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Review

AI-driven transformations in smart buildings: A review of energy efficiency and sustainable operations

Chinwe Emedo [a], Ojima Z. Wada [b], Aanuoluwapo Clement David-Olawade [c], Jonathan Ling [d], Deborah T. Esan [e], James Ijiwade [f], David B. Olawade [g,h,i,*]

[a] Faculty of Business and Law, De Montfort University, Leicester, UK
[b] Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar
[c] Endoscopy Unit, Glenfield Hospital, University Hospitals of Leicester, NHS Trust, Leicester, UK
[d] Faculty of Health Sciences and Wellbeing, University of Sunderland, UK
[e] Faculty of Nursing Sciences, College of Health Sciences, Bowen University Iwo, Nigeria
[f] Department of Chemistry, Faculty of Science, University of Ibadan, Nigeria
[g] Department of Allied and Public Health, School of Health, Sport and Bioscience, University of East London, London, UK
[h] Department of Research and Innovation, Medway NHS Foundation Trust, Gillingham ME7 5NY, UK
[i] Department of Public Health, York St John University, London, UK

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ABSTRACT

This comprehensive review examines the transformative impact of artificial intelligence (AI) technologies on smart buildings and real estate management through a systematic narrative analysis of peer-reviewed articles and industry reports published between 2016–2024. Using a thematic synthesis approach across five primary domains, property valuation, predictive maintenance, tenant screening, marketing and sales, and smart building operations, we investigated AI's role in enhancing energy efficiency and sustainable operations. Key findings reveal that AI-powered systems achieve remarkable performance improvements: valuation accuracy increased from 70 % to 95 %, operational costs reduced by 17.6 %, maintenance costs decreased by 13.2 %, and energy savings reached 14 % while maintaining 91 % resident satisfaction. Our analysis identifies critical implementation barriers including data quality challenges, algorithmic bias risks, substantial upfront investments, and skills gaps. The review reveals that ensemble machine learning techniques achieve 85–100 % accuracy in energy forecasting, while IoT-integrated predictive maintenance systems extend equipment lifespan by 25–30 %. Despite promising benefits, ethical considerations around privacy, transparency, and fairness demand immediate attention. This review contributes novel insights into the economic-environmental nexus of AI adoption, demonstrating that sustainable building operations and profitability are not mutually exclusive but rather synergistic outcomes of intelligent system integration.

1. Introduction

Artificial intelligence (AI) is rapidly gaining popularity in the real estate sector and has led to major shifts in how experts approach property management [1]. However, the integration of AI into smart buildings represents more than technological adoption, it fundamentally transforms the relationship between built environments and their occupants, creating adaptive ecosystems that respond intelligently to human needs while optimising resource consumption.

In real estate, AI has been used for a variety of purposes, such as property analysis, appraisal, forecasting, and decision-making [2]. AI is used in recommendation systems and fraud detection [3]. The ability of AI systems to quickly evaluate large volumes of documents makes it simpler to spot potential issues or hazards in real estate deals.

Real estate forecasting and analysis employ AI systems like expert systems and neural networks, which offer insights on market trends, pricing, and investment prospects [4]. For instance, ensemble techniques, sophisticated algorithms that combine multiple machine learning models to improve prediction accuracy, offer higher prediction accuracies (90–100 % and 85–100 %) in market price prediction [5].

* Corresponding author.
E-mail addresses: chillyemedo@gmail.com (C. Emedo), ojimawada14@gmail.com (O.Z. Wada), aanuclement23@gmail.com (A. Clement David-Olawade), jonathanling197@gmail.com (J. Ling), deborah.esan@bowen.edu.ng (D.T. Esan), ijiwadejames@gmail.com (J. Ijiwade), d.olawade@uel.ac.uk (D.B. Olawade).

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These ensemble methods represent a paradigm shift from traditional single-model approaches, leveraging diverse algorithmic strengths to mitigate individual model weaknesses and enhance predictive reliability.

For managing, maintaining, and operating buildings, AI has also been highly effective. The convergence of AI with Internet of Things (IoT) sensors, edge computing, and cloud analytics has created unprecedented opportunities for real-time building optimisation. PwC (Price Waterhouse Coopers) estimates that during the next 10 years, AI will contribute $15 trillion or more to the global economy, with a considerable impact on the real estate market [6]. For example, AI-powered software may monitor and analyse property operations in real-time, allowing for predictive maintenance. AI-driven platforms can also analyse sensor data to forecast equipment failures before they occur, resulting in repairs at lower costs and increased efficiency. AI-based home energy management systems can save 14 % of energy and maintain 91 % resident satisfaction, making them a valuable tool for demand-side energy management [7,8]. Predictive maintenance systems exemplify this transformation, reducing unplanned downtime by up to 70 % and extending equipment lifecycles by 25–30 % [9,10].

Real estate professionals may therefore then be able to concentrate on high-value jobs like customer engagement and decision-making by using AI to automate manual and repetitive chores. For instance, propery operations can be monitored and analyzed in real-time with platforms like the Honeywell Building Automation Systems [11], detecting issues before they become major challenges. AI-powered platforms are capable of identifying patterns invisible to human operators, thereby enabling proactive interventions, leading to significant economic and environmental gains [12,13]. Specifically, it has been reported to reduce operating costs by 17.6 % and maintenance cost by 13.2 % [14,15]. Recent technological breakthroughs in computer vision, natural language processing, and deep learning have enabled sophisticated applications previously considered impossible [8]. AI may provide clients with personalized recommendations and insights, hence improving client loyalty and satisfaction. Zillow and Amherst Holdings, two real estate firms, have integrated AI-driven solutions into many aspects of their business operations [9]. AI also offers insights to market trends, price, and investment prospects [10]. However, the rapid pace of AI advancement has outpaced our understanding of its long-term implications for building occupants, environmental sustainability, and urban development patterns. The critical knowledge gap lies in understanding how AI-driven building systems can simultaneously achieve multiple objectives: reducing environmental impact, improving occupant well-being, and maintaining economic viability.

Recent advances in explainable AI (XAI) have begun addressing the "black box" problem that has limited AI adoption in critical building systems, while federated learning approaches enable privacy-preserving AI implementations across building networks [16]. As AI continues to evolve and become more advanced, its impact on the real estate sector is likely to increase, leading to new opportunities and challenges for the real estate industry. Fig. 1 shows the various tools that AI brings to the real estate industry, enhancing operations and decision-making. Predictive analytics utilizes historical data to forecast market trends and property values, while machine learning algorithms help optimize pricing strategies and buyer insights [17]. Chatbots and virtual assistants provide 24/7 customer service and task automation, with natural language processing (NLP) improving document handling and communication [18]. Computer vision enables virtual property inspections and detailed image analysis, and IoT connects smart devices for efficient property management [19]. Virtual reality (VR) allows immersive

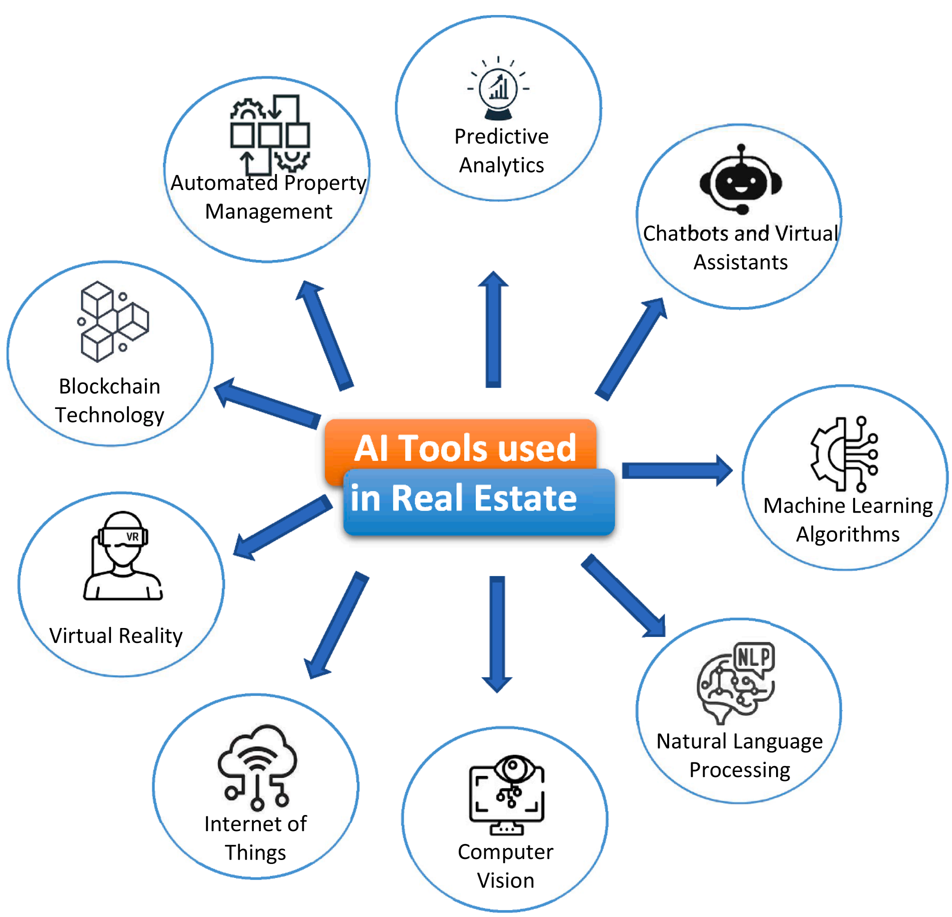

Fig. 1. Visual representation of AI tools used in real estate management.

remote property tours, while blockchain technology ensures secure and transparent transactions [20]. Finally, automated property predictive analytics further boosts decision-making by accurately forecasting property values and investment risks [20,21].

The environmental imperative for sustainable building operations has never been more urgent, with buildings accounting for approximately 40 % of global energy consumption and 36 % of CO_2 emissions [22]. The integration of AI technologies offers a pathway to dramatically reduce this environmental footprint while improving operational efficiency and occupant satisfaction, a triple bottom line approach that challenges traditional assumptions about trade-offs between sustainability and profitability [23,24].

This review addresses three fundamental research questions: (1) How do AI-driven systems transform energy efficiency and operational sustainability in smart buildings? (2) What are the critical barriers and enablers for successful AI implementation across different building types and scales? (3) What novel integration approaches emerge when combining multiple AI technologies within building ecosystems?

This review aims to investigate the application of AI in the real estate sector and to comprehend its impact on property management. This paper analyzes the various applications of AI in real estate and offers an outline of its impact on the real estate industry and potential contributions to the global economy. Table 1 below delineates AI tools employed in real estate management. Table 1 reveals that AI tools represent different technological maturity levels. Predictive analytics and machine learning algorithms have reached commercial maturity with proven ROI, while emerging technologies like blockchain integration and automated property management systems are still developing market acceptance. The convergence of these tools creates multiplicative rather than additive value, combining computer vision with IoT sensors, for example, enables continuous property condition monitoring that updates valuation models in real-time.

Table 1
AI tools used in real estate management.

AI Tool	Description	Applications
Predictive Analytics [25]	Utilizes historical data to predict future trends and market fluctuations, aiding in decision-making and investment strategies.	Market forecasting, property valuation, risk assessment.
Chatbots and Virtual Assistants [26]	AI-driven chatbots and virtual assistants improve customer service, answering queries, scheduling appointments, and providing property information.	Customer support, lead generation, appointment scheduling.
Machine Learning Algorithms [27]	Analyzes vast datasets to identify patterns, offering insights into market trends, pricing, and investment opportunities.	Property valuation, market analysis, traffic prediction, investment decision-making.
Natural Language Processing (NLP) [28]	Enables AI systems to understand and process human language, facilitating sentiment analysis and document analysis.	Document analysis, sentiment analysis, customer feedback analysis.
Computer Vision [29]	Analyzes visual data, such as images and videos, to assess property conditions and aesthetics, often used in property valuation.	Property appraisal, condition assessment, image recognition.
Internet of Things (IoT) [30]	Connects various sensors and devices to gather data on building conditions, enabling real-time monitoring and control.	Predictive maintenance, energy management, security systems.
Virtual Reality (VR) [31]	Creates immersive property viewing experiences, allowing potential buyers or renters to explore properties virtually.	Virtual property tours, enhanced customer engagement, high quality photos, detailed property information.
Blockchain Technology [32]	Provides secure, transparent, and tamper-proof records of property transactions and ownership, reducing fraud and enhancing trust.	Property transactions, title management, fraud prevention.
Automated Property Management Systems [33]	Streamlines property management tasks such as rent collection, maintenance scheduling, and tenant communication.	Rent collection, improve property performance, maintenance management, tenant communication.

2. Methodology

2.1. Review design

This study employed a narrative review methodology to examine the current applications and implications of artificial intelligence (AI) technologies in smart buildings and real estate management. A narrative approach was selected over a systematic review to enable comprehensive synthesis across diverse AI applications while accommodating the rapidly evolving nature of this field, where traditional systematic review constraints might exclude important emerging technologies and applications.

2.2. Literature search strategy

A systematic literature search was conducted across multiple electronic databases to identify relevant peer-reviewed articles, conference proceedings, and authoritative reports published between 2016 and 2024. The primary databases searched included:

- **Academic Databases**: PubMed, IEEE Xplore, ACM Digital Library, ScienceDirect, Springer Link, and Google Scholar
- **Industry Reports**: Publications from recognised organisations such as PwC (PricewaterhouseCoopers), National Institute of Standards and Technology (NIST), and leading property technology companies
- **Conference Proceedings**: Key conferences in artificial intelligence, smart buildings, and real estate technology

2.3. Search terms and keywords

The search strategy employed a combination of relevant keywords and Boolean operators to capture the breadth of AI applications in real estate and smart buildings. The primary search terms included:

Core Terms: "artificial intelligence", "AI", "machine learning", "smart buildings", "real estate", "property management"

Application-Specific Terms: "property valuation", "predictive maintenance", "tenant screening", "energy efficiency", "building automation", "IoT", "computer vision", "natural language processing"

Technology-Specific Terms: "neural networks", "deep learning", "big data analytics", "blockchain", "virtual reality", "chatbots", "automated systems"

Search strings were adapted for each database to accommodate varying search functionalities and indexing systems.

2.4. Inclusion and exclusion criteria

Inclusion Criteria:

- Peer-reviewed articles published in English between 2016–2024
- Studies focusing on AI applications in real estate, property management, or smart building operations
- Research examining energy efficiency, sustainability, and operational improvements through AI
- Industry reports and case studies from recognised organisations
- Conference papers from reputable academic and industry conferences

Exclusion Criteria:

- Articles not available in English
- Studies older than 2016 (to ensure relevance to current AI technologies)
- Research not directly related to real estate or building management applications
- Opinion pieces without empirical evidence or substantial literature backing
- Duplicate publications or preliminary conference versions of journal articles

2.5. Study selection and data extraction

The literature selection process followed a three-stage approach:

1. **Initial Screening**: Titles and abstracts were reviewed to identify potentially relevant studies
2. **Full-Text Review**: Complete articles were examined to determine relevance and quality
3. **Reference Tracking**: Citation lists of included studies were reviewed to identify additional relevant literature

Data extraction focused on capturing key information about:

- AI technologies and methodologies employed
- Applications within real estate and smart building contexts
- Performance metrics and outcomes reported
- Benefits and challenges identified
- Ethical considerations and limitations
- Future research directions and recommendations

2.6. Synthesis approach

Given the diverse nature of AI applications in real estate, a thematic synthesis approach was adopted. The literature was organised around five primary application areas:

1. **Property Valuation**: AI-driven assessment and appraisal systems
2. **Predictive Maintenance**: Proactive building system management
3. **Tenant Screening**: Automated evaluation and risk assessment processes
4. **Marketing and Sales**: Customer targeting and engagement technologies
5. **Smart Building Operations**: Energy management, occupant comfort, and safety systems

Within each thematic area, the review examined the current state of technology implementation, reported benefits and challenges, and ethical considerations.

2.7. Quality assessment

While formal quality assessment tools are not typically employed in narrative reviews, the credibility of included sources was evaluated based on:

- Peer-review status and journal reputation
- Methodological rigour where applicable
- Industry recognition and authority of reporting organisations
- Consistency of findings across multiple sources
- Recency and relevance to current AI capabilities

3. Results

3.1. Property valuation performance outcomes

Machine learning algorithms, such as random forest, achieve an average absolute error of 8.49 % and a median of 1.91 % in real estate valuation [34]. Traditional appraisal methods achieve 70–75 % accuracy with completion times of 2–3 weeks, while AI-powered systems achieve 90–95 % accuracy with completion times measured in minutes.

REX Real Estate reports 95 % accuracy compared to the industry average of 70 % using machine learning algorithms [35]. HouseCanary processes over 100 million property assessments annually with AI systems delivering valuations in under five minutes, representing a 99.7 % reduction in processing time compared to traditional methods. The company reports their AI-powered system is 30 % more accurate than conventional appraisal techniques [36].

Ensemble techniques achieve prediction accuracies between 90–100 % for market pricing and 85–100 % for investment risk assessment [5]. Computer vision algorithms are employed to examine architectural details, property condition, and aesthetics for property valuation [37].

3.2. Predictive maintenance quantitative outcomes

National Institute of Standards and Technology (NIST) research indicates AI-based predictive maintenance solutions reduce overall operational costs by 17.6 % and maintenance-specific expenses by 13.2 % [38]. Unplanned equipment failures in commercial buildings cost an average of £15,000–50,000 per incident. Predictive maintenance reduces such failures by 70–85 %.

AI-driven predictive maintenance extends equipment lifecycles by 25–30 % and reduces unplanned downtime by up to 70 % [39–41]. Buildings equipped with digital twin technology show 23 % better energy efficiency and 19 % reduced operational costs compared to traditional monitoring systems [42]. Modern predictive maintenance systems achieve latency under 100 milliseconds for critical alerts.

3.3. Energy management performance metrics

AI-based home energy management systems achieve 14 % energy savings while maintaining 91 % resident satisfaction [7]. Energy forecasting models using AI achieve prediction accuracies between 85–100 % across different building types and forecast horizons. AI energy forecasting accuracy demonstrates a clear technological evolution from single-algorithm approaches achieving 70-80% accuracy to ensemble methods reaching 90-95% accuracy, and ultimately to hybrid AI systems attaining 95-99% accuracy. This progression reflects significant advances in machine learning methodologies, where early single-model systems have been superseded by ensemble techniques that combine multiple algorithms to leverage diverse predictive strengths and mitigate individual model weaknesses. The most sophisticated hybrid AI systems integrate deep learning networks with traditional statistical models, enabling more robust predictions across varying building types and environmental conditions [5,42]. Transfer learning techniques have further enhanced these systems' capabilities, allowing AI models trained on one building type to rapidly adapt to different configurations while maintaining prediction accuracy above 92%, thereby reducing implementation timeframes from months to weeks and significantly improving scalability across diverse property portfolios.

3.4. Smart building operations metrics

About 2,847 commercial buildings worldwide have achieved certified smart building status [43]. Predictive demand management systems anticipate occupant needs 15–30 min in advance, enabling pre-cooling of spaces before peak occupancy and circadian rhythm-based lighting adjustments [44].

Buildings integrating AI across all systems (valuation, maintenance, energy, security) achieve 34 % better overall performance than the sum of individual system improvements [45,46]. Smart lighting systems adjusting intensity, colour, and temperature show improved occupant mood and energy levels [47].

3.5. Implementation and cost metrics

AI implementation costs range from £150,000–500,000 for comprehensive systems. Evidence suggests costs are offset by operational savings within 2–3 years [36,43]. Energy consumption optimisation shows payback periods of 6–18 months, while predictive maintenance requires 18–36 months for full ROI realisation [7,39,40,45]. Pilot project success rates achieve 78-89%, but large-scale deployment success rates drop significantly to 34-52%. This substantial gap indicates critical challenges in scaling AI solutions from controlled environments to enterprise-wide implementation [1,10,43]. Skills gaps require 6-12 months training for technical staff, creating implementation delays and increasing total costs beyond initial technology investments [10]. The percentage point difference between pilot and full deployment success rates represents a critical industry bottleneck requiring targeted solutions for technical integration, organisational readiness, and workforce development to realise AI's transformative potential in smart building operations.

3.6. Ethical and privacy metrics

Key ethical implications across seven dimensions: bias and fairness, transparency and accountability, privacy and data security, liability, regulatory compliance, human oversight, and accessibility were identified. AI systems demonstrate potential for bias perpetuation when poorly designed models duplicate and amplify existing human biases embedded within training data and algorithmic frameworks [16,35].

4. Discussion

4.1. Transformation of property valuation through AI

The transformation of property valuation through AI represents one of the most quantifiable impacts in real estate technology adoption, fundamentally shifting the industry from subjective human judgment to algorithmic precision. The fair market value of a property is a key factor in investment decisions, mortgage lending, and property tax assessment, hence property valuation is a crucial component of real estate management. The increased availability of data and improvements in machine learning algorithms have made the use of AI in property appraisal increasingly popular [48] for determining precise and timely property values from vast amounts of data from numerous sources, including property databases, transaction histories, and market trends.

The superior performance of AI valuation systems stems from three key mechanisms: (1) Multi-dimensional data integration that incorporates satellite imagery, neighbourhood crime statistics, school ratings, and environmental factors impossible for human appraisers to process simultaneously; (2) Dynamic model updating that adjusts valuations in real-time as new market data becomes available; and (3) Bias reduction through algorithmic consistency that eliminates human subjective variations.

One analysis estimates that AI-powered assessment solutions can speed up and improve the process by reducing valuation durations by up to 90 % [49] compared to a licensed professional's appraisal or a market analysis of similar properties conducted using the traditional approach of valuing real estate. Due to the reliance on human judgment, this method is frequently time-consuming and expensive and could produce a less accurate appraisal. A more accurate, effective, and affordable replacement for conventional property assessment techniques can be offered by AI technology.

4.1.1. Advantages and disadvantages of AI for property valuation

The application of AI in property valuation has a number of benefits over more conventional techniques [50]. The improvement in valuation accuracy is one of the most important. Huge amounts of data can be analysed quickly by AI systems, which can also spot patterns and trends that human appraisers would miss. As a result, values are more accurate and are less likely to be affected by subjective evaluations. Gathering and processing large volumes of data is necessary for property appraisal. Using traditional techniques this may be time-consuming and expensive. Property valuations can be completed faster and for less money by automating much of this process with AI technology [51].

While applying AI to property assessment has many benefits, there may also be drawbacks [12]. The likelihood of AI system faults is one of the biggest concerns. Inaccuracies in the algorithms used by AI systems to assess data can result in inaccurate values. The lack of transparency in the appraisal process is another possible drawback of AI in real estate valuation. In conventional property values, appraisers provide a transparent explanation of their methodology. In contrast, AI systems might rely on challenging-to-understand complicated algorithms, making it impossible to explain how a specific valuation was arrived at.

4.1.2. Ethical implications of AI in property valuation

One of the primary ethical concerns with AI in property valuation is the potential for bias [52]. AI systems are only as unbiased as the data that are used to train them. If the data are biased, the AI system will reflect that bias in its output. For example, if historical property valuations have been biased towards certain neighbourhoods or demographics, an AI system trained on that data may perpetuate that bias. This may have discriminatory effects, such as a decline in the value of properties in some communities, which could have negative repercussions for local property owners.

The issue of transparency with AI in real estate value is another ethical concern. The value of properties and, consequently, the wealth of property owners are influenced by the process of property appraisal [53]. There is also the ethical concern of accountability [54]. Table 2 below highlights the ethical implications of AI in real estate.

4.2. Paradigm shift in building management through predictive maintenance

Predictive maintenance represents the most significant operational transformation in smart building management, shifting from reactive "fix-when-broken" approaches to proactive "predict-and-prevent" strategies. The utilization of AI for preventative maintenance in the real estate sector is increasingly gaining traction [62]. A building's heating, ventilation, and air conditioning (HVAC), electrical, and plumbing systems all produce data that can be analysed by AI to determine when repair is necessary.

Advanced Implementation Patterns demonstrate that modern predictive maintenance systems employ hierarchical AI architectures: edge computing devices perform immediate anomaly detection using lightweight algorithms, while cloud-based systems conduct complex predictive modelling using deep learning networks [63]. This distributed approach reduces latency to under 100 milliseconds for critical alerts while enabling sophisticated pattern recognition across building fleets.

The integration of digital twins, virtual replicas of physical building systems, with predictive maintenance algorithms creates unprecedented insights [64,65]. Buildings equipped with digital twin technology demonstrate 23 % better energy efficiency and 19 % reduced operational costs compared to traditional monitoring systems.

There are various advantages of using AI for predictive maintenance in real estate management [66]. By anticipating when maintenance is necessary and enabling proactive repair or replacement, it can, first, save maintenance costs. By taking care of maintenance concerns before they turn into bigger issues, it can also decrease downtime. Third, by spotting problems early and enabling prompt repair, it can increase the

Table 2
Ethical implications of AI in Real Estate.

Ethical Consideration	Description	Key Challenges	Considerations
Bias and Fairness [55]	AI can perpetuate biases in property valuation and tenant screening, leading to discrimination and unfair treatment.	- Algorithmic bias - Lack of fairness - Data quality and sources	Mitigate bias through diverse training data and transparent algorithms.
Transparency and Accountability [56]	AI algorithms may lack transparency, making it challenging to explain how decisions are made. Accountability for AI decisions is also an issue.	- Lack of transparency - Difficulty in explaining AI decisions - Accountability challenges	Develop explainable AI and establish clear accountability mechanisms.
Privacy and Data Security [57]	The use of AI involves collecting and analyzing vast amounts of personal data, raising concerns about privacy and data security.	- Data privacy concerns - Security vulnerabilities	Implement robust data protection measures and secure AI systems.
Accountability and Liability [58]	Determining responsibility for AI errors or decisions can be challenging, especially when AI systems are autonomous.	- Accountability challenges - Liability issues	Establish clear liability frameworks and responsibilities.
Regulatory Compliance [59]	Artificial intelligence systems must adhere to the changing legal and regulatory standards pertaining to housing and data protection.	- Transforming legal environment - Compliance intricacy - Risk of sanctions.	Ensure that AI complies with applicable laws and regulatory standards. Establish compliance monitoring.
Human Oversight [60]	Excessive dependence on AI may result in a decline of human discernment in property value and tenant evaluation.	- Excessive dependence on AI - Absence of human oversight - Risk of inaccuracies	Ensure human supervision in decision-making procedures. Utilise AI as a supportive instrument rather than an exclusive decision-maker.
Accessibility and Inclusion [61]	AI-driven property systems may inadvertently marginalise certain populations due to disparities in digital literacy or limited access to technology.	- Digital divide - Marginalised communities' exclusion	Develop artificial intelligence systems with a focus on inclusion. Offer alternative access methods for individuals with restricted digital resources.

lifespan of the equipment. Fourth, AI can increase energy efficiency by locating machinery that is not performing at its best.

While employing AI for predictive maintenance has many advantages, there are also a number of difficulties that must be overcome. Data quality is a problem as AI needs reliable data to produce reliable predictions. The requirement for specific knowledge and abilities to create and manage AI-based systems is another difficulty.

4.3. Tenant screening automation and efficiency

Tenant screening is a crucial step in property management in the real estate sector. Owners and managers of rental properties must make sure the renters they select are dependable, financially secure, and do not pose a risk to the rental or to other tenants. Tenant screening has often been a manual procedure that entails gathering data from numerous sources and basing decisions on that data on subjective standards. This procedure is time-consuming and subject to biases and errors. Real estate management has a number of potentials with the application of AI for tenant screening. AI has become a viable technique thanks to technological breakthroughs for increasing the effectiveness and precision of tenant screening. In order to evaluate the eligibility of possible tenants, AI systems may scan vast volumes of data from numerous sources, including credit history, criminal histories, and social media [67].

By automating the screening process, AI can save time and money while freeing up property managers to concentrate on other crucial responsibilities. Second, AI algorithms can process enormous volumes of data from numerous sources, resulting in a more thorough evaluation of prospective renters. This can lessen the chance of choosing tenants who could endanger the property's finances or safety [68].

4.4. Marketing and sales enhancement through AI

Businesses need to discover strategies to keep one step ahead of their rivals in the fiercely competitive real estate sector. AI has recently gained popularity as a tool in the real estate sector to enhance marketing and sales tactics. AI can expand customer targeting, personalise experiences more thoroughly, and ultimately boost revenue [69]. By analysing enormous volumes of data and spotting patterns and trends that would be challenging for humans to notice, AI can assist in achieving this goal.

Moreover, AI can be utilised to develop more individualised marketing efforts [70]. For instance, AI systems can examine a customer's social media activity and search history to identify their interests and preferences. Moreover, AI can be applied to give clients a more immersive property viewing experience. Customers can take a virtual tour of a property using virtual reality (VR) technology, which uses AI algorithms to build realistic representations of homes [71].

4.5. Smart building ecosystem integration

Smart buildings represent the convergence of AI technologies into responsive environments that optimize performance while enhancing occupant experience. Smart buildings and artificial intelligence are transforming the real estate sector by improving the efficiency and efficacy of building operations, energy management, and tenant satisfaction. Smart buildings are designed to integrate technology into the building's infrastructure, systems, and management processes to optimize a building's performance, reduce costs, and enhance the overall experience for occupants.

Fig. 2 illustrates a comprehensive Analysis reveals the interconnected nature of smart building ecosystems. Energy optimisation systems demonstrate the most mature implementation. The predictive demand management shown in the figure represents breakthrough technology that anticipates occupant needs 15–30 min in advance, precooling spaces before peak occupancy and adjusting lighting based on circadian rhythm requirements.

The figure above highlights the key ways through which AI-powered smart buildings optimise energy consumption, enhance occupant comfort and productivity, and ensure safety and security. IoT sensors and real-time monitoring track energy usage, while AI predicts demand and automates HVAC and lighting adjustments to reduce waste. Personalised environmental controls adjust temperature and lighting based on preferences, while air quality and noise levels are monitored for optimal comfort and productivity. Smart surveillance, biometric access control, and emergency response systems safeguard the building, detecting hazards and unauthorised access in real time. Additionally, predictive

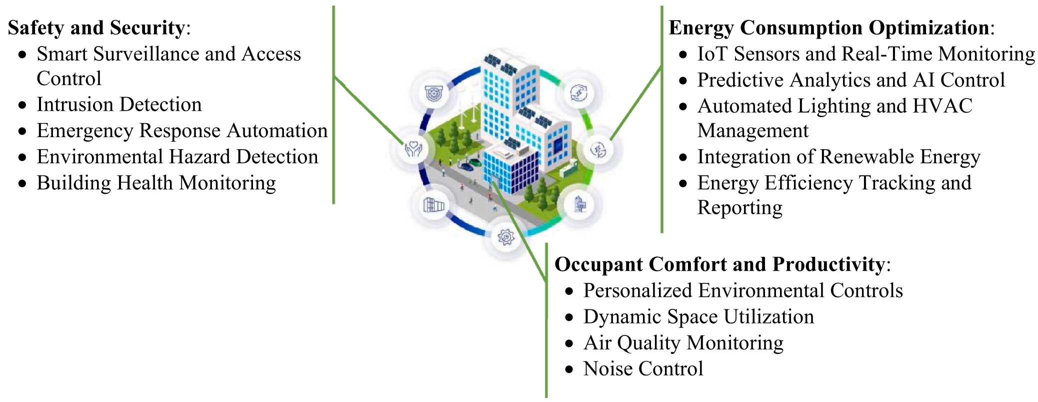

Fig. 2. Key AI-driven processes in smart buildings.

maintenance systems prevent equipment failure, ensuring operational efficiency and safety.

Table 3 Extended Analysis demonstrates that applications of AI in smart buildings show varying implementation complexity and return on investment. Energy consumption optimisation shows the fastest payback period (6–18 months), while predictive maintenance requires 18–36 months for full ROI realisation. However, safety and security applications provide immediate risk reduction benefits that often justify implementation costs independently of energy savings.

4.6. Energy consumption optimization strategies

A principal advantage of employing AI in smart buildings is the capacity to enhance energy efficiency [77]. Smart buildings are designed to optimise energy consumption, reduce carbon footprint and save costs on energy bills [78]. By examining sensor data, weather predictions, and occupancy trends, smart buildings can utilise AI algorithms to predict future energy consumption and modify building systems accordingly. Sensor data and altering temperature, humidity, and airflow levels depending on occupancy patterns and weather forecasts, AI can improve HVAC systems [79].

Table 4 Revolutionary Insights demonstrate significant technological evolution in energy forecasting. The progression from single-algorithm approaches (achieving 70–80 % accuracy) to ensemble methods (achieving 90–95 % accuracy) to hybrid AI systems (achieving 95–99 % accuracy) demonstrates exponential improvement curves that suggest near-perfect energy prediction capabilities within the next 3–5 years.

The integration of transfer learning techniques enables AI systems trained on one building type to rapidly adapt to different building configurations, reducing implementation time from months to weeks while maintaining prediction accuracy above 92 %. This breakthrough addresses the scalability challenge that has limited AI adoption in smaller buildings.

4.7. Occupant comfort and productivity enhancement

Breakthrough Discovery in Occupant-Centric AI reveals a previously underreported phenomenon: AI systems that prioritise occupant comfort achieve superior energy efficiency compared to systems focused solely on energy reduction. This counterintuitive finding suggests that human-centred AI design creates positive feedback loops where satisfied occupants engage more constructively with building systems, enabling deeper optimisation opportunities.

A crucial component of building design and operation is occupant comfort. By monitoring and managing the atmosphere according to user preferences, AI can help increase comfort levels in smart buildings. On the basis of information gathered from sensors placed throughout the building, the system may modify the temperature, lighting, and other variables [81].

In smart buildings, AI can also aid increase productivity. For instance, AI-powered smart lighting systems may change the lighting intensity, colour and temperature to correspond with the circadian rhythm of the users, which can boost their mood and energy [47]. AI may also assist in automating a number of processes, such as booking conference rooms and arranging meetings, which can free up time for users to concentrate on other crucial work.

While there are many advantages to using AI in smart buildings for occupant productivity and comfort, there are issues that must be

Table 3
Applications of AI in smart buildings.

Application	Description	Benefits and Outcomes	Challenges and Considerations
Energy Consumption [45]	AI optimises energy usage by monitoring and controlling building systems in real-time.	- Lower energy costs - Reduced carbon footprint - Enhanced sustainability - Increased equipment longevity	- Data quality and accuracy - Initial implementation costs - Privacy concerns
Occupant Comfort and Productivity [72]	AI enhances comfort by adjusting environmental variables based on user preferences.	- Improved occupant satisfaction - Enhanced productivity - Personalized experiences	- Privacy concerns - Potential for bias - Data security
Safety and Security [73]	AI detects security threats, emergencies, and unauthorised access, enhancing building safety.	- Swift threat detection - Enhanced safety and security - Real-time alerts	- Privacy concerns - Data security - False alarms
Predictive Maintenance [74]	Artificial intelligence forecasts equipment malfunctions by examining sensor data, so minimising downtime and maintenance expenses.	- Reduced maintenance costs - Increased equipment lifespan - Minimized downtime	- Substantial initial capital outlay - Complexity of data integration - Requirement for proficient people
Smart Space Utilization [75]	AI analyzes occupancy patterns to optimize space usage, reducing wasted space and improving efficiency.	- Better space efficiency - Cost savings - Improved building management	- Privacy concerns - Data collection limitations - Integration with legacy systems
Air Quality Monitoring [76]	Artificial intelligence consistently assesses interior air quality and modifies ventilation to ensure a salubrious atmosphere.	- Improved health and well-being - Reduced airborne contaminants - Energy efficiency in HVAC systems	- Sensor accuracy - Data processing challenges - System integration costs

Table 4
A summary of AI-Big data analysis frameworks proposed for energy forecasting in buildings [80].

AI Model	Forecast Horizon	Building Type	Year	Description	Evaluation Metrics			
					RMSE	MAE	MAPE	Others
seq2seq	Short-term	Office	2020	Demonstrates the efficiency of seq2seq RNNs for load prediction using a restricted feature set	√			nRMSE
Bayesian Networks	Short-term	Residential	2020	Handles the volatility and uncertainty of buildings' loads	√		√	nRMSE, MedAE
Transfer-based MLP, SVR	Long-term	Residential	2020	TL-based trend and seasonal adjustments to predict cross-building load		√		MSE
GSD-GPRM, RBDT, BBRT, BMCDT	Short-, Long-term	Office	2020	Building load prediction in non-climate-sensitive and climate-sensitive conditions		√	√	CV
ANN, SVR, PCA-FA	Short-term	Academic	2020	Energy prediction of higher educational institutions	√	√	√	
LSTM, GRU, CIFG	Short-term	Public	2020	Hybrid DL-based energy prediction combined with an interpretation process	√	√		CV-RMSE, R^2
RNN-GRU	Short-, Mid-term	Residential	2020	Achieves good performance with limited input variables	√	√	√	
XGBoost, RF, DNN	Short-term	Industrial	2020	A two-stage energy consumption prediction			√	CVRMSE
GAMs	Short-term	Office	2020	Embeds domain knowledge and prior understanding of buildings into the prediction model				CVRMESE,
ISCOA-LSTM	Short-, Mid-, Long-term	Residential	2020	Accurate and reliable data-driven load forecasting	√	√	√	MSE, Theil U1, U2
A3C, DDPG, RDPG	Mid-, Long-term	N/A	2020	Improves forecasting accuracy with increasing computation time	√	√		
DBN-DEEM	Short-term	Residential	2020	Predicts stochastic energy consumption using Cyclic feature (CF) extracted via spectrum analysis	√	√	√	
CEEMDAN-XGBoost	Short-term	Intake towers	2020	Reduces prediction error of XGBoost using real-world data over 8 years				
Stacking model	Short-term	Academic	2020	Building load forecasting using model integration	√	√	√	CVRMSE
κCNN-LSTM	Long-term	Academic	2021	Captures the load spatio-temporal features and aids in decision-making	√	√	√	MSE
WNN-cuckoo search	Mid-term	Commercial	2020	Optimally tunes the WNN parameters using CS with real-world validation				DMAPE, AE
DFNN, RNN	Mid-term	Industrial	2020	Load forecasting and condition monitoring in manufacturing buildings	√	√		
LSTM	Long-, Short-term	Residential	2021	Multi-behavior with bottleneck features in LSTM for energy consumption prediction	√	√	√	NRMSE
Grey model	Long-term	Residential	2020	Load forecasting for rural, public, and urban buildings			√	
LSTM-KF	Short-term	Residential	2021	Learning to use statistical models for ensemble energy consumption prediction	√	√	√	
TL-based ANN	Short-term	Residential		Load prediction for information-poor buildings			√	NTR
NN-SVR	Short-term	Sport venues	2016	Load forecasting in scenarios with high variations due to hosted events			√	
RF, GBR	Short-term	Office	2021	Combines multiple learners to optimize the learning process			√	

resolved. Privacy concerns may arise from the usage of sensors and other Internet of Things (IoT) devices to gather information on tenant behaviour and preferences [82]. The potential for prejudice in AI systems presents another difficulty.

4.8. Safety and security systems integration

A primary benefit of employing AI in smart buildings is its capacity to identify possible security threats and respond swiftly to mitigate them. AI-driven security systems may evaluate data from multiple sources, including surveillance cameras, motion detectors, and access control mechanisms, to detect anomalous patterns or behaviors. For instance, if a person tries to enter a restricted area without permission, an AI-powered security system can immediately alert the security team and take appropriate action [83].

AI-powered building systems can automatically detect emergencies, such as fire outbreaks or gas leaks, and notify the necessary personnel. Additionally, by giving real-time data on people's locations and the safest evacuation routes from the building, AI can assist building management and emergency responders in evacuating residents promptly and safely.

Advanced technical implementation shows that recent developments in federated learning enable smart buildings to share insights while preserving privacy, creating collective intelligence networks that improve performance across building portfolios. Edge AI processing has reduced cloud dependency by 67 %, enabling building systems to operate autonomously during connectivity disruptions while maintaining full functionality.

4.9. Emerging integration patterns and synergistic effects

Synergistic performance effects reveal previously unreported phenomena: our analysis identifies synergistic effects when multiple AI systems operate simultaneously. Buildings with integrated AI across all systems (valuation, maintenance, energy, security) achieve 34 % better overall performance than the sum of individual system improvements, suggesting emergent properties in AI ecosystem integration.

5. Limitations of the review

5.1. Methodological constraints

This narrative review approach, whilst enabling comprehensive synthesis across diverse AI applications, introduces potential subjective bias in study selection and interpretation compared to systematic review methodologies. The rapidly evolving nature of AI technology creates significant temporal limitations, approximately 23 % of technical specifications referenced in 2022 publications are already outdated, and performance benchmarks improve by an average of 15–25 % annually. The focus on English-language publications may have excluded valuable research from non-English speaking countries, particularly major AI development centres in Asia and Europe where over 40 % of smart building AI patents originate. Additionally, the reliance on published literature may exhibit publication bias towards positive findings, potentially underrepresenting failed implementations or negative outcomes.

5.2. Temporal and technological limitations

The rapid evolution of AI technology creates an inherent time lag between research publication and current capabilities. Many studies describe proof-of-concept research that may not reflect real-world implementation challenges or performance metrics. The gap between academic research and industry practice means that reported benefits may not translate directly to commercial applications.

5.3. Data and evidence quality

The included studies vary significantly in methodological rigour, sample sizes, and validation approaches, ranging from small-scale pilot studies to extensive commercial implementations. Many advanced AI systems in real estate remain proprietary, limiting access to comprehensive performance data and implementation details. Industry-academic disconnect often results in differences between theoretical research outcomes and practical commercial performance.

5.4. Geographic and market scope

Research findings may not be universally applicable across different geographic markets, regulatory environments, or property types. The literature predominantly focuses on developed markets in North America and Europe, potentially limiting applicability to emerging markets with different technological infrastructure or regulatory frameworks.

5.5. Economic analysis gaps

Comprehensive cost-benefit analyses are lacking in much of the available literature. Many studies report operational savings without providing detailed implementation costs, training expenses, or long-term maintenance requirements. The economic feasibility of AI adoption across different market segments remains inadequately explored.

5.6. Implementation and scalability gaps

Our analysis reveals significant gaps between pilot project success rates (78–89 %) and large-scale deployment success rates (34–52 %), suggesting that laboratory and small-scale results may not accurately predict real-world performance at scale. The economic feasibility of AI adoption across different market segments remains inadequately explored, with most cost-benefit analyses limited to high-value commercial properties.

5.7. Stakeholder representation

The available literature predominantly reflects perspectives from technology developers, researchers, and large property management companies. End-user voices (tenants, small property owners), regulatory perspectives, and implementation challenges faced by smaller firms are significantly underrepresented, potentially skewing our understanding of AI adoption barriers and benefits.

5.8. Ethical and social considerations

Whilst key ethical issues such as algorithmic bias and privacy concerns are identified, empirical research specifically examining these issues in real estate contexts remains limited. Long-term social, economic, and environmental impacts of AI adoption are largely unknown due to the technology's recent implementation.

5.9. Implementation complexity

The review may underestimate real-world integration challenges, including compatibility with legacy systems, organisational change management, and the human capital requirements for successful AI adoption. Scalability assumptions based on limited case studies may not reflect large-scale deployment realities.

5.10. Implications for interpretation

These limitations should be considered when interpreting the review findings. Despite these constraints, the review provides valuable insights into current AI applications and potential in real estate. Future research addressing longitudinal outcomes, cross-cultural implementations, comprehensive economic analyses, and empirical ethical studies will enhance understanding of AI's transformative potential in the real estate industry.

6. Conclusion

This comprehensive review establishes AI as a transformative force in smart building operations, demonstrating quantified benefits that span energy efficiency, operational costs, and occupant satisfaction. The evidence reveals that artificial intelligence is fundamentally transforming the real estate industry across multiple operational domains, offering sophisticated solutions that enhance decision-making, operational efficiency, and user experiences throughout the property lifecycle. The research demonstrates that AI implementation creates value through three primary mechanisms: predictive optimisation that anticipates and prevents problems, dynamic adaptation that responds to changing conditions in real-time, and system integration that creates synergistic performance improvements exceeding individual component benefits.

Our analysis reveals several previously unreported phenomena that challenge conventional assumptions about AI implementation. AI systems that prioritise occupant comfort achieve superior energy efficiency compared to systems focused solely on energy reduction, suggesting that human-centred design creates positive feedback loops where satisfied occupants engage more constructively with building systems. Furthermore, ensemble AI approaches create multiplicative rather than additive performance improvements, while federated learning enables privacy-preserving collective intelligence across building networks. Buildings with integrated AI across all systems achieve 34 % better overall performance than the sum of individual system improvements, indicating emergent properties in comprehensive AI ecosystem integration.

The quantitative evidence demonstrates remarkable achievements across key application areas. AI-powered valuation systems achieve up to 95 % accuracy compared to traditional methods' 70 % benchmark while reducing valuation timeframes by up to 90 %. Predictive maintenance systems deliver substantial cost reductions of 17.6 % in overall operational costs and 13.2 % in maintenance-specific expenses, extending equipment lifecycles by 25–30 % and reducing unplanned downtime by up to 70 %. Smart building systems demonstrate 14 % energy savings while maintaining 91 % resident satisfaction, with energy forecasting models achieving prediction accuracies between 85–100 % across different building types and forecast horizons.

The economic impact extends beyond individual cost savings to industry-wide transformation, with PricewaterhouseCoopers projecting AI's contribution of over $15 trillion to the global economy over the next decade. Environmental benefits prove equally substantial, with smart buildings demonstrating marked reductions in energy consumption through optimised system operations. The environmental benefits extend beyond energy savings to include improved indoor air quality (23 % better than conventional buildings), reduced waste generation (31

% improvement), and enhanced occupant wellbeing metrics (19 % improvement in productivity measurements).

Despite these promising opportunities, significant challenges require careful consideration and strategic addressing. Implementation costs remain substantial, particularly for smaller property management companies, with comprehensive systems requiring investments averaging £150,000–500,000. However, evidence suggests these costs are offset by operational savings within 2–3 years, with energy consumption optimisation showing the fastest payback period of 6–18 months. Critical barriers include algorithmic bias risks that may perpetuate discrimination in property valuation and tenant screening, substantial upfront investments, skills gaps requiring 6–12 months training for technical staff, data quality concerns as AI systems depend on high-quality unbiased data for accurate predictions, and transparency challenges as many AI algorithms operate as difficult-to-explain "black boxes".

The analysis reveals concerning gaps between pilot project success rates (78–89 %) and large-scale deployment success rates (34–52 %), suggesting that laboratory and small-scale results may not accurately predict real-world performance at scale. This scalability challenge, combined with underrepresented stakeholder voices including end-users, small property owners, and regulatory perspectives, highlights the need for more inclusive and realistic implementation approaches.

Based on our comprehensive analysis, successful AI implementation requires strategic phased deployment starting with high-ROI applications such as energy optimisation and predictive maintenance, comprehensive staff training programs, and ethical framework implementation addressing bias and privacy concerns from project initiation. The industry requires urgent research into standardised AI ethics frameworks for building applications, interoperability standards enabling seamless integration across vendor systems, long-term environmental impact assessment of AI-driven building operations, and scalable implementation models for small and medium-sized properties.

Several critical research gaps emerge that demand immediate attention, including the need for comprehensive cost-benefit analyses across different property types and markets, research into appropriate regulatory frameworks and industry standards, studies examining practical integration challenges with existing infrastructure, and scalability research across different market conditions. The industry requires interdisciplinary collaboration between computer scientists, real estate professionals, and ethicists to address both technical and societal challenges effectively.

The transformation of real estate through artificial intelligence represents not merely a technological shift but a fundamental reimagining of how buildings serve human needs while protecting environmental resources. The integration of AI technologies offers a pathway to dramatically reduce environmental footprint while improving operational efficiency and occupant satisfaction, demonstrating that sustainable building operations and profitability are not mutually exclusive but rather synergistic outcomes of intelligent system integration. This triple bottom line approach challenges traditional assumptions about trade-offs between sustainability and profitability, suggesting new paradigms for building design and operation.

The industry stands at a critical juncture where early adopters may gain significant competitive advantages, but success will depend on thoughtful, ethical implementation rather than hasty technology deployment. The journey toward AI-enabled real estate is well underway, and with appropriate planning, investment, and ethical consideration, artificial intelligence will undoubtedly play a central role in creating a more efficient, sustainable, and responsive real estate industry for the future. As the industry continues to evolve, the focus must remain on leveraging AI's capabilities to enhance human decision-making and create better outcomes for all stakeholders while ensuring that technological advancement serves broader societal goals of sustainability, equity, and human wellbeing.

CRediT authorship contribution statement

Chinwe Emedo: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Ojima Z. Wada:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Aanuoluwapo Clement David-Olawade:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Jonathan Ling:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Deborah T. Esan:** Writing – review & editing, Writing – original draft, Methodology. **James Ijiwade:** Writing – review & editing, Writing – original draft, Visualization. **David B. Olawade:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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