °C to 27 °C during the 24 hours, with humidity levels ranging from 33% to 30%, indicating its ability to control humidity and create a comfortable living environment for occupants (See Figure 3). Figure 4 illustrates that when the temperature is high, the humidity is low, and vice versa, illustrating the temperature-humidity interrelationship in the living environment. As mentioned above, the experimental temperature is at a high range due to the limitations of the testbed. Nevertheless, as the Smart House is well insulated, the smart appliance successfully optimises energy usage and uses negligible energy when reaches the desired optimum temperature in a smart environment. This can be observed in Figure 3 through the smart charts derived from the collected real-time data.

CLOSING REMARKS

Smart home technologies are essential for improved energy energy, resulting in reducing carbon footprints. The household conditions can significantly improve with the deployment of smart technologies (Ehsanifar et al., 2023), and health and well-being can be improved through better management of internal environments, safety, and security. From the experiment, it is shown that the use of efficient appliances in a sensor-controlled energy-efficient smart home environment creates a comfortable living environment for the occupants with low energy consumption. The energy-efficient testbed successfully optimised the energy usage when reached the desired optimum temperature according to AHSRAE guidelines. The use of smart sensors contributes to real-time data and allows continuous improvement in smart product development. Furszyfer Del Rio et al. (2021) describe the potential sustainability benefits of smart home technologies that can support cost benefits and contribute to social and environmental impacts.

The waste reduction through smart homes can be directly connected to lean in the context of energy efficiency, energy waste reduction, data-driven decision-making, and improving user functionality. The review shows that Smart homes relate to increased capacity, better tracking, improvements in equipment utilisation, streamlined operations, and lower emissions.

Smart homes allow waste reduction through increasing efficiency, appraising user control in a home environment, and inducing continuous improvement. A summary of how the notion of smart home addresses lean principles is presented in Table 3. The findings presented in Table 3 are consistent with some synergies identified in Table 2, adapted from Awwal et al. (2023).

Table 3 Lean principles and Smart Home in waste reduction

Lean Waste	Energy Usage (EPA, 2007)	Synergies with Smart Home
Overproduction & Over processing	Additional energy consumed in operating equipment and more energy consumed due to unnecessary processing	A smart home allows energy efficiency through smart appliances, smart monitors and controls, and the integration of renewable technologies
Defects	Energy consumed in making defective products-, increasing lighting, heating, and cooling demand and energy consumption	A smart home allows the monitoring of real-time data and enables determining when there is a need for product replacement (e.g. Building materials and appliances) during the lifecycle of the building
Waiting/Delays	Streamlining operations	-Automation in smart homes allows streamlining daily operations and reduce waste

Table 3 depicts that the adoption of smart home technologies allows waste reduction/elimination during a building’s lifecycle. The contributions were categorised into three groups: Overproduction and overprocessing-where smart home can minimise energy usage through better tracking and optimisation; Defects- Smart home allows real-time data collection; it can offer information on building deterioration over time, for example, if the humidity level is continuously high, measures can be taken to improve the condition, or if the appliances are older and consuming more energy, a replacement can be considered through smart data observation and waiting/delays- automation in a smart home can streamline operations which can result into increasing energy efficiency, especially in a well-insulated smart home which can retail heat for a longer time.

It should be noted that Table 2 is limited to the conceptual analysis presented in the paper. which needs further empirical data. The paper is limiting the study to a specific element of the smart system (e.g. radiator) and a case study in terms of building envelop (HSHRF). The smart house as an experimental testbed has some limitation, for instance, the building does not have a direct connection with the outdoor environment, which impacts independent variables such as temperature, precipitation, humidity etc. The experiment applied in this research is small, and not applied in a larger case study; further research is needed to assess the applicability.

Despite the limitations, this paper points out that Smart Home’ connects to a ‘Lean’ perspective from an efficiency and operations point of view. It is evident that energy-efficient devices and systems, such as smart thermostats, lighting controls, and energy monitoring systems, contribute to reducing overall energy consumption in a smart house. Thus, smart homes could be explored further as an improved approach to promote energy efficiency and a better lifestyle for the building occupants and contribute to sustainability development goals. Energy consumption is a pressing concern worldwide. Smart home through lean construction allows optimisation, streamline workflows, and maximise efficiency which supports several SDGs for instance SDG-7 Affordable and Clean Energy; SDG-11- Sustainable Cities and Communities; SDG-12 Responsible Consumption and Production and SDG 13- Climate Action. In conclusion, the deployment of smart home technologies from a lean construction point of view offers valuable insights into energy waste on a larger scale and provides guidance for future research on informed regulatory decisions toward a more sustainable built environment.

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REFERENCES

Aisyah, R. A., Gunawan, K., & Gazali, A. (2023). *Lean Construction Through Waste Register Method: A Case Studies Project in Indonesia*. 1303–1313.

Albany, M., Alsahafi, E., Alruwili, I., & Elkhediri, S. (2022). A review: Secure Internet of thing System for Smart Houses. *Procedia Computer Science*, *201*, 437–444.

Aldrich, F. K. (2003). Smart Homes: Past, Present and Future. In R. Harper (Ed.), *Inside the Smart Home* (pp. 17–39). Springer-Verlag.

Andrade, S. H. M. S., Contente, G. O., Rodrigues, L. B., Lima, L. X., Vijaykumar, N. L., & Francês, C. R. L. (2022). Smart Home Tracking: A Smart Home Architecture for Smart Energy Consumption in a Residence with Multiple Users. *Wireless Personal Communications*, *123*(4), 3241–3262.

Asadullah, M., & Raza, A. (2016). An overview of home automation systems. *2016 2nd International Conference on Robotics and Artificial Intelligence (ICRAI)*, 27–31.

Awwal, S., Tzortzopoulos, P., Kagioglou, M., & Soliman-Junior, J. (2023). *Managing User Requirements in Social Housing Upgrading*. 1072–1081.

Balta-Ozkan, N., Davidson, R., Bicket, M., & Whitmarsh, L. (2013). Social barriers to the adoption of smart homes. *Energy Policy*, *63*, 363–374.

Basarir-Ozel, B., Nasir, V. A., & Turker, H. B. (2023). Determinants of smart home adoption and differences across technology readiness segments. *Technological Forecasting and Social Change*, *197*, 122924.

Chakraborty, A., Islam, M., Shahriyar, F., Islam, S., Zaman, H. U., & Hasan, M. (2023). Smart Home System: A Comprehensive Review. *Journal of Electrical and Computer Engineering*, *2023*, 1–30.

Chauhan, R. K., Chauhan, K., & Badar, A. Q. H. (2022). Optimization of electrical energy waste in house using smart appliances management System-A case study. *Journal of Building Engineering*, *46*, 103595.

Chenari, B., Carrilho, J. D., & Silva, M. G. da. (2016). Towards sustainable, energy-efficient and healthy ventilation strategies in buildings: A review. *Renewable and Sustainable Energy Reviews*, *59*, 1426–1447.

Chien, S.-F. (2013). An Emergent Smart House. In *Communications in Computer and Information Science* (Vol. 369, p. 209).

Du, H., Han, Q., Yang, D., de Vries, B., & van Houten, T. (2023). Data privacy and smart home energy appliances: A stated choice experiment. *Heliyon*, *9*(11), e21448.

Ehsanifar, M., Dekamini, F., Spulbar, C., Birau, R., Khazaei, M., & Bărbăcioru, I. C. (2023). A Sustainable Pattern of Waste Management and Energy Efficiency in Smart Homes Using the Internet of Things (IoT). *Sustainability (Basel, Switzerland)*, *15*(6), 5081.

EPA, (2007). Lean, Energy & Climate Toolkit, Achieving Process Excellence Through Energy Efficiency and Greenhouse Gas Reduction. y Ross & Associates Environmental Consulting, Ltd. in association with Industrial Economics, Inc.

Essa, M. J. A. M. (2019). Home energy management of thermostatically controlled loads and photovoltaic-battery systems. *Energy*, *176*, 742–752.

European Commission, Directorate-General for Research and Innovation, & Joint Research Centre. (2017). *The Strategic Energy Technology (SET) Plan*. Publications Office.

Farzaneh, H., Malehmirchegini, L., Bejan, A., Afolabi, T., Mulumba, A., & Daka, P. P. (2021). Artificial Intelligence Evolution in Smart Buildings for Energy Efficiency. *Applied Sciences*, *11*(2).

Furszyfer Del Rio, D. D., Sovacool, B. K., & Griffiths, S. (2021). Culture, energy and climate sustainability, and smart home technologies: A mixed methods comparison of four countries. *Energy and Climate Change*, *2*, 100035.

Hakawati, B., Mousa, A., & Draidi, F. (2024). Smart energy management in residential buildings: The impact of knowledge and behavior. *Scientific Reports*, *14*(1), 1702.

Hossain, Md. U., & Thomas, S. N. (2019). Influence of waste materials on buildings' life cycle environmental impacts: Adopting resource recovery principle. *Resources, Conservation and Recycling*, *142*, 10–23.

Huang, J., Xing, C.-C., Shin, S. Y., Hou, F., & Hsu, C.-H. (2018). Optimizing M2M Communications and Quality of Services in the IoT for Sustainable Smart Cities. *IEEE Transactions on Sustainable Computing*, *3*(1), 4–15.

Koskela, L. (2004). Making-Do—The Eighth Category of Waste. In S. Bertelsen & C. T. Formoso (Eds.), *12th Annual Conference of the IGLC*. IGLC.net.

Koskela, L., Bølviken, T., & Rooke, J. (2013). *Which are the wastes of construction?* 905–914.

Lertlakkhanakul, J., Choi, J. W., & Kim, M. Y. (2008). Building data model and simulation platform for spatial interaction management in smart home. *Automation in Construction*, *17*(8), 948–957.

Li, Z., Li, J., Li, X., Yang, Y., Xiao, J., & Xu, B. (2020). Design of Office Intelligent Lighting System Based on Arduino. *Proceedings of the 3rd International Conference on Mechatronics and Intelligent Robotics (ICMIR-2019)*, *166*, 134–138.

Liljenström, C., Björklund, A., & Toller, S. (2022). Including maintenance in life cycle assessment of road and rail infrastructure—A literature review. *The International Journal of Life Cycle Assessment*, *27*(2), 316–341.

Lutolf, R. (1992). Smart Home concept and the integration of energy meters into a home based system. *Seventh International Conference on Metering Apparatus and Tariffs for Electricity Supply 1992*, 277–278.

Ma, Q., Tan, H., & Zhou, T. (2023). Mutual authentication scheme for smart devices in IoT-enabled smart home systems. *Computer Standards & Interfaces*, *86*, 103743.

Matsui, K. (2018). An information provision system to promote energy conservation and maintain indoor comfort in smart homes using sensed data by IoT sensors. *Future Generation Computer Systems*, *82*, 388–394.

Munirathinam, S. (2020). Chapter Six—Industry 4.0: Industrial Internet of Things (IIOT). In P. Raj & P. Evangeline (Eds.), *The Digital Twin Paradigm for Smarter Systems and Environments: The Industry Use Cases* (Vol. 117, pp. 129–164). Elsevier.

Murty, V. V. V. S. N., & Kumar, A. (2020). Optimal Energy Management and Techno-economic Analysis in Microgrid with Hybrid Renewable Energy Sources. *Journal of Modern Power Systems and Clean Energy*, *8*(5), 929–940.

Naidu, S. D. (1998). Understanding Smart Sensors: By Randy Frank. Artech House, Boston, MA, 1996, xvi + 269 pages. *Mechatronics*, *8*(3), 287–288.

Nakıp, M., Çopur, O., Biyik, E., & Güzeliş, C. (2023). Renewable energy management in smart home environment via forecast embedded scheduling based on Recurrent Trend Predictive Neural Network. *Applied Energy*, *340*, 121014.

Nezhad, A. E., Rahimnejad, A., Nardelli, P., Gadsden, S., Sahoo, S., & Ghanavati, F. (2022). A Shrinking Horizon Model Predictive Controller for Daily Scheduling of Home Energy Management Systems. *IEEE Access*, *10*, 1–1.

Nie, X., Mohamad Daud, W. S. A. W., & Pu, J. (2023). A novel transactive integration system for solar renewable energy into smart homes and landscape design: A digital twin simulation case study. *Solar Energy*, *262*, 111871.

Niu, X., Li, C., Li, X., & Zhang, Y. (2024). Impacts of workplace automation on energy poverty: The new challenge of achieving SDG 7 in the context of technological revolution. *Heliyon*, *10*(3), e25087.

Nižetić, S., Djilali, N., Papadopoulos, A., & Rodrigues, J. J. P. C. (2019). Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management. *Journal of Cleaner Production*, *231*, 565–591.

Oudat, N. A., Aljaafreh, A., Saleh, M., & Alaqtash, M. (2019). IoT-Based Home and Community Energy Management System in Jordan. In *Procedia Computer Science* (Vol. 160, p. 148).

Owais, O. A., Poshdar, M., GhaffarianHoseini, A., & Ghaffarianhoseini, A. (2023). Lean Construction Waste Reduction Through the Autonomous Vehicle Technology. *Proceedings of the 31st Annual Conference of the IIGLC (IGLC31)*, 163–173. IGLC.net.

Paul, A., Baumhögger, E., Elsner, A., Reineke, M., Hueppe, C., Stamminger, R., Hoelscher, H., Wagner, H., Gries, U., Becker, W., & Vrabec, J. (2022). Impact of aging on the energy efficiency of household refrigerating appliances.*Applied Thermal Engineering*, *205*.

Pavlou, P. A., Liang, H., & Xue, Y. (2007). Understanding and Mitigating Uncertainty in Online Exchange Relationships: A Principal-Agent Perspective. *MIS Quarterly, 31*(1), 105–136. JSTOR.

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings*, *40*(3), 394–398.

Schieweck, A., Uhde, E., Salthammer, T., Salthammer, L. C., Morawska, L., Mazaheri, M., & Kumar, P. (2018). Smart homes and the control of indoor air quality. *Renewable and Sustainable Energy Reviews*, *94*, 705–718.

Škulj, G., Sluga, A., Bračun, D., Butala, P., & Vrabič, R. (2019). Energy efficient communication based on self-organisation of IoT devices for material flow tracking. *CIRP Annals*, *68*(1), 495–498.

Sutherland, J., & Bennett, B. (2007). *The Seven Deadly Wastes of Logistics: Applying Toyota Production System Principles to Create Logistics Value*.

Tzortzopoulos, P., Kagioglou, M., & Koskela, L. (2020). *Lean construction: Core concepts and new frontiers* (1;1st;1st;). Routledge.

Vijayan, D. S., Rose, A. L., Arvindan, S., Revathy, J., & Amuthadevi, C. (2020). Automation systems in smart buildings: A review. *Journal of Ambient Intelligence and Humanized Computing*.

Wong, J. K. W., Leung, J., Skitmore, M., & Buys, L. (2017). Technical requirements of age-friendly smart home technologies in high-rise residential buildings: A system intelligence analytical approach. *Automation in Construction*, *73*, 12–19.

Wu, D., Feng, W., Li, T., & Yang, Z. (2023). Evaluating the intelligence capability of smart homes: A conceptual modeling approach. *Data & Knowledge Engineering*, *148*, 102218.

Yang, H., Lee, H., & Zo, H. (2017). User acceptance of smart home services: An extension of the theory of planned behavior. *Industrial Management & Data Systems*, *117*(1), 68–89.

Zala, K., Aliyu, A., Mishra, R., Conor, S., Conor, F., & Mian, N. (2017). An experimental study of front surface thermal performance of domestic and commercial electric heating solutions using thermography and thermocouples. *International Journal of COMADEM*.

Zhang, F., Chan, A. P. C., & Li, D. (2023). Developing smart buildings to reduce indoor risks for safety and health of the elderly: A systematic and bibliometric analysis. *Safety Science*, *168*, 106310.