Disruptive Innovators Network

Connected Home Technologies in Social Housing

In collaboration with

Bromford Flagship

Abstract

This literature review explores the potential of connected home technologies in social housing, examining their opportunities and challenges in housing management, tenant well-being, and organisational adoption.

While IoT solutions – such as environmental sensors, smart thermostats, and digital twins – offer the ability to leverage real-time data, large-scale deployment remains limited and complex. Early trials of smart home technologies suggest potential benefits in areas like maintenance efficiency, energy optimisation, and regulatory compliance (e.g., Awaab's Law), but these have yet to translate into proven, large-scale implementation across the sector.

A key challenge is that both landlords and tenants must see clear, tangible benefits before committing to full-scale adoption. However, many implementations fail to translate technical capabilities into practical, everyday improvements. Financial constraints, system compatibility issues, and misalignment with organisational processes create barriers to scaling these technologies. Tenant engagement is equally crucial – these systems must work for tenants, not just be imposed upon them. Without well-designed, transparent deployment strategies that clearly demonstrate how they improve daily life, uptake is likely to remain challenging.

For landlords, IoT presents an opportunity to improve predictive maintenance, enhance energy efficiency, and enable data-driven decision-making – but only if there is a clear financial case that justifies long-term investment. For suppliers, the social housing sector represents a growing but underdeveloped market, yet many existing solutions fail to align with real-world housing needs, particularly in terms of ensuring devices work seamlessly across different systems. A shift is needed towards integrated solutions that prioritise compatibility with both housing management systems and other IoT technologies, rather than operating as standalone products.

This review highlights critical gaps that must be addressed for IoT in social housing to progress beyond isolated trials to meaningful, effective adoption. Ensuring that lessons from existing initiatives are shared and used to overcome common barriers is key to avoiding repeated challenges and identifying best practices. Key priorities for future research include evaluating large-scale implementations, improving tenant engagement strategies, and developing practical integration frameworks that ensure connected home technologies deliver real, measurable value for both landlords and tenants.

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1. Introduction

1.1 Purpose of the Literature Review

The purpose of this literature review is to explore existing research on connected home technologies, particularly in the context of social housing. It aims to define key concepts, assess the current landscape, highlight benefits and challenges, and identify gaps in knowledge that will inform subsequent phases of the research project.

Connected home technologies are increasingly recognised as transformative tools within the social housing sector, promising significant improvements in operational efficiency, tenant well-being, and regulatory compliance (Rogage et al., 2022, Johnes et al., 2023, Kassem et al., 2019). However, the journey from small-scale pilots to wide-scale adoption remains fraught with challenges, ranging from technical interoperability to financial constraints and tenant trust issues (Adeyeye, 2024; Kassem, et al., 2019).

This review serves as a foundational step in the broader research initiative, "Exploring the Deployment and Impact of Connected Home Technologies in the Social Housing Sector"[1]. The project is led by the Disruptive Innovators Network (DIN) and informed by key sector stakeholders, including landlords, tenants, and IoT suppliers, and aims to:

1. Define what constitutes a "connected home" within the social housing context.
2. Assess the current extent of connected home technology deployments, including their benefits and challenges.
3. Capture tenant perspectives on connected home technologies to ensure equitable and user-friendly implementations.
4. Evaluate the readiness of the sector to scale these technologies, focusing on organisational, technical, and financial factors.
5. Identify gaps in the market and opportunities for innovation, particularly in affordable and scalable solutions tailored for social housing.

By synthesising existing literature, case studies, and theoretical frameworks, this document provides an evidence-based starting point for identifying actionable insights and strategic priorities. The findings will underpin the research methodology for other research methods, including stakeholder interviews, surveys, workshops and market analysis, ensuring alignment with both sector-wide goals and localised needs.

[1] To view the project brief in full, please **click here**.

1. Introduction

1.2 Research Questions

This review is guided by three core research questions:

1. **What are the current trends in connected home technologies in the social housing sector?** This question explores the types of technologies being adopted, their applications, and the extent of their integration within housing organisations.
2. **What are the benefits and challenges of deploying connected home technologies?** This includes examining advantages such as cost savings, improved tenant outcomes, and regulatory compliance, alongside barriers like technical limitations, organisational readiness, and tenant acceptance.
3. **How prepared is the sector for scaling these technologies?** This question assesses the capacity of social housing providers to expand the adoption of connected home technologies, considering financial, technical, and human resource factors.

By addressing these questions, the literature review aims to establish a robust knowledge base that will inform the next stages of the research project, from data collection to actionable recommendations.

1.3 Scope

This review focuses on connected home technologies that provide landlords with data-driven insights into property performance and condition. Examples include environmental monitoring systems, energy management tools, and safety devices designed to enhance operational efficiency, ensure compliance, and improve asset management. While the emphasis is property-centric, tenant data is inherently intertwined, as these technologies often reflect interactions with living environments. This study prioritises practical strategies for scaling such technologies within social housing portfolios while ensuring tenant experiences remain integral.

Human-centred applications, such as assistive living or medical monitoring devices, are outside this review's scope (e.g., see Akhmetzhanov et al., 2024; Agee et al., 2021; Rock et al., 2024). However, research in these domains provides useful insights into adoption barriers, user engagement strategies, and ethical considerations that can inform property-focused implementations. As the ultimate aim is to improve living conditions and tenant satisfaction through better maintenance, resource allocation, and proactive interventions, some learnings from human-centred IoT research remain relevant to this discussion.

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1. Introduction

1.4 Ethical Considerations

The adoption of connected home technologies brings significant ethical considerations, particularly around privacy, trust, and transparency. These systems inevitably collect data that may reflect tenant behaviours, raising concerns about perceived surveillance. Previous studies (e.g., He et al., 2021; Balta-Ozkan et al., 2014) highlight that a lack of clear communication about data usage can lead to tenant resistance and concerns over autonomy. To avoid eroding trust, landlords must communicate clearly about how data will be collected, used, and protected, ensuring compliance with data protection regulations such as GDPR (Adeyeye, 2024).

Tenants' engagement and trust are critical for successful implementation. Misinterpretation of data or a lack of transparency risks fostering adversarial relationships, as demonstrated in Buckingham et al. (2022), where initial enthusiasm for smart monitoring systems declined when tenants felt excluded from decision-making. Instead, co-designing solutions with tenants and maintaining clear policies can help ensure the technology serves shared interests (Agee et al., 2021; Walker et al., 2024). Research on the ethics of IoT in housing suggests that embedding principles of transparency and tenant agency can improve adoption outcomes (Johnes et al., 2023). By proactively addressing ethical concerns, landlords can mitigate risks and increase the likelihood of successful long-term implementation.

Additional ethical dimensions include:

- **Accessibility:** Tenants should easily access and understand their home's data (Adeyeye, 2024; Agee et al., 2021).
- **Inclusivity:** Smart home design must consider diverse needs, including age and digital literacy (Choi et al., 2020; Buckingham et al., 2022).
- **Accountability:** Clear mechanisms should allow tenants to challenge data use and decisions (Walker et al., 2024; Johnes et al., 2023).
- **Equity:** IoT deployments must avoid disadvantaging vulnerable tenants (Balta-Ozkan et al., 2014; He, Green & White, 2021).

To maximise benefits, ethical approaches must balance operational needs with tenant rights, fostering collaboration and ensuring technologies enhance both property management and tenant well-being.

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2. Theoretical Framework

2.1 Key Concepts

- **Connected Homes**
  We define a connected home as a residence equipped with smart technologies (IoT devices) that enable real-time data exchange for enhanced living conditions and operational insight. These systems typically include technologies such as smart thermostats, environmental sensors, or automated appliances, all interconnected via the Internet of Things (IoT) (Biljana et al., 2016; Gaur et al., 2021). The goal is to create responsive living environments that adapt to residents' needs while optimising resource use and reducing costs (Aldrich, 2020; Maswadi et al., 2020). In social housing, connected home technologies can, in theory, improve tenant well-being, support regulatory compliance, and streamline property management processes (Davila Delgado et al., 2020; He et al., 2021). Additionally, they could play a crucial role in addressing sector-wide challenges, such as fuel poverty and housing quality disparities (Johnes et al., 2023; Walker et al., 2024).
- **Internet of Things (IoT)**
  The Internet of Things (IoT) refers to a network of physical devices, sensors, and software that communicate and exchange data via the internet. This interconnected system facilitates real-time monitoring and management of home functions, such as temperature, humidity, air quality, and energy usage. For social housing providers, IoT could enable a transition from reactive ("break-fix-model") to proactive ("predict-prevent-model") management by providing data-driven insights into maintenance needs, energy efficiency, and tenant behaviours (Islam et al., 2015). Emerging IoT protocols like ZigBee and Z-Wave also enhance interoperability, addressing a key barrier to scaling these technologies across diverse housing portfolios (Maswadi et al., 2020).
- **Digital Twins**
  Digital twins are virtual replicas of physical systems or environments that are continuously updated in real time using IoT data. In housing, digital twins can simulate building performance, predict maintenance needs, and optimise resource allocation (Yossef and Aharon-Gutman, 2023). For example, a digital twin of a social housing property can model energy consumption patterns, identify inefficiencies, and recommend cost-effective upgrades. This technology is particularly valuable for retrofitting older housing stock to meet modern energy standards, such as achieving Net Zero goals (He et al., 2021). Moreover, digital twins can support large-scale asset management by integrating data from multiple properties into a centralised platform, enabling landlords to make informed decisions more efficiently.

2. Theoretical Framework

2.2 Theoretical Models

Technology Acceptance and Use

For connected home technologies to succeed, tenants must perceive clear, immediate benefits. If users do not see how these systems improve their daily lives—whether through lower energy bills, better home comfort, or faster maintenance response—they are unlikely to engage with them (Fard et al., 2021; Agee et al., 2021). Without these, even well-designed solutions may struggle to gain traction (He et al., 2021; Buckingham et al., 2022).

Building on the Technology Acceptance Model (TAM) proposed by Davis back in 1989, which emphasised the perceived usefulness and ease of use, more recent frameworks have expanded our understanding of tenant adoption. The Proposed Acceptance Model (Tetik et al., 2024; Maskeliūnas et al., 2019) integrates IoT-specific factors, while the Unified Theory of Acceptance and Use of Technology (UTAUT) (Zhou et al., 2024) considers broader social and behavioural influences. These models highlight that beyond usability, factors such as trust, perceived risk, and habit formation are critical for widespread tenant adoption (Marikyan et al., 2019; He et al., 2021; Buckingham et al., 2022):

- **Perceived Usefulness:** Tenants prioritise tangible benefits such as improved safety, comfort, and well-being. They are more likely to engage if technologies directly enhance their quality of life (Tetik et al., 2024).
- **Perceived Ease of Use and Effort Expectancy:** Tenants value simple, intuitive systems that require minimal effort to use. User-friendly interfaces, automation, and clear instructions are particularly important for tenants with limited digital literacy (Maskeliūnas et al., 2019).
- **Social Influence and Trust:** Tenant perceptions of peer experiences, community norms, and trusted voices strongly shape adoption. Early tenant engagement, co-design processes, and transparent communication about data privacy are essential to building trust and fostering acceptance (Marikyan et al., 2019).
- **Facilitating Conditions and Support:** Adoption depends on accessible training, digital support, and affordability. If tenants lack guidance or resources, they may disengage. Clear communication, financial assistance, and technical support help remove barriers to participation (Fard et al., 2021; Sepasgozar et al., 2020).

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2. Theoretical Framework

Diffusion of Innovations (Rogers, 2003)

For connected home technologies to be widely adopted, landlords must see a compelling business case. Without clear financial, operational, and/or regulatory benefits, investment will likely remain slow. Decision-makers need confidence that cost savings, maintenance efficiencies, and compliance improvements justify the upfront costs (Davila Delgado et al., 2020; He et al., 2021). Beyond financial factors, ethical and reputational considerations—such as enhancements of tenant well-being or sustainability commitments—also shape adoption decisions (Adeyeye, 2024).

Rogers' **Diffusion of Innovations** theory (2003) provides valuable insight into how connected home technologies could spread within the social housing sector. Five key characteristics influence adoption:

- **Relative Advantage**: The perceived benefits compared to existing solutions, such as lower maintenance costs, improved energy efficiency, or better tenant retention (e.g., Aldrich, 2020; Doukari et al., 2022).
- **Compatibility**: Seamless integration with existing IT systems, housing management processes, funding models and other IoT technology (platforms) ensures smoother adoption (Davila Delgado et al., 2020; He et al., 2021).
- **Complexity:** Ease of deployment and use affects adoption, particularly in large housing portfolios. Solutions requiring minimal training and disruption are preferable (Sepasgozar et al., 2020).
- **Trialability:** Opportunities for small-scale pilots help mitigate risk and provide evidence of Return-on-Investment (ROI) before large-scale implementation (Buckingham et al., 2022; Walker et al., 2024).
- **Observability:** Demonstrating tangible benefits—such as energy savings, improved air quality, or reduced repair requests—encourages wider buy-in (Johnes et al., 2023; Walker et al., 2024).

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2.3 Practical Relevance

These theoretical models provide a structured approach to understanding the adoption, implementation, and scaling of connected home technologies within social housing.

The Technology Acceptance and Use perspective incorporates multiple frameworks to explore tenant adoption behaviours. The Technology Acceptance Model (TAM) (Davis, 1989) emphasises perceived usefulness and ease of use, which are essential for tenant engagement (Maskeliūnas et al., 2019). However, more recent models, such as the Unified Theory of Acceptance and Use of Technology (UTAUT) (Zhou et al., 2024), extend this understanding by incorporating social influence, facilitating conditions, and effort expectancy (Marikyan et al., 2019; He et al., 2021). These frameworks highlight that trust, perceived risk, digital literacy, and habit formation are equally critical to widespread adoption (Buckingham et al., 2022).

The Diffusion of Innovations Theory (Rogers, 2003) provides a landlord-focused lens, identifying key drivers for organisational adoption, business case justification, and strategic integration of IoT within housing portfolios. It highlights factors such as relative advantage (cost savings, operational efficiencies), compatibility (alignment with existing systems), and observability (demonstrable benefits like energy savings and improved air quality) (Davila Delgado et al., 2020; Buckingham et al., 2022; Walker et al., 2024). These elements are critical in shaping landlord investment decisions and accelerating sector-wide adoption.

Recognising that strategic policy alignment, staff training, and financial investment are critical enablers, this research examines how housing organisations can implement systemic changes to support IoT deployment at scale (Adeyeye, 2024; Sepasgozar et al., 2020). By leveraging these insights, this study will develop actionable recommendations to address adoption barriers, enhance tenant experiences, and optimise housing operations, ultimately supporting the scaling of connected home technologies within the social housing sector.

3. Current State of Connected Homes in Social Housing

3.1 Pilot Studies and Deployments

Pilot studies in social housing have demonstrated both the potential benefits and the challenges of Pilot studies in social housing have demonstrated significant potential for connected home technologies to enhance operational efficiency, improve tenant health and well-being, and address systemic housing challenges. At the same time, these pilots highlight critical barriers to adoption, such as infrastructure, tenant engagement, and scalability.

Resident Engagement

Engaging tenants in connected home technology pilots remains a challenge but is vital for long-term success. While smart dashboards have been introduced to promote energy-saving behaviours, results have been mixed. Walker et al. (2024) found that even when tenants were given access to real-time IoT data, engagement remained low due to a lack of perceived benefit or clear guidance on how to act on the information provided. This underscores the need for transparent communication, simplified user interfaces, and proactive housing provider interventions to ensure IoT adoption is both effective and sustainable. For example:

- Low digital literacy among tenants reduced engagement with advanced tools.
- Privacy concerns were cited as a barrier to widespread adoption (Walker et al., 2024).

These findings underscore the need for transparency, accessible user interfaces, and tenant education to build trust and encourage participation.

Scalability Trials

Efforts to scale IoT technologies across entire housing estates have revealed challenges such as legacy infrastructure, integration complexities, and lack of standardisation. Yossef and Aharon-Gutman (2023) highlighted that a unified approach to technology deployment could address these barriers, but it requires significant investment and collaboration between stakeholders.

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3.2 Technology Types

1. Hardware

- Environmental Sensors: IoT-enabled environmental sensors provide real-time data on temperature, humidity, CO_2 levels, and air quality, allowing landlords to identify and mitigate issues such as damp, mould, and poor ventilation before they escalate. These systems support proactive maintenance strategies, reducing tenant health risks, particularly respiratory illnesses like asthma (Walker et al., 2024; Paterson et al., 2021). Research has demonstrated their impact in social housing: Walker et al. (2024) found that real-time monitoring in 280 homes helped housing providers identify high-risk properties and prioritise maintenance interventions. Paterson et al. (2021) highlighted the strong link between elevated VOCs, PM2.5 levels, and asthma risks, reinforcing the need for integrated air quality monitoring alongside temperature and humidity tracking. Johnes et al. (2023) further emphasised that combining IAQ sensors with behavioural interventions, such as encouraging better ventilation habits, can enhance tenant well-being and reduce long-term health risks.

Key Examples

- o **Aico:** Monitors temperature, humidity, CO_2, and fire safety, offering early warnings for damp, ventilation issues, and other hazards.
- o **Switchee:** A smart thermostat with built-in environmental sensors, enabling tenants and landlords to track home conditions while optimising heating efficiency.
- o **Presence Sensors:** Detect tenant movement patterns, helping landlords identify inactivity risks among vulnerable tenants and improve occupancy management.
- o **IoTSG:** Deploys IoT-enabled environmental sensors to monitor damp and mould risks, integrating with data analytics platforms for proactive interventions.
- o **IOpt:** Uses smart environmental sensors to collect real-time indoor air quality and humidity data, helping housing providers target preventative maintenance efforts.

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- **Energy Efficiency:** Smart home technologies, such as smart thermostats, energy management systems (EMSs), and AI-driven automation tools, have been piloted to optimise heating, reduce energy consumption, and address fuel poverty. These systems leverage real-time data analytics and machine learning algorithms to reduce waste and improve efficiency, ensuring that heating and energy use align with actual tenant needs (Sepasgozar et al., 2020). Research suggests that AI-enhanced EMSs can reduce energy consumption by 10–38% through automated optimisation and demand-response strategies. However, successful implementation depends on user engagement, as some tenants—particularly older or digitally excluded groups—may find these systems intrusive or difficult to use.

  Key Examples

  - **Octopus Energy Smart Meters:** Provide real-time energy tracking and variable pricing, enabling tenants to better manage costs and consumption.
  - **Beanbag:** Monitors building fabric performance, detecting heat loss, damp, and mould risks, supporting targeted retrofits to enhance energy efficiency.
  - **Switchee:** Uses learning algorithms to optimise heating schedules, reducing energy waste while ensuring tenant comfort.
  - **IOpt:** Deploys real-time energy monitoring to assess property-level inefficiencies and provide data-driven recommendations for landlords.

- **Health and Well-being Support:** Ambient monitoring systems have been trialled to enhance tenant health and safety, particularly for vulnerable groups such as the elderly, those with mobility impairments, or tenants with pre-existing health conditions (Akhmetzhanov et al., 2024). These technologies allow landlords and care providers to detect potential risks early, enabling proactive interventions that support independent living and improve overall well-being.

Key Examples

  - **CareTech Telecare Systems:** Support daily activity monitoring and remote assistance, ensuring timely interventions for tenants who may need additional care.

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- Cognitive IoT Applications and related items:
    - **Cognitive IoT Applications:** AI-powered solutions that adapt to tenant needs, optimising indoor conditions for individuals with respiratory conditions or early signs of illness (Maskeliūnas et al., 2019). Maswadi et al. (2020) highlight automated medication reminders and physiological tracking features that can prevent health complications.
    - **Fall Detection Sensors:** Lightweight, non-intrusive sensors that detect physical activity patterns and alert caregivers in the event of a fall, ensuring rapid emergency response (Maskeliūnas et al., 2019).
    - **Air Quality Monitoring:** Johnes et al. (2023) found that IAQ sensors play a critical role in mitigating respiratory health risks, especially when combined with behavioural interventions, such as encouraging proper ventilation practices.
- **Security and Access Control:** Smart security systems provide enhanced safety and accessibility for tenants, reducing unauthorised access risks and improving building security. These technologies are particularly valuable in high-density social housing, where traditional security measures may be insufficient.

  Key Examples
    - **Intratone:** Provides contactless smart door entry systems, improving security and accessibility for tenants.
    - **Ring:** Video doorbells and motion-activated security cameras allow remote monitoring and provide alerts for suspicious activity.
- **Water Leak Detection & Property Protection:** Water leak detection technologies help prevent property damage, reduce maintenance costs, and improve tenant safety by identifying leaks before they escalate into serious issues.

  Key Examples
    - **LeakBot:** Monitors water flow anomalies, detecting leaks early to prevent costly damage.
    - **Guardian:** Combines remote water shut-off capabilities with leak detection, offering comprehensive property protection.
- **Pest and Waste Management:**
    - **SMART Pest Control:** Automated IoT traps monitor and manage pest infestations.
    - **Bigbelly Bins:** Fill-level sensors optimise waste collection schedules, reducing costs and environmental impact.

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- **Smart Lighting and HVAC:**
  - **Philips Hue:** Adjusts lighting based on occupancy or natural daylight, improving energy efficiency.
  - **Nest Thermostat:** Learns occupant behaviour to automate heating and cooling, optimising comfort and energy use.
- **Integrated Systems & Smart Connectivity:** While some connected home solutions aim to integrate multiple functionalities, true interoperability remains rare. Most systems operate in silos, making data sharing and cross-platform functionality difficult. Challenges include incompatibility between devices, lack of standardisation, and difficulties retrofitting older properties.

Key Examples

  - **ZigBee & Z-Wave:** Enable device interoperability, yet adoption varies across vendors.

2. Software

Software plays a crucial role in harnessing the full potential of IoT technologies in social housing, enabling data-driven decision-making, automation, and predictive maintenance. These solutions include data platforms, automation tools, predictive analytics, and AI-driven applications, each contributing to operational efficiency, energy optimisation, and proactive housing management.

- **Data Platforms & Cloud-Based Analytics:** Cloud-based platforms store, process, and visualise data collected from IoT devices, providing landlords with actionable insights to improve property management. These platforms aggregate data from multiple sources, allowing for better trend analysis, maintenance forecasting, and energy efficiency monitoring. Examples include the Microsoft Azure IoT Hub or Vericon Portals.
- **Automation & Smart Control Systems:** Automation tools enhance efficiency by responding to environmental conditions in real time, reducing manual intervention while improving tenant comfort. These systems integrate with heating, ventilation, and lighting to adjust settings automatically based on occupancy and environmental triggers.
- **Housing Management Integrations:** Automated controls optimise ventilation and heating based on real-time humidity, CO_2, and temperature data, ensuring energy savings and improved indoor air quality.

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- **Predictive Analytics & AI-Driven Insights:** AI-driven predictive analytics leverage historical and real-time data to forecast maintenance needs, optimise energy use, and enhance risk management. These systems help housing providers prioritise interventions, reducing reactive repairs and associated costs.
- **User Interfaces & Dashboards:** Accessible web and mobile dashboards present IoT data in an intuitive format, allowing both landlords and tenants to monitor energy usage, indoor air quality, and maintenance needs in real time. These interfaces are essential for tenant engagement, ensuring users can see and act upon the data their homes generate.

3.3 Case Study: Smartline

A notable case study worth highlighting is the Smartline project, led by the University of Exeter in collaboration with Coastline Housing and Cornwall Council. It investigated how connected home technologies could improve health, wellbeing, and housing quality in rural social housing communities (Buckingham et al., 2022; Johnes et al., 2023). Funded by the European Regional Development Fund, the initiative ran from 2017 to 2022 and deployed IoT-enabled sensors across 279 households to explore the technological and social dimensions of connected homes (Menneer et al., 2023). While the project highlighted the transformative potential of data-driven solutions, it ended with the conclusion of its funding.

IoT sensors were employed to monitor indoor air quality, temperature, and humidity, addressing issues such as damp, mould, and energy inefficiency (Johnes et al., 2023; Menneer et al., 2022). The project also explored how digital tools could enhance tenant health and social connectedness, particularly in rural settings (Buckingham et al., 2022; Long et al., 2022). Advanced sampling strategies optimised sensor placement, improving resource efficiency and deployment scalability (Menneer et al., 2023).

Key findings demonstrated strong links between relative humidity, temperature, and mould growth, enabling more targeted interventions (Menneer et al., 2022). Homes with inadequate heating commonly experienced poor air quality and damp, reinforcing the need for retrofitting to improve living conditions (Johnes et al., 2023). Barriers such as low digital literacy and limited broadband access, particularly among older tenants, reduced engagement with the technologies (Buckingham et al., 2022). However, tenants with stronger social networks reported higher levels of well-being, and many appreciated the transparency and responsiveness enabled by IoT solutions (Long et al., 2022). Privacy concerns and initial skepticism about data use underscored the importance of trust-building and clear communication (Buckingham et al., 2022).

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Despite these successes, the project faced challenges. Aligning IoT technologies with legacy housing systems required significant adaptation (Johnes et al., 2023), and limited internet access in rural areas highlighted the need for infrastructure improvements to ensure equitable benefits (Buckingham et al., 2022). Additionally, cluster analysis methods proved effective in improving sensor placement efficiency and data reliability (Menneer et al., 2023).

Smartline demonstrates the transformative potential of connected home technologies in social housing. Key lessons include:

- Sensor data can enable predictive maintenance, improved energy efficiency, and targeted interventions.
- Tenant engagement in the design and deployment phases is crucial for trust-building and relevance.
- Advanced sampling strategies enhance the scalability and effectiveness of IoT deployments.

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4. Benefits of Connected Homes

Connected home technologies present numerous potential benefits for both landlords and tenants within the social housing sector. The prospective advantages span tenant well-being, operational efficiency, regulatory compliance, and long-term sustainability goals.

4.1 Improved Tenant Well-Being

Connected homes offer solutions that directly enhance the quality of life for tenants. For example:

- **Monitoring:** Devices such as Aico environmental sensors and Vericon's Surveyor Cube monitor humidity and air quality, enabling early detection and prevention of damp and mould. Research highlights that early interventions can reduce respiratory health risks and associated healthcare costs (Balta-Ozkan et al., 2014). Walker et al. (2024) observed that consistent environmental monitoring significantly improved indoor air quality in social housing. Additionally, Johnes et al. (2023) emphasise that tenant behaviours, such as ventilation habits, can significantly influence air quality outcomes, underscoring the importance of combining monitoring technologies with tenant education and engagement strategies.
- **Energy Efficiency:** Smart thermostats and energy management systems help tenants optimise heating schedules, reducing energy consumption and mitigating fuel poverty. Research shows that households using these systems experience improved thermal comfort and lower energy costs (Gaur et al., 2021). Studies indicate that smart energy systems can cut energy usage by 15–20%, benefiting both tenants and landlords (Balta-Ozkan et al., 2014; Aldrich, 2020). Additionally, automated systems requiring minimal tenant interaction have proven particularly effective for older residents, ensuring consistent comfort without manual adjustments (Choi et al., 2020).
- **Safety:** IoT-enabled safety systems, such as interconnected smoke detectors, provide real-time alerts and enable remote monitoring. These systems enhance tenant safety by notifying both residents and housing providers of potential hazards, facilitating quicker responses (He et al., 2021). Additionally, integrated systems that combine fire alarms with CO2 and smoke detection offer more comprehensive safety coverage (Yossef & Aharon-Gutman, 2023).
- **Health and Well-being Support**: Ambient monitoring systems detect risks like prolonged inactivity or sudden temperature drops, triggering welfare checks for vulnerable tenants. Choi et al. (2020) emphasise the importance of these systems for older adults or tenants with chronic conditions. Maskeliūnas et al. (2019) note that non-intrusive sensors and adaptive IoT technologies significantly enhance tenant health outcomes while reducing healthcare costs. Transparent communication about these systems' benefits, as suggested by Buckingham et al. (2022), fosters trust and encourages tenant engagement in health-focused initiatives.

4. Benefits of Connected Homes

4.2 Cost Savings for Landlords

The integration of IoT solutions into housing management systems has been shown to have the potential to reduce operational costs:

- **Predictive Maintenance:** IoT devices, such as smart sensors and boiler monitoring systems, enable real-time asset tracking, allowing landlords to detect issues before they escalate into costly repairs. Vericon's boiler monitoring systems help identify inefficiencies early, reducing emergency call-outs and unplanned maintenance costs. Research shows that predictive maintenance can lower repair expenses by up to 30% and extend asset lifespan (Doukari et al., 2022). AI integration enhances these capabilities by analysing large datasets to identify failure patterns and predict component wear, while environmental sensors improve alert accuracy and repair prioritisation (Sepasgozar et al., 2020). Walker et al. (2024) emphasised the need for integrated IoT platforms that combine maintenance alerts with historical performance data, while scalable, interoperable systems are essential for seamless integration with housing management strategies.
- **Reduced Energy Consumption:** IoT-enabled smart meters and thermostats provide landlords with detailed insights into energy consumption patterns, enabling energy-saving measures across property portfolios. Sepasgozar et al. (2020) highlight that integrating AI with IoT devices further enhances these systems by enabling real-time optimisation and predictive adjustments, assuming even greater energy efficiency between 10-38%. Smart thermostats, such as those studied by Choi et al. (2020), effectively reduce energy waste by automatically adjusting settings based on occupancy and temperature preferences. Additionally, systems like Switchee optimise heating schedules and flag under-heated properties, supporting compliance with fuel poverty reduction initiatives (Gaur et al., 2021).
- **Operational Efficiency Gains:** Integrated IoT solutions that aggregate data from multiple sources allow housing providers to allocate maintenance resources more effectively, streamlining operations. Rogage et al. (2022) highlighted that automated data-driven workflows reduced manual inspections and freed up operational teams to focus on critical tasks. The use of digital twins, which create real-time simulations of property performance, can further enhance planning for retrofits and maintenance (He et al., 2021). Walker et al. (2024) found that real-time environmental monitoring in social housing enabled housing providers to identify at-risk homes, supporting more proactive maintenance planning. However, their findings also suggest that while IoT data provides valuable insights, its effectiveness depends on how well housing providers integrate it into decision-making processes.

4. Benefits of Connected Homes

4.3 Regulatory Compliance

With increasing regulatory pressure to improve energy efficiency, reduce carbon emissions, and maintain safe living environments, connected home technologies offer prospectively transformative tools to support compliance efforts.

- **Energy Performance Targets:** IoT technologies such as smart sensors and digital twins enable real-time monitoring of energy performance, providing actionable insights to support compliance with regulations like Minimum Energy Efficiency Standards (MEES) and improve Energy Performance Certificate (EPC) ratings (Islam et al., 2015). Digital twins are particularly effective in simulating retrofitting scenarios, helping landlords identify cost-effective energy-saving upgrades tailored to individual properties (Menneer et al., 2023). These tools facilitate compliance with net-zero targets by optimising energy efficiency measures across housing portfolios. Rogage et al. (2019) underscore that IoT-enabled platforms aggregate data from multiple sensors to pinpoint inefficiencies, enabling housing providers to strategically plan retrofitting efforts, reduce carbon emissions, and meet broader sustainability goals.
- **Air Quality Standards:** Ensuring safe and healthy indoor environments is a key priority in social housing, with increasing emphasis on environmental monitoring and regulatory compliance. The introduction of Awaab's Law has heightened the urgency of addressing damp and mould, requiring landlords to take timely action (Housing Ombudsman, 2023). However, beyond moisture control, indoor air quality, ventilation, and temperature regulation also play crucial roles in tenant health. IoT monitoring systems enable real-time tracking of humidity, temperature, and air pollutants, allowing early intervention (Walker et al., 2024). Paterson et al. (2021) highlight that elevated VOCs and PM2.5 contribute to respiratory risks, reinforcing the need to monitor air pollutants alongside damp and humidity levels. Additionally, Johnes et al. (2023) stress that ventilation patterns and tenant behaviours significantly impact air quality, suggesting compliance strategies should integrate both environmental monitoring and behavioural insights. IoT systems support compliance by automating alerts, generating actionable insights, and improving transparency, helping landlords meet regulatory obligations (Yossef and Aharon-Gutman, 2023).

4. Benefits of Connected Homes

- **Fire Safety:** The integration of smart fire safety systems, such as interconnected smoke alarms and CO detectors, is instrumental in meeting fire safety standards. These systems offer features like remote monitoring, instant alerts, and system-wide diagnostics, enabling landlords to manage compliance across their property portfolios more efficiently (He et al., 2021). Combining fire safety data with centralised housing management platforms ensures real-time compliance monitoring and streamlines reporting for audits and inspections. This is particularly valuable for larger housing providers managing extensive portfolios. Zaidan and Zaidan (2020) emphasise the role of multi-layered IoT systems in enhancing the resilience and reliability of safety monitoring, particularly in mitigating risks from episodic device failures or network disruptions.
- **Water Compliance and Legionella Management:** Compliance with water safety regulations, particularly around Legionella prevention, is another area where IoT technologies are increasingly valuable. Smart water monitoring systems, such as Plexus Innovation's Guardian IoT-enabled sensors, provide real-time tracking of water temperatures and flow, ensuring compliance with water hygiene standards. Automated alerts can signal deviations from safe thresholds, prompting timely interventions and reducing risks associated with Legionella outbreaks (Rogage et al., 2019). These systems also allow housing providers to demonstrate proactive compliance during audits. IoT can simplify the management of water systems in large portfolios by aggregating data into centralised dashboards, providing housing providers with a comprehensive view of compliance status across all properties.

4.4 Enhanced Data-Driven Decision Making

Connected home technologies empower housing providers to leverage real-time data for informed and strategic decision-making. These solutions support improved resource allocation, targeted interventions, and enhanced tenant experiences.

1. **Actionable Insights**

- IoT platforms such as Microsoft Azure IoT Hub and Vericon Systems aggregate data from multiple devices into centralised dashboards, providing real-time analytics to monitor building performance and prioritise interventions (Walker et al., 2024). These systems use predictive analytics to anticipate maintenance needs, shifting operations from reactive to proactive management.

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4. Benefits of Connected Homes

- Yossef and Aharon-Gutman (2023) highlight the ability of such platforms to visualise trends and inefficiencies, enabling landlords to allocate resources more efficiently and reduce operational costs. Tools that integrate with Building Information Modelling (BIM) further enhance data utility by linking IoT insights to lifecycle asset management, streamlining long-term planning (Rogage et al., 2019).
- Advanced IoT solutions can also monitor energy consumption patterns, detect inefficiencies, and provide recommendations for retrofitting, aligning with sustainability goals while improving operational effectiveness (Zaidan and Zaidan, 2020).
- Rogage et al. (2022) demonstrate how AI-driven automation enhances real-time monitoring and decision-making in large infrastructure projects. Applying similar AI-powered IoT data pipelines to social housing could provide near-instant visibility into asset performance, allowing for faster, data-driven interventions. Automated dashboards could support housing officers in monitoring real-time changes in environmental conditions, occupancy patterns, and potential risks (e.g., damp and mould) across multiple properties.
- Hnat et al. (2011) emphasise that the quality and placement of sensors significantly influence the reliability of actionable insights. Improper deployment can result in incomplete data or biases that compromise decision-making. Strategic placement methodologies, such as clustering or tenant-specific configurations, can optimise data accuracy.

2. Customised Tenant Support

- Connected home technologies enable housing providers to offer tailored support by tracking environmental and behavioural data, such as temperature irregularities, prolonged inactivity, or excessive humidity (Choi et al., 2020). These insights allow landlords to proactively identify vulnerable tenants and address potential risks, such as inadequate heating or poor air quality (Johnes et al., 2023). For instance, welfare checks can be automated through notifications triggered by anomalous patterns, improving tenant well-being and fostering trust.
- Aggregate data can also inform broader community-level strategies, helping housing providers identify common challenges, such as damp and mould, and design targeted interventions that improve overall living conditions (Islam et al., 2015). However, ensuring tenant acceptance requires robust data governance frameworks. Transparency around data collection, usage, and storage is essential to mitigate concerns about surveillance and misuse. Walker et al. (2024) emphasise that ethical data practices, including anonymisation and secure sharing, are critical to maintaining trust and compliance with regulations like GDPR.

4. Benefits of Connected Homes

- Hnat et al. (2011) note that episodic failures—caused by environmental disruptions or device malfunctions—can compromise tenant-specific insights. They recommend redundancy in data collection and automated failure detection systems to ensure continuous and reliable monitoring.

3. Operational Efficiency

- The integration of IoT data into real-time management platforms allows housing providers to optimise workflows and improve efficiency. Predictive maintenance alerts generated by systems like Vericon or Switchee enable proactive interventions that reduce emergency repairs and associated costs (Walker et al., 2024).

4. Long-Term Planning

- Digital twins and historical data analysis allow landlords to simulate property performance under different scenarios, facilitating strategic planning for retrofits and upgrades. Hnat et al. (2011) underscore the role of robust data pipelines in supporting these models, ensuring that housing providers can confidently rely on projections and simulations.
- In infrastructure projects, Digital Twin applications have demonstrated their value in enhancing real-time monitoring and predictive insights (Rogage et al., 2022). While the social housing sector has yet to fully implement Digital Twin technology, integrating IoT-based real-time data with predictive AI models could allow housing providers to simulate property performance over time, forecast repair needs, and optimise long-term investment strategies. Greenwood et al. (2017) highlight how BIM-based lifecycle planning improves asset management by standardising asset data and enhancing predictive maintenance. Applying similar principles in social housing could strengthen long-term retrofit strategies.

5. Overcoming Data Gaps

- IoT deployments in social housing can face data completeness issues, particularly in cases of sensor damage, removal, or poor connectivity. Hnat et al. (2011) stress the importance of implementing automated health checks and adaptive systems that flag anomalies or gaps in data collection. These mechanisms enable landlords to address issues promptly, maintaining the integrity of their data-driven decision-making processes.

6. Future Opportunities

- Integrating IoT data with artificial intelligence (AI) capabilities offers opportunities for even greater precision and efficiency. For example, machine learning algorithms can analyse historical data to refine predictive models, further reducing maintenance costs and improving service delivery (Stojkoska and Trivodaliev, 2017). Tenant-facing tools, such as mobile apps or dashboards, can empower residents by providing insights into their energy use or environmental conditions, fostering greater tenant engagement and shared responsibility for sustainability efforts.

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5. Challenges and Barriers

While the benefits of connected home technologies in social housing are promising, significant challenges and barriers hinder their widespread adoption and effective implementation. These challenges span technical, organisational, and tenant-related dimensions, each of which requires targeted strategies to overcome.

1. **Interoperability Issues**

- One of the most persistent technical barriers in IoT adoption is the lack of interoperability between devices from different manufacturers. Proprietary protocols often hinder seamless integration, leading to inefficiencies and increased costs for housing providers (Fard et al., 2021).
- Rogage et al. (2019) emphasise that inconsistent data standards result in data silos, which limit cross-platform insights and prevent housing associations from obtaining a holistic view of their assets. Implementing common data environments (CDEs) can facilitate seamless data exchange and system interoperability, enabling actionable insights from collected data.
- Stojkoska and Trivodaliev (2017) advocate for the adoption of open-source frameworks and universal communication protocols, which could address the fragmentation at both device and platform levels. Such standardisation would significantly enhance the scalability and interoperability of IoT deployments. Similarly, Zaidan and Zaidan (2020) suggest that collaborative industry-wide efforts to establish common standards are essential for avoiding vendor lock-in.

2. **Connectivity Limitations**

- Reliable connectivity is foundational for real-time IoT functionality, yet many rural areas and older housing estates suffer from inadequate internet infrastructure, resulting in delayed interventions and gaps in data transmission (He et al., 2021).
- Hybrid connectivity solutions, such as local hubs or mesh networks, can mitigate these challenges. Local hubs temporarily store data during outages, while mesh networks strengthen signal coverage in large housing estates (Rogage, 2020).
- Zaidan and Zaidan (2020) propose hierarchical control mechanisms, where local nodes (e.g., sensors or hubs) manage and store data temporarily during disruptions, and higher-level nodes coordinate the overall data flow. This layered structure ensures redundancy and reduces the risk of data loss in areas with inconsistent connectivity.

5. Challenges and Barriers

- Additionally, Stojkoska and Trivodaliev (2017) recommend employing adaptive communication protocols that dynamically adjust to varying network conditions in real-time, enhancing overall system resilience.
- Beyond infrastructure, Menneer et al. (2023) underscore the importance of designing robust network solutions to address common disruptions, such as unplugged devices, removed batteries, and weak signal coverage, which further jeopardise data reliability.

3. Deployment and Physical Challenges

- Strategic sensor deployment is critical to ensuring that data collected is representative, reliable, and actionable. Menneer et al. (2023) demonstrated the value of cluster analysis for optimising sensor placement, which enhances resource efficiency and scalability. Poor planning risks creating gaps in data collection, leading to under-representation of property types or tenant demographics.
- IoT devices often face risks such as tampering, removal, or damage, particularly when residents view them as intrusive or unnecessary (Johnes et al., 2023). Initiatives like rugged device designs and tenant education can mitigate these risks.
- Tenant dissatisfaction with the aesthetic appearance of IoT devices, often described as unattractive "plastic boxes," can reduce engagement and acceptance over the long term (Buckingham et al., 2022). Collaborative efforts with manufacturers to design aesthetically pleasing devices can help address these concerns.
- Zaidan and Zaidan (2020) suggest prototyping and iterative design processes that involve tenant feedback, ensuring that devices meet both functional and aesthetic requirements. This participatory approach not only improves device design but also fosters trust and acceptance among tenants.

4. Data Security and Privacy Concerns

- IoT systems inherently collect and transmit sensitive tenant data, such as environmental conditions and energy usage patterns. Without adequate protection, these systems are vulnerable to cyberattacks, potentially compromising data integrity and tenant trust (Balta-Ozkan et al., 2014).
- Zaidan and Zaidan (2020) recommend multi-layered cybersecurity protocols, including robust encryption, secure authentication mechanisms, and regular system audits. These measures safeguard data while ensuring compliance with evolving cybersecurity standards.

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- Real-time monitoring systems, as suggested by Stojkoska and Trivodaliev (2017), can proactively detect and neutralise potential security threats, thereby mitigating risks before they escalate.
- Compliance with regulations such as GDPR adds another layer of complexity, particularly when involving third-party vendors. Clear governance frameworks defining data ownership, access rights, and privacy-preserving techniques—such as anonymisation and secure sharing practices—are critical for maintaining tenant trust and ensuring accountability (Rogage, 2020).

5.2 Organisational Barriers

1. Skills Gaps

- **Specialised Expertise:** Effective deployment and management of connected home technologies require specialised skills in IoT architecture, data analytics, and system integration, areas where social housing providers can lack in-house expertise (He et al., 2021). This reliance on external vendors can increase costs and delay adoption.
- **Building Internal Capacity:** Rogage (2021) highlights the value of interdisciplinary training programmes that integrate technical and housing management skills to build data literacy across teams. Partnerships with technology providers and targeted training for existing staff can partially address this gap, though these initiatives require upfront investment. Sepasgozar et al. (2020) further suggest that organisations foster collaboration between IT and housing teams to ensure smooth integration and management of IoT systems.
- **Tenant Collaboration:** Engaging tenants in the design and deployment of IoT systems is crucial to addressing usability concerns and fostering adoption. Marikyan et al. (2019) emphasise that tenant co-design initiatives help bridge gaps in understanding, ensuring solutions are practical and meet tenant needs.

2. Resistance to Change

- **Cultural Barriers:** The introduction of connected home technologies often disrupts established workflows, creating resistance among staff accustomed to traditional methods (Rogers, 2003). Organisational inertia is particularly pronounced when IoT solutions, such as predictive maintenance, require a shift from reactive to proactive management strategies.
- **Change Management:** Clear communication of benefits and tailored change management initiatives are essential to overcoming resistance. Marikyan et al. (2019) emphasise that involving staff early in the decision-making process and providing ongoing support during implementation builds trust and reduces pushback.

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5. Challenges and Barriers

- **Ethical and Data Concerns:** Staff resistance may also stem from ethical concerns about data collection, ownership, and usage. Marikyan et al. (2019) suggest that developing transparent policies and governance structures to address these issues is essential to building organisational confidence in IoT solutions.

3. **Financial Constraints**

- **High Upfront Costs:** The expenses for IoT devices, installation, and subscriptions are significant barriers, particularly for smaller housing associations (Fard et al., 2021). Tenants may also perceive these technologies as expensive luxuries, which can reduce acceptance (Marikyan et al., 2019).
- **Balancing Costs with Benefits:** Long-term savings must be demonstrated through clear cost-benefit analyses to justify investments (Sepasgozar et al., 2020).
- **Grant Funding and Sustainability:** While grants and incentives help offset upfront costs, sustained adoption requires strategic financial planning. Leveraging pilot results to secure further funding or partnerships can support long-term goals (Marikyan et al., 2019).
- **Scalability and Value:** Investing in scalable, interoperable systems reduces duplication and ensures long-term compatibility, offering better value for housing associations (Walker et al., 2024).

4. **Time Constraints and Competing Priorities**

- Social housing providers often face competing demands, such as compliance with regulations like Awaab's Law or addressing immediate tenant needs (Rogage et al., 2021, Housing Ombudsman 2023). These priorities can deprioritise IoT adoption, particularly when staff are stretched across multiple responsibilities. A phased implementation approach with realistic timelines can help balance these competing demands.

5. **Cybersecurity Preparedness**

- Organisations may lack adequate cybersecurity frameworks to protect against breaches, a risk that undermines tenant trust and creates reputational damage (Marikyan et al., 2019). Ensuring robust data security protocols, staff training, and ongoing system monitoring are critical organisational responsibilities that affect both adoption and compliance with regulations.

5. Challenges and Barriers

5.3 Tenant Concerns

1. **Privacy and Trust Issues**

- **Surveillance and Data Misuse Concerns:** Tenants can express concerns about surveillance and potential misuse of personal data in connected home technologies. A lack of transparency around data usage, access, and control can erode trust, discouraging engagement and adoption (Balta-Ozkan et al., 2014; Sepasgozar et al., 2020). Marikyan et al. (2019) highlight that tenants may perceive these technologies as intrusive, particularly when tangible benefits for them are unclear. Walker et al. (2024) reinforce this, finding that even when tenants were given real-time IoT data through co-designed dashboards, engagement remained low due to a lack of perceived value. Without clear communication on how IoT improves their living conditions, tenants may feel monitored rather than empowered, heightening privacy concerns. Similarly, Buckingham et al. (2022) found that social housing tenants were wary of digital surveillance, particularly when they lacked control over how data was used, further supporting the need for transparent communication and tenant engagement in IoT rollouts. Maskeliūnas et al. (2019) further stress that willingness to adopt IoT depends on tenants understanding how these systems meet their specific needs, making transparent communication and trust-building essential.
- **Transparent Communication:** Early engagement with tenants is critical. Providing clear, accessible information about data handling policies—such as anonymisation, encryption, and sharing practices—can alleviate privacy concerns and encourage trust (Rogage et al., 2020). Co-design processes that actively involve tenants in shaping data privacy measures, as suggested by Sepasgozar et al. (2020), help foster ownership and trust. Additionally, Maskeliūnas et al. (2019) highlight that building trust requires not just transparency but also a focus on empowerment—ensuring tenants understand their control over IoT data and how it is used. Long et al. (2022) underscore that peer networks and a sense of community can foster trust in IoT systems. When tenants see their neighbours engaging positively with connected technologies, their own willingness to adopt increases.

5. Challenges and Barriers

- **Privacy-Enhancing Technologies:** Advanced techniques, such as differential privacy and federated learning, enable robust analytics while minimising privacy risks (Stojkoska and Trivodaliev, 2017). Embedding these technologies into IoT systems ensures compliance with privacy standards and reduces data exposure, as recommended by Sepasgozar et al. (2020). Marikyan et al. (2019) also stress the need for systems to align with ethical frameworks, further reducing tenant mistrust. Maskeliūnas et al. (2019) add that user-centric designs that prioritise simplicity and clear feedback mechanisms for data usage further support tenant acceptance and trust.
- **Mitigating AI-Related Privacy Risks:** AI systems integrated with IoT devices amplify privacy concerns due to the large volumes of personal data required for machine learning. Sepasgozar et al. (2020) recommend designing AI algorithms to prioritise edge processing, where data analysis occurs locally on devices rather than being transmitted to centralised servers. This approach aligns with tenant preferences for control over their data, a critical factor identified by Marikyan et al. (2019). Maskeliūnas et al. (2019) further suggest that AI-driven systems include adjustable privacy settings, enabling tenants to choose the level of data sharing they are comfortable with, fostering greater autonomy and trust.

2. Accessibility and Ease of Use

- **Design for Inclusivity:** Smart home systems must prioritise intuitive interfaces and accessibility features. Rogage et al. (2019) and Maskeliūnas et al. (2019) advocate for designing systems that cater to diverse tenant needs, from simplified controls to robust accessibility options. Maswadi et al. (2020) highlight the importance of training and ongoing support especially tailored to the needs of older and less tech-savvy tenants.
- **Comprehensive Support:** Providing multiple layers of support can significantly improve tenant confidence and engagement. Effective measures include:
  - Tailored Training: Offering workshops, onboarding sessions, and easy-to-understand training materials helps empower tenants with diverse digital competencies (Rogage et al., 2019).
  - Multi-Channel Assistance: Combining phone helplines, in-home support, and online resources ensures tenants have accessible avenues for resolving technical issues.
  - Cultural and Linguistic Adaptations: Translating guides into multiple languages and considering cultural contexts can remove barriers for tenants in multicultural communities (Rogage, 2021).
  - Community-Level Support: Long et al. (2022) highlight the role of peer networks and communal resources in bridging digital literacy gaps. Encouraging tenants to share experiences and support each other in adopting new technologies can foster greater confidence and sustained engagement.

5. Challenges and Barriers

- Community-Level Support: Long et al. (2022) highlight the role of peer networks and communal resources in bridging digital literacy gaps. Encouraging tenants to share experiences and support each other in adopting new technologies can foster greater confidence and sustained engagement.

- **Simplified Functionality:** Automation features, voice assistance, and preset controls can minimise cognitive load and improve usability for tenants with limited technical experience (Maskeliūnas et al., 2019). Marikyan et al. (2019) further emphasise the importance of balancing simplicity with functionality to ensure widespread adoption.

- **Challenges for Vulnerable Groups:** Limited digital literacy and usability concerns can hinder tenant engagement with IoT devices, particularly among older adults and vulnerable populations (Fard et al., 2021). Poor user experiences often lead to abandonment of technologies perceived as complex or unintuitive. Akhmetzhanov et al. (2024) stress that accessible, intuitive design is crucial to minimising training needs, while Buckingham et al. (2022) highlight that many social housing tenants lack confidence with digital tools, reinforcing the need for clear, hands-on support to ensure IoT adoption is practical and inclusive.

3. Physical Presence

The physical presence of IoT devices in tenants' homes introduces unique challenges that can influence long-term deployment and acceptance. These devices are not purely functional additions; their physical and visual impact can significantly shape tenant perceptions and engagement.

- **Tenant Buy-In:** Tenant acceptance depends on understanding how IoT improves their living conditions. Transparent communication about benefits—such as reduced damp, lower energy bills, and improved well-being—builds trust and engagement. Marikyan et al. (2019) highlight the importance of demonstrating immediate, relatable benefits to counter resistance, while Long et al. (2022) note that social cohesion improves adoption, as tenants are more likely to engage when they see peers benefiting. Meneer et al. (2022) add that real-time humidity and temperature monitoring can enhance engagement by making mould risk visible, encouraging proactive behaviours like adjusting ventilation or heating. Buckingham et al. (2022) reinforce this by demonstrating that digital literacy and trust are key factors influencing adoption, and that providing tenants with user-friendly, real-time insights can improve acceptance and engagement. Simple, accessible dashboards showing real-time risk levels can help drive adoption and long-term tenant participation.

5. Challenges and Barriers

- **Tampering and Damage Risks:** IoT devices may be at risk of being tampered with, removed, or damaged, either accidentally or intentionally, particularly in situations where residents feel the devices are intrusive or unnecessary (Johnes et al., 2023). Hnat et al. (2011) further highlight that children, pets, and routine household activities like cleaning can lead to unintentional sensor dislodgement or damage.
- **Operational Failures:** Poor sensor placement and environmental fluctuations can lead to inaccurate readings, limiting their reliability (Meneer et al., 2023). Their study found that mould risk models relying on high humidity thresholds (e.g., 80%) often underestimate actual hazards, as mould can develop at lower humidity levels in real-world housing conditions. This highlights the need for better calibration of IoT sensors and redundancy in monitoring systems to ensure reliable data collection.
- **Aesthetic and Spatial Concerns:** Many tenants express dissatisfaction with the visual impact of devices, often describing them as intrusive "plastic boxes" that clash with their home environments. These concerns can reduce tenant satisfaction and willingness to accept long-term deployment (Buckingham et al., 2022). Hnat et al. (2011) also suggest redundancy in sensing systems and automated failure detection to mitigate these challenges.
- **Iterative Design with Tenant Input:** Involving tenants in the design process ensures that devices meet both functional and aesthetic needs (Zaidan and Zaidan, 2020). Marikyan et al. (2019) note that co-design approaches improve trust, satisfaction, and the likelihood of long-term adoption.

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6. Market Landscape

6.1 Market Gaps

Despite the growing market for connected home technologies, several challenges remain, particularly for the social housing sector.

- **Affordable and Scalable Solutions:** Many IoT products remain cost-prohibitive for smaller housing associations, limiting their ability to scale deployments. Walker et al. (2024) note that high installation and maintenance costs often deter investment. Modular IoT solutions, which enable phased implementation and reduce upfront financial barriers, have been identified as a key opportunity to address this issue (Zaidan and Zaidan, 2020). Additionally, lightweight, non-intrusive sensors and solar-powered devices, as highlighted by Maskeliūnas et al. (2019), may provide cost-effective alternatives for large-scale implementation. Maswadi et al. (2020) emphasise that long-term financing models and partnerships with suppliers could further support affordability and sustainability in social housing deployments.
- **Flexible APIs and Data Integration Capabilities:** Limited interoperability is a recurring issue, with many IoT systems lacking flexible APIs or standardised protocols (Eastman et al., 2011; Rogage, 2021). Stojkoska and Trivodaliev (2017) highlight that fragmented systems often lead to siloed data and reduced cross-platform insights. Standards like ZigBee and Z-Wave offer promising solutions by enabling communication between devices from different manufacturers while maintaining low energy consumption, which is critical for large-scale deployments in social housing (Maswadi et al. 2020). However, as Greenwood et al. (2017) note in their study of Lean-BIM integration, a lack of standardised frameworks limits real-time data exchange across digital systems, mirroring the challenges seen in housing IoT ecosystems. To address this, open-source platforms and structured integration models could help mitigate vendor lock-in, ensuring seamless, scalable data interoperability between IoT, building management, and asset monitoring systems.
- **Intelligent Energy Management Systems:** Intelligent energy management systems, such as real-time Demand Side Management (DSM), remain underutilised in social housing (Zaidan and Zaidan, 2020). These systems could optimise energy use and mitigate fuel poverty. Sepasgozar et al. (2020) demonstrate that AI-integrated IoT systems can reduce energy consumption by up to 38%. Additionally, solutions like Switchee, which adapt to user behaviour, highlight the importance of practical, accessible designs for energy-saving technologies (Choi et al., 2020).

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6. Market Landscape

- **Predictive Maintenance Solutions:** Predictive maintenance technologies have shown significant promise in reducing operational disruptions and extending asset lifecycles (Davila Delgado et al., 2020). However, reactive approaches still dominate the sector, particularly in addressing damp and mould. The Housing Ombudsman (2023) found that many landlords continue to rely on tenant-reported complaints rather than adopting preventative measures, despite growing regulatory pressure. This failure to act pre-emptively has led to severe maladministration findings, reinforcing the need for predictive IoT monitoring to identify risks before they escalate. As Yossef and Aharon-Gutman (2023) highlight, legacy infrastructure and limited analytics capabilities remain key barriers to the adoption of proactive maintenance strategies. To address this, machine learning algorithms integrated into IoT systems (Maskeliūnas et al., 2019) could enable landlords to prioritise maintenance interventions based on real-time risk analysis, reducing costs and improving tenant outcomes.
- **Intuitive Data Visualisation Tools:** IoT dashboards often prove overly complex for non-technical users, creating barriers to adoption (Rogage et al., 2021). Stojkoska and Trivodaliev (2017) stress the need for user-friendly, simplified interfaces to empower housing officers and decision-makers. Visualisation tools that provide actionable insights tailored to users' roles—whether tenants or housing staff—are particularly important in ensuring effective decision-making.
- **Lifecycle Management Systems:** Integrating IoT data with Building Information Modelling (BIM) platforms remains a significant gap, hindering comprehensive asset management (Eastman et al., 2011). Such integration would centralise data for proactive maintenance and long-term planning. Stojkoska and Trivodaliev (2017) advocate for smart ecosystems that combine BIM with IoT to improve efficiency, maintenance, and tenant outcomes. While BIM has been successfully implemented in construction and asset-heavy industries, its application in housing remains underdeveloped. Rogage et al. (2022) demonstrate how Digital Twin approaches enhance large-scale infrastructure monitoring by linking IoT data with site models. In social housing, a similar integration of IoT with asset management platforms could improve maintenance strategies, especially in large property portfolios.

6. Market Landscape

6.2 Sector Preparedness

The rapid expansion of the IoT market for social housing has led to a proliferation of providers offering diverse solutions, yet sector readiness varies considerably.

- **Affordable and Scalable Solutions:** High implementation costs remain a significant hurdle for smaller housing associations, which often operate under tight budgets and rely on grant funding to initiate IoT projects (Walker et al., 2024). Affordable and scalable options are critical to ensure that IoT adoption does not exacerbate inequalities between large and small housing providers. Zaidan and Zaidan (2020) argue that modular and cost-efficient IoT frameworks, combined with adaptive financing models, can facilitate broader adoption.
- **Customisation for Social Housing:** Off-the-shelf IoT solutions often fail to meet the unique challenges of social housing, such as multi-unit connectivity and high-density deployments (Choi et al., 2020). Tailored solutions that prioritise reliable infrastructure and tenant-specific needs, as discussed by Maskeliūnas et al. (2019), are critical for ensuring effective adoption.
- **Interoperability and Open Standards:** The absence of universal standards for data formats and communication protocols continues to hinder seamless integration between IoT devices from different providers. Research from Davila Delgado et al. (2020) and Rogage (2021) highlights that vendor lock-in and fragmented systems limit the effectiveness of IoT deployments by creating silos of unconnected data. Stojkoska and Trivodaliev (2017) advocate for the adoption of open APIs and standardised communication protocols to improve system compatibility and foster collaboration across diverse platforms.
- **Tenant-Centric Design and Engagement:** Many IoT solutions lack user-friendly interfaces and fail to adequately address tenant concerns, such as privacy, data security, and accessibility. Choi et al. (2020) and Buckingham et al. (2022) emphasise the need for co-designed solutions that involve tenants early in the development process. This approach builds trust and ensures systems meet tenant expectations. Incorporating multilingual support, offline functionality, and accessible training materials can address the digital divide, particularly in communities with limited internet access or diverse demographics (Walker et al., 2024). Long et al. (2022) highlight the potential for community-level initiatives to complement IoT adoption, suggesting that tenant buy-in could improve through shared hubs or peer support networks that bridge gaps in trust and digital literacy.

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6. Market Landscape

- **Preparedness for Emerging Technologies:** As IoT solutions evolve, housing providers must prepare for integrating advanced technologies such as digital twins, AI-driven analytics, and blockchain for enhanced data security. Zaidan and Zaidan (2020) stress that gradual implementation strategies are essential for reducing organisational risks while maintaining tenant trust. Building organisational readiness through infrastructure upgrades and staff training will be critical for ensuring these technologies are effectively adopted (Maskeliūnas et al., 2019).

By addressing these market gaps, IoT providers and housing associations can enhance the scalability and impact of connected home technologies in the social housing sector. Collaborative efforts to improve standardisation, affordability, and tenant engagement are critical for future progress.

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7. Recommendations for Further Research

This literature review identifies several areas where further research is needed to advance the understanding and implementation of connected home technologies in social housing.

7.1 Gaps in Existing Literature

- **Tenant-Centric Studies:** Existing research disproportionately focuses on technical and organisational challenges while often overlooking tenant experiences. Studies rarely explore tenants' perspectives on privacy, ease of use, and the perceived value of smart home devices (Walker et al., 2024; Choi et al., 2020). Further work should examine tenants' needs and concerns, such as trust in data handling, usability preferences, and how connected home technologies can meaningfully improve daily life. Maswadi et al. (2020) underscore the importance of evaluating user-centric features, such as accessible interfaces and customisable data privacy settings, to ensure broader acceptance.
- **Large-Scale Evaluations:** Much of the research is limited to small-scale pilots, which fail to capture the complexities of larger deployments. Studies on wide-scale implementations could reveal insights into scalability, sustainability, and the operational impacts of connected home technologies. Additionally, such evaluations could identify regional differences in outcomes due to variations in infrastructure, housing stock, tenant demographics, and policy environments (Davila Delgado et al., 2020; Yossef & Aharon-Gutman, 2023).
- **Interoperability and Legacy Systems:** Research into interoperability is critical to understanding how IoT solutions can integrate with legacy systems commonly found in social housing (Eastman et al., 2011). Exploring the role of protocols like ZigBee and Z-Wave, as well as open standards, could support the development of more seamless IoT ecosystems. Studies should evaluate how cross-platform compatibility can streamline operations and enhance scalability (Rogage, 2021; Stojkoska and Trivodaliev, 2017).

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7. Recommendations for Further Research

7.2 Proposed Areas for Exploration

- **Stakeholder Interviews:** Qualitative research with key stakeholders—including landlords, technology providers, tenants, and policymakers—can offer nuanced insights into adoption challenges and opportunities. Topics could include the effectiveness of tenant engagement strategies, overcoming internal resistance to change, and forming partnerships with external service providers. For example, interviews could shed light on how housing associations balance operational efficiency with tenant satisfaction (Choi et al., 2020; Rogage, 2021).
- **Surveys and Case Studies:** Targeted surveys could quantify adoption levels, tenant satisfaction, and perceived barriers across different demographics. Complementary case studies, such as those examining the implementation of predictive maintenance or environmental monitoring systems, could provide practical lessons and highlight replicable best practices (Walker et al., 2024).
- **Emerging Technologies:** Research should examine cutting-edge IoT solutions, including AI-driven analytics, context-aware sensors, and digital twins, which can improve predictive maintenance, energy efficiency, and overall operational insights. Additionally, evaluating the scalability of interoperable platforms and their integration with smart ecosystems could inform adoption strategies in social housing (Eastman et al., 2011; Yossef & Aharon-Gutman, 2023).
- **Human-Centred Design and Usability:** Future research must prioritise human-centred design principles, particularly to address challenges related to digital literacy, accessibility, and tenant autonomy. Solutions co-designed with tenants, especially those from vulnerable groups, could enhance usability, build trust, and mitigate resistance to adoption. Maswadi et al. (2020) highlight the potential of simplified interfaces and customisable features to address the needs of elderly and digitally inexperienced tenants.
- **Cultural and Demographic Contexts:** Exploring how cultural differences and tenant demographics influence IoT adoption could provide more tailored and effective solutions. Studies that incorporate these variables would help ensure that connected home technologies are inclusive and sensitive to diverse tenant needs, as suggested by Long et al. (2022).

8. Conclusion

This literature review provides a comprehensive foundation for understanding the current state of connected home technologies in social housing, highlighting key benefits, challenges, and opportunities for innovation

8.1 Key Insights

- **Benefits:**
  - Improved tenant well-being through early detection and prevention of issues such as damp and mould.
  - Operational cost savings via predictive maintenance, reduced emergency repairs, and optimised energy management.
  - Enhanced compliance with regulations like Awaab's Law and Minimum Energy Efficiency Standards.
- **Challenges:**
  - Technical barriers, including interoperability and connectivity limitations, which hinder the integration of IoT devices.
  - Organisational constraints, such as a lack of in-house expertise, change management resistance, and financial limitations.
  - Tenant-related challenges, including digital literacy gaps, privacy concerns, and resistance to new technologies.
- **Market Gaps:**
  - A lack of affordable and scalable IoT solutions tailored to the unique requirements of social housing, including high-density and multi-unit settings.
  - Limited compatibility with legacy systems, creating data silos and integration challenges.
  - Insufficient user-friendly tools and interfaces for non-technical stakeholders, including housing officers and tenants.

8. Conclusion

8.2 Implications for the Research Study

- **Tenant-Centric Focus:** Prioritising tenant concerns around privacy, usability, and trust is essential to the success of connected home technologies. Co-designing solutions with tenants can improve adoption rates and ensure inclusivity.
- **Organisational Capacity:** Housing providers need to develop skills, governance frameworks, and change management processes to enable IoT adoption. Partnerships with suppliers can support knowledge-sharing and implementation.
- **Scalability and Integration:** Identifying best practices for scaling IoT deployments, including system interoperability and seamless integration with housing management platforms, is crucial for long-term impact.
- **Market Innovation:** Technology providers must focus on creating affordable, interoperable, and tenant-centric IoT solutions tailored to the social housing sector. Addressing gaps in user experience and accessibility will unlock new opportunities.

The findings from this review will inform stakeholder interviews, surveys, and case studies, ensuring the research captures diverse perspectives and provides actionable recommendations. By addressing these challenges and gaps, this project aims to support the effective deployment of connected home technologies, delivering healthier homes, cost efficiencies, and improved tenant satisfaction. For landlords and suppliers alike, these innovations represent an opportunity to drive transformative change in the social housing sector.

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