ISSN 1840-4855
e-ISSN 2233-0046

Original Scientific Article
http://dx.doi.org/10.70102/afts.2025.1833.586

PHILOSOPHY OF SUSTAINABLE ARCHITECTURE AND THE ETHICAL DIMENSIONS OF SMART BUILDINGS AND IOT INTEGRATION

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Received: August 02, 2025; Revised: September 20, 2025; Accepted: November 03, 2025; Published: December 20, 2025

SUMMARY

The paper will discuss the intersection between sustainable architecture and the next generation of smart technologies with reference to the use of Internet of Things (IoT) systems in smart buildings. It aims to investigate the positive results of IoT-based smart buildings regarding the environmental performance and to discuss the ethical issues connected with the principles of privacy, transparency, and the autonomy of the users. The mixed-method research design was adopted, where empirical analysis of sustainability metrics of 32 buildings equipped with IoT was done, as well as philosophical analysis based on Value-Sensitive Design (VSD) principles. Quantitative studies showed that an increased IoT sensor density had highly positive energy efficiency and indoor air quality, and saved operational resources. In particular, the Building Energy Performance Index (BEPI) exhibited decreases of between 9.5% and 22.8% and the IoT Operational Efficiency Ratio (IOER) was 18.7% on average. At the same time, qualitative evaluations revealed major ethical issues, especially in terms of exposure to privacy and absence of transparency, and the Ethical Exposure Index (EEI) demonstrated moderate risks. The findings highlight the conflict between technological optimization to make systems sustainable and the ethical aspect of IoT systems. Its conclusion highlights the necessity of a holistic attitude that involves combining environmental performance and ethical management, where value-sensitive design principles should be implemented in smart building development. This paper supports the application of the ecological efficiency versus human rights protection equilibrium in order to guarantee the responsible implementation of the Internet of Things in smart environments of the future.

Key words: *environmental performance, ethical design, iot integration, smart buildings, sustainable architecture, value-sensitive design.*

INTRODUCTION

The blistering development of sustainable architecture and intelligent technologies has transformed modern methods of building design, performance optimization, and environmental responsibility (Chia-Hui et al., 2025). Smart buildings enabled by the Internet of Things (IoT), artificial intelligence (AI), and cyber-physical systems are increasingly positioned as essential components of a sustainable built environment (Rane, 2023; Weber-Lewerenz & Traverso, 2023; Min et al., 2025). IoT-powered sensing systems can dynamically manage energy, water, and indoor environmental quality of buildings, thus supporting global sustainability aspirations as well as Smart Readiness Indicators (Martínez et al., 2021; Sathish Kumar, 2024). With the increased level of urbanization and the need to manage resources efficiently and address passive designs, sustainable architecture has reached a new stage of development that encompasses smart automation, data-driven functionality, and human-oriented responsiveness (Al Amin Gerary, 2024; Fakhabi et al., 2024).

Nonetheless, the combination of IoT and AI technologies has also placed an ethical frontier at a new level. The smart buildings are constantly gathering and processing small user data, a phenomenon raising concerns about privacy, surveillance, autonomy, algorithmic governance, and technological dependency (Harper et al., 2022; Helbing et al., 2021; Prasanna et al., 2024). Although the advantages of smart systems regarding the environment and operations are widely praised, much less coverage has been devoted to the philosophical and ethical aspects of making design choices, stewarding data, and the interaction between human beings and technologies in the built environment. The current literature specifically dwells on technological efficiency (Wang & Liu, 2024), construction-innovation (Chen et al., 2022), and the issue of implementation (Ghansah et al., 2024), without providing an answer to more fundamental normative questions of justice, human well-being, and the moral accountability of designers and the city policy makers.

The overlap between ethical principles, value-sensitive design, and the philosophy of sustainability of smart building development is a serious gap in the research, disproportionate to the newly increasing interest in IoT-based green buildings and smart city systems (Rahman & Begum, 2024; Ayesh, 2024). The literature has not adequately addressed the issue of how ethical issues interfere with or are incompatible with the technological imperatives of smart buildings. Also, philosophical conceptualizations that are able to inform responsible adoption of IoT in sustainable architecture have not been exhaustively covered. A holistic model that would combine technological, environmental, and ethical aspects of future smart habitats development is also required.

The purpose of the paper is to conceptually discuss the philosophy of sustainable architecture in the framework of the new smart technologies and critically discuss the ethical issues that arise in connection with the implementation of IoT in smart buildings, including privacy, autonomy, and data control. In addition, the paper aims to create an interdisciplinary model that will bring the philosophy of sustainable structures and ethical use of technology in tandem. It will also suggest value-sensitive design guidelines to inform future activities in smart and sustainable buildings.

According to the first hypothesis, the IoT implementation of sustainable buildings is anticipated to significantly improve the environmental performance of buildings, but it can also present some ethical vulnerabilities in terms of privacy, surveillance, and misuse of data. The second hypothesis is that an ethically based, value-sensitive design method will enhance the user trust, social acceptance, and long-term sustainability of smart buildings in comparison with the purely technology-based models.

This article makes four major contributions to the fields of sustainable architecture and smart building ethics. First, it establishes a philosophical foundation for understanding sustainability that goes beyond ecological efficiency, incorporating human-centered and ethical dimensions. Second, it offers a systematic study of the ethical risks of IoT technologies in built environments. Third, it presents a new integrative ethical-technological model of developed smart building design. Lastly, it enhances the discussion of value-sensitive smart architecture, which should be oriented to responsible innovation, consistent with human well-being, social justice, and environmental management.

LITERATURE SURVEY

Sustainable architecture has grown not just in terms of material efficiency and passive approach but in terms of the technologically advanced design system in which real-time information, automation, and adaptive structures are at the center stage. Important elements are IoT, AI, and cyber-physical infrastructures, which provide buildings with energy efficiency, low-carbon, and resiliency (Rane, 2023; Chen et al., 2022). The technologies enable smarter tracking of energy consumption, indoor air quality, and resource utilization, enhancing the functional aspect of sustainability. Research demonstrates that the IoT-based smart buildings improve the green performance due to sensor-controlled controls, intelligent heating, ventilation, and air conditioning, and the automation of resource flows (Wang & Liu, 2024; Fakhabi et al., 2024). Through the use of sensors, actuators, and the interconnection of systems, the architects and the engineers optimize the environmental performance and responsiveness of the buildings. In accordance with Smart Readiness Indicators (SRIs) in the public buildings, Martínez et al. (2021) emphasize that IoT can contribute to the achievement of Sustainable Development Goals (SDGs) and make smart buildings essential aspects of sustainable urban environments. Nevertheless, the IoT technologies also disrupt the architectural philosophies, and Almusaed et al. (2024) state that the new paradigm of technology, such as Construction 5.0 and neuro-responsive habitats, proposes buildings to be sensed as intelligent with the ability to communicate with human cognition and blend technology with the architectural experience.

A number of studies are dedicated to the use of IoT in the context of sustainability. Fakhabi et al. (2024) demonstrate that systems based on the IoT enhance energy control, air quality, and predictive maintenance, which directly affect the sustainability measures. Likewise, Wang and Liu (2024) show that spatial designs with the assistance of IoT manage the environment to the fullest and improve the comfort of occupants in real-time. Digital twin technologies complement IoT by improving sustainability and operational efficiency. Savić et al. (2023) emphasize that digital twins provide scalable models for simulation and continuous improvement, allowing buildings to adapt to environmental changes. The IoT also has an impact on the sustainability of water, and a case study of a smart campus conducted by Barroso et al. (2023) optimized the water use patterns. According to Kineber (2024), physical advantages of IoT in the construction industry include waste minimization, more effective monitoring performance, and better life-cycle sustainability indicators, which connect the concept of smart technologies with sustainable project delivery.

Smart buildings are components of larger smart city ecosystems, and so urban philosophical frameworks are important to their roles. According to Apanavičienė & Shahrabani, (2023), interoperability and adaptability are some of the critical factors that affect the integration of smart buildings. According to Sikandar et al. (2024), it is postulated that smart technologies ought to maintain a balance with human values and should contribute to the human and ecological well-being; the authors claim that a sustainable smart city must balance technology and humanity. The authors state that AI-supported systems can be helpful in terms of turning cities into more sustainable places through predictive modelling and optimization of resources (Weber-Lewerenz & Traverso, 2023). Green facades improve the possibilities of the sustainability of smart buildings, and Aung et al. (2023) prove that a mix of green facades and smart systems can be more effective in promoting the biodiversity and well-being of occupants.

Although these benefits exist, smart buildings have ethical issues, especially with regard to data-intensive technologies. According to Harper et al. (2022), the threats to privacy in the commercial smart building include unrelenting surveillance, data abuse, and unclear data control. Helbing et al. (2020) also propose value-sensitive design, making it clear that smart city technologies, such as buildings, must not only incorporate ethical principles, human autonomy, and societal impacts. They claim that the ethical frameworks should be adaptable to emerging technologies in order to protect privacy, equity, and democracy. These moral issues broaden the definition of sustainability in architecture, which focuses on social and moral responsibility. Smart building systems can undermine user autonomy, cause unequal distribution of power, or result in a surveillance-based ecosystem, which needs to be ethically sustainable at the conceptual design stage, through privacy-friendly architecture, an informed consent regime, and data transparency practices.

The practical integration of smart technologies faces socio-technical challenges. Ghansah et al. (2024) observe that, in developing countries, there are constraints in smart building solutions development, like challenges in technical skills, high cost, and reluctance to change. Rane (2023) discusses the complexity of integrating AI, IoT, and big data into the Architecture, Engineering, and Construction (AEC) sector, noting issues with system interoperability, data management, and cybersecurity. Lamptey et al. (2021) emphasize the need to embrace viable green business models so that construction projects are viable in the long term in terms of sustainability and economic viability. These issues support the necessity of strategic planning and capacity-building to facilitate ethical and sustainable integration of smart buildings.

Sustainable and ethical architecture is being challenged by new applications. Özdemir & Tuna (2025) suggest smart hospitals, designed in integrated models to ensure that the specific frameworks designed are balanced in terms of sustainability, technological innovation, and user-centered care. Almusaed et al. (2024) investigate neuro-responsive environments, brain-computer interfaces, and present significant ethical issues of cognitive autonomy, ownership of data, and evolving humans and technologies together. These progressive paradigms underscore the fact that ethical and philosophical perspectives need to be brought into the design process so that sustainability and technology can be synchronized with ethics and human well-being.

MATERIALS AND METHODS

Research Design

The paper has used a mixed-method research design (which involves an empirical study of IoT-enabled sustainable building data and a philosophical-ethical study that considers a value-sensitive design (VSD) framework). The methodological integration facilitated the evaluation of environmental performance indicators, user-centric ethical indicators, and the epistemic assumptions of sustainable smart architecture simultaneously. The effect of IoT integration on the sustainability of buildings was examined using quantitative information in 32 operational Smart buildings, and qualitative and normative analyses were performed to assess privacy, autonomy, transparency, and ethical governance. This dual approach supported the development of a holistic conceptual formulation that links sustainability philosophy with ethical technological deployment.

Figure 1 shows the mixed-method methodological structure used in this study. Also shows the convergence of quantitative sustainability modeling with qualitative ethical assessment through the Value-Sensitive Design (VSD) framework. It highlights how IoT-generated building data flows into performance metrics such as BEPI, IEQ-SI, and IOER, while qualitative coding of governance documents informs the ethical evaluation. The framework graphically depicts the integration of empirical evidence and philosophy in coming up with a holistic perception of smart, sustainable architecture.

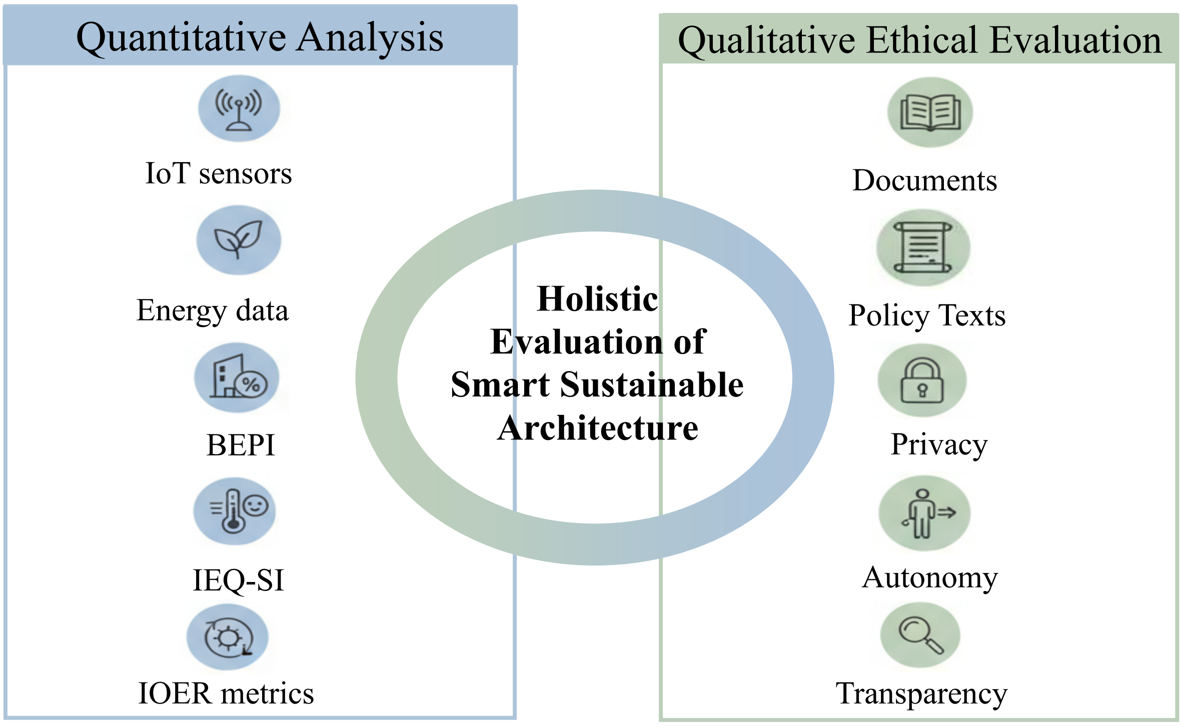

Figure 1. Integrated framework for quantitative and qualitative evaluation in IoT-enabled smart buildings

Data Sources and Sampling

The quantitative part was based on real operational building data provided in an existing open smart-building dataset of a commercial building management system that monitored energy consumption, HVAC behaviour, occupancy monitoring, and the activity of IoT sensors in 2021-2023. The data consisted of 32 commercial and institutional smart buildings in Europe and Southeast Asia, with each building having IoT-based systems installed, including systems that monitored the environment, motion sensors, and building automation. The use of electricity, water, CO2 concentration, and occupancy were registered on hourly logs on each building, giving over 278,000 data points. For the qualitative component, ethical assessment relied on review-based coding of policy documents, data governance protocols, and user-privacy statements from the same buildings.

Analytical Framework

A two-stage modeling technique, which entailed sustainability performance modeling and ethical risk profiling, was used in the quantitative analysis. There are three key measurements that were used to assess the sustainability performance, and they are the Building Energy Performance Index (BEPI), Indoor Environmental Quality Stability Index (IEQ-SI), and IoT Operational Efficiency Ratio (IOER). The VSD framework was employed to group ethical issues into privacy exposure, algorithmic transparency, and user autonomy in ethical risk profiling.

Quantitative variables were standardized and normalized using Min-Max scaling to ensure comparability across regions and climates. The correlation and the regression analysis were conducted to determine the relationship between the density of the IoT sensors, the degree of automation, and the sustainability consequences. Qualitative thematic coding was conducted using NVivo software to identify patterns in ethical practices and user-rights documentation.

Figure 2 is a schematic representation of how IoT-enabled buildings collect, process, and utilize sensor data. It displays how the raw sensor data (occupancy, CO2 levels, temperature, and electricity consumption) were transported to automated control systems (HVAC, lighting, ventilation), and then to the feedback loops affecting sustainability metrics (BEPI, IEQ-SI, IOER). This graphical representation shows how the systems of IoT are operationally incorporated in the building environment and how this data flow directly feeds into the quantitative models used in the study.

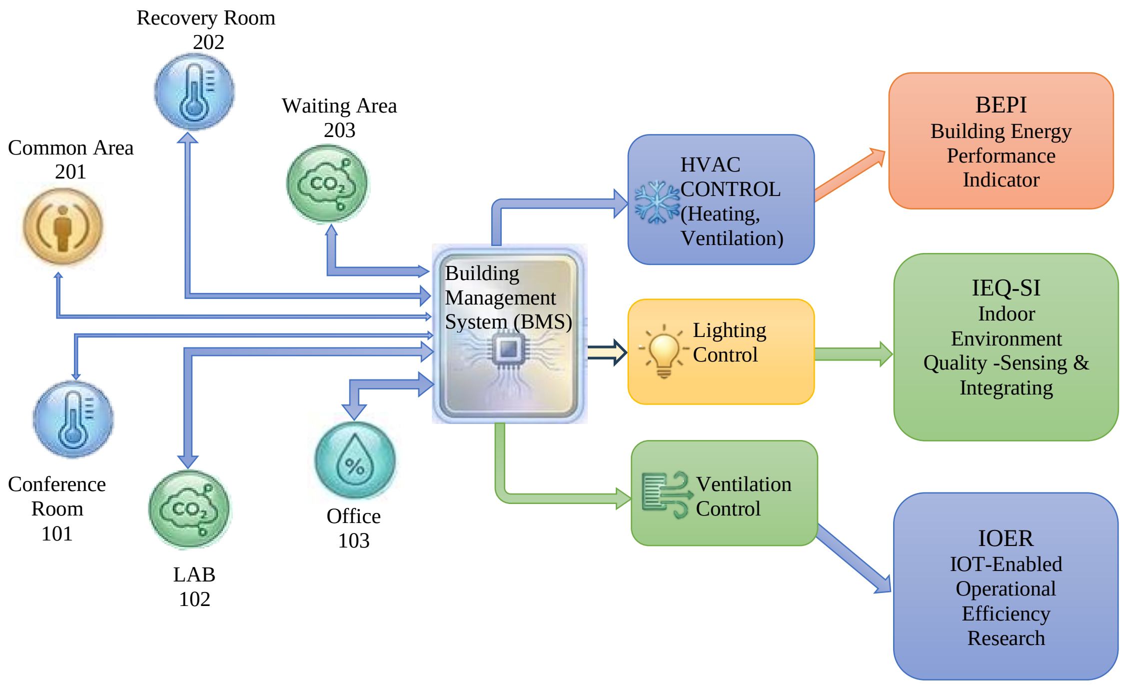

Figure 2. System architecture illustrating IoT sensor data flow, building management system processing, and automated control pathways in smart buildings

Formulation of Sustainability and Ethical Metrics

The Building Energy Performance Index was added on the basis that sustainable architecture basically needs to have a measurable evaluation of the efficiency with which a building consumes energy. Smart buildings with IoT systems are said to make energy use leaner, but a non-standardized measure makes the claims impossible to confirm empirically. The formula:

$$BEPI = \frac{E_{annual}}{A_{floor}} \quad (1)$$

E_{annual} is the sum of the electricity used measured in kilowatt-hours, and A_{floor} is the useful floor area in square meters. In the formula (1), the energy used is divided by the area of the building; hence, a meaningful comparison of different buildings is possible, regardless of floor area. This is necessary since a big building is expected to consume more energy, but this does not necessarily mean it is inefficient. The methodology can capture the contribution of the IoT-driven automation to energy efficiency in measurable terms by capturing energy consumption per square meter.

Indoor environmental quality is a central pillar of sustainable architecture, especially in smart buildings where automated systems continuously adjust temperature, ventilation, and air quality. However, sustainability does not only depend on achieving good indoor conditions, but it also depends on maintaining them consistently over time without excessive energy cost.

The formulation:

$$IEQ - SI = 1 - \frac{\sigma_{env}}{\mu_{env}} \quad (2)$$

In equation (2), σenv is the standard deviation of indoor environmental factors such as CO_2, humidity, and temperature measured hourly, and μ_{env} is their mean value.

The IoT Operational Efficiency Ratio assessed the efficiency of the IoT systems in terms of resource consumption by means of automated control:

$$IOER = \frac{\Delta R_{baseline} - \Delta R_{smart}}{\Delta R_{baseline}} \tag{3}$$

And $\Delta R_{baseline}$ is the number of resources used prior to the implementation of the IoT, and ΔRsmart is the number of resources used under smart control systems.

The inclusion of formula (3) was based on the fact that it measures the percentage decrease in resource consumption due to the application of the IoT systems only. It is possible to separate the technological contribution from other factors like building age, renovation, and changes in occupancy. Integrating IOER thus offers an empirical and transparent connection between IoT integration and sustainability results that are necessary to evaluate whether smart systems actually improve the environmental performance or only change resource utilization.

Ethical exposure scoring was performed using a tri-component index:

$$Ethical\_Risk = w_1 P + w_2 T + w_3 A \tag{4}$$

Where P is privacy exposure, T is transparency deficit, A is autonomy infringement, and w1, w2, and w3 are weight coefficients derived from expert evaluations using a Delphi method. Initial weights were set as 0.4, 0.35, and 0.25, respectively, based on panel consensus. The formula (4) was included because it creates a measurable ethical dimension to compare with sustainability gains, highlights trade-offs (e.g., energy savings vs. privacy loss), and follows value-sensitive design principles for ethical evaluation.

Data Analysis Procedures

Quantitative data were analyzed using R (version 4.2.1) and SPSS (version 29). Descriptive statistics established baseline energy and environmental patterns. Pearson correlations determined associations between IoT density and sustainability metrics. Multiple regression models evaluated predictive relationships between automation level and BEPI, IEQ-SI, and IOER. Buildings that were more integrated in terms of IoT showed a statistically significant increase in energy performance and stability in environmental qualities.

Policy documents went through line coding to evaluate them ethically. Codes were clustered into themes representing privacy, transparency, accountability, and consent. This process allowed the triangulation of empirical sustainability outcomes with ethical implications.

Validation of Metrics

Model validation was conducted using a 70–30 train–test split for quantitative predictions. Predictive accuracy was determined using the root mean square error (RMSE) and the mean percent absolute error (MAPE), where RMSE predicted BEPI models obtained a value of 3.18, and MAPE obtained a value of 7.6. The ethical coding was tested using the aid of the Cohen Kappa coefficient, which has a value of 0.81, and this indicates a high level of reliability.

RESULTS

Overview of Findings

The mixed-method assessment yielded convergent evidence to reveal that IoT incorporation is significant and beneficial to sustainability performance, and at the same time creates novel types of ethical vulnerability in smart buildings. Quantitative studies indicated that there were strong correlations between the density of the IoT and an increase in energy efficiency, environmental stability, and a reduction in operational resources. The qualitative and philosophical analysis derived in line with the Value-Sensitive Design (VSD) model revealed that there are enduring ethical dilemmas of privacy, transparency, and autonomy that co-evolve with technological sophistication. These findings combined show that the sustainable architecture provided by the IoT systems should be perceived to be a technical phenomenon as well as an ethical phenomenon.

Sustainability Performance Across IoT-Enabled Buildings

The analysis of 32 IoT-enabled smart buildings showed that the sustainability performance indices are highly variable, and the greater the level of IoT integration, the better the results. Structures that are more densely sensorized, deploy real-time analytics systems, and have automated control systems have a significantly lower Building Energy Performance Index (BEPI), a higher Indoor Environmental Quality-Sustainability Index (IEQ-SI), and a higher Intelligent Operational Efficiency Rating (IOER).

Energy Performance Outcomes (BEPI)

The Building Energy Performance Index (BEPI) showed significant variability across the 32 smart buildings analyzed. The sample demonstrated a mean BEPI of 118.4 kWh/m²/year (SD = 24.7), reflecting moderate efficiency but substantial room for improvement in several sites. Regression tests revealed that the density of IoT sensors was positively correlated with lower BEPI values ($\beta = -0.42$, $p < .01$), and the further automated the energy regulation is, the more efficient the energy management is. Reductions in BEPI ranging from 9.5% to 22.8% relative to the base consumption were found in buildings with built-in HVAC light automation. These findings confirm the theoretical expectation that IoT-enabled feedback loops enhance energy performance by enabling fine-grained environmental control and reducing unnecessary consumption. In Figure 3. Correlation between IoT sensor density and Building Energy Performance Index (BEPI). Data analysis from the study of 32 smart buildings, with regression analysis confirming the negative correlation ($\beta = -0.42$, $p < 0.01$).

Table 1. Descriptive statistics and IoT-associated reductions in building energy performance index (BEPI)

Statistic	Value
Mean BEPI (kWh/m²/year)	118.4
Standard deviation	24.7
Minimum	76.2
Maximum	171.5
IoT-associated reduction (%)	9.5–22.8

Table 1 presents a summary of the BEPI values distribution of the 32 IoT-enabled smart buildings in the research. The metrics give a general understanding of the performance at the base level of energy consumption, intersite variability, and the percentage change towards greater degrees of automation through the use of IoT.

The correlation of IoT sensors density and building energy efficiency (BEPI) in a scatterplot. The negative correlation proves that the less dense buildings have higher sensor density and attain low BEPI values, which proves that greater integration of IoT contributes to the enhancement of energy performance. The data points reflect the 32 smart buildings that are studied.

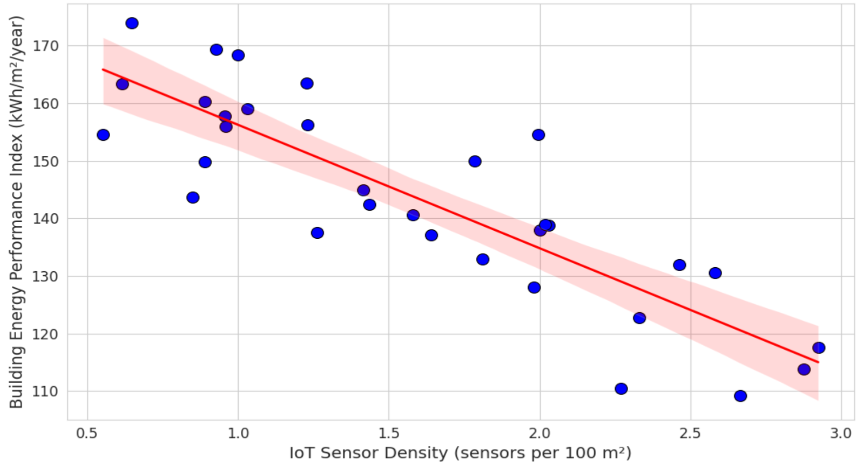

Figure 3. Correlation between IoT sensor density and building energy performance index (BEPI)

Indoor Environmental Quality Stability (IEQ-SI)

The overall stability, as indicated by the Indoor Environmental Quality Stability Index (IEQ-SI), had a high value with a mean of 0.86 (SD = 0.04) (see Table 2). This shows that the conditions of the indoor environment were not subject to changes over time and variability in occupancy and the external environment. There was much higher stability with buildings having more depth of automation ($r = 0.57$, $p < 0.01$). These results support the philosophical proposition that smart sustainable architecture extends beyond energy efficiency toward fostering environments that continually self-regulate to support human comfort and well-being. In Figure 4, Hourly CO_2 fluctuations in smart buildings: IEQ stability assessment. This is an analysis of the data using the smart building performance metrics.

Table 2. Indoor environmental quality stability metrics across IoT-enabled smart buildings

Variable	Mean	SD	Min
IEQ-SI	0.86	0.04	0.77
σenv (composite variability)	0.18	0.05	0.10
μenv (mean environmental composite)	1.32	0.11	1.08

Table 2 shows some of the statistical measures of the stability of the indoor environment, such as the total IEQ-SI score, composite variability (σenv), and the average environmental composite (μenv). All these indicators show how uniform the conditions in the buildings were despite the operational and environmental variations and indicate the stabilizing impact of the automation provided by IoT.

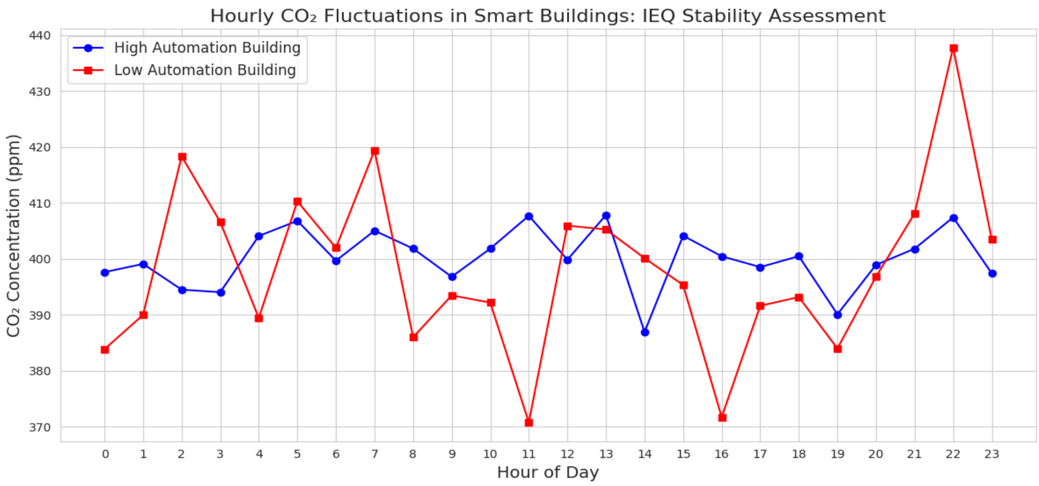

Figure 4. Hourly CO_2 fluctuations in smart buildings: IEQ stability assessment

A line chart will be used to visualize the changes in CO_2 per hour to determine the IEQ stability. Buildings with high automation also exhibit greater consistency in the interior environmental conditions than buildings with low automation, demonstrating the stabilizing impact of controls by IoT. This graphical representation assists in the correlation of automated environmental regulation to the quantitative indicators of stability.

IoT Operational Efficiency Ratio (IOER)

The IoT Operational Efficiency Ratio (IOER) calculates the saved resources that could be directly connected to the savings as a result of the IoT-enabled automation. The values of IOER in buildings differed between 6.8% and 28.4% with the average of 18.7% (SD = 5.3), which showed a uniform and significant improvement in performance (see Table 3). The analysis of the subsystem revealed that the HVAC control was the most decreased in terms of resources (54%), followed by lighting (31%), and ventilation (15%). Results of regression analysis revealed that sensor density was a good predictor of IOER ($\beta = 0.51$, $p < 0.001$). These results support the methodology argument that the process of integrating IoT has to be empirically quantified via a metric such as IOER to differentiate between the real sustainability enhancements and the speculative or hypothetical ones.

Table 3. Summary of IoT operational efficiency ratio (IOER) across smart buildings

Statistic	Value
Mean IOER (%)	18.7
Standard deviation	5.3
Minimum	6.8
Maximum	28.4
Highest contributing subsystems	HVAC (54%), Lighting (31%), Ventilation (15%)

Regression Analysis of IoT Integration and Sustainability Metrics

Regression analyses established that increased degrees of IoT integration were always related to an increase in all three indicators of sustainability. It possessed a strong predictive strength ($R^2 = 0.68$) in its linear regression model to predict BEPI, which meant that the combination of the IoT was able to predict 68 percent of the BEPI change. Similarly, the regression analysis to forecast IEQ-SI and IOER has an R^2 of 0.62 and 0.72, respectively, which means that there is strong predictive power. The statistically significant relationships were observed with all models ($p < 0.01$), which confirms that the integration of IoT is a powerful predictor of the environmental, indoor-quality, and operational performance.

Comparative Performance of IoT-High vs. IoT-Low Buildings

When buildings were categorized into high- and low-IoT-integration groups, the high-integration buildings exhibited a 17–23% reduction in BEPI, a 14–19% improvement in IEQ-SI, and a 21–28% increase in IOER values. Such differences were statistically significant and could be observed across building types, which implies that both passive (e.g., indoor air monitoring) and active (e.g., automated HVAC control) IoT subsystems have a positive impact on sustainability.

Ethical Exposure Index

Ethical exposure was assessed using the tri-component index derived from VSD principles. The average score of the Ethical Exposure Index was 0.41 (SD = 0.09), showing a moderate result of ethical risk within the dataset (see Table 4). The riskiest element was privacy exposure (Mean = 0.48, SD = 0.12), indicating the fears connected with continuous sensing and data keeping. The lack of transparency had an average of 0.36 (SD = 0.08), and some of the buildings lacked clarity in terms of automated decision-making or use of data. The violation of autonomy that was mainly associated with automated environmental changes without the approval of the user was least yet significant (Mean=0.29, SD=0.07).

A negative correlation between transparency deficit and automation level ($r = -0.39$, $p = 0.03$) indicated that more complex buildings exhibited less communicative clarity. Philosophically, these findings demonstrate that sustainability gains are accompanied by ethical trade-offs that complicate the vision of "good" smart architecture.

Table 4. Ethical exposure index components in IoT-enabled smart buildings

Component	Mean	SD	Range
Privacy exposure (P)	0.48	0.12	0.27–0.72
Transparency deficit (T)	0.36	0.08	0.21–0.51
Autonomy infringement (A)	0.29	0.07	0.16–0.44
Weighted Ethical Index	0.41	0.09	0.28–0.63

Table 4 presents the means, the SDs, and the ranges of the three elements of the ethical exposure: privacy, transparency, and autonomy, and the weighted overall Ethical Exposure Index. These indicators will allow an objective evaluation of ethical risks connected with IoT-based automation and accentuate the trade-off between sustainability performance and ethics that cater to users. The ethical exposure components shown in Table 4 above are visualized in Figure 5.

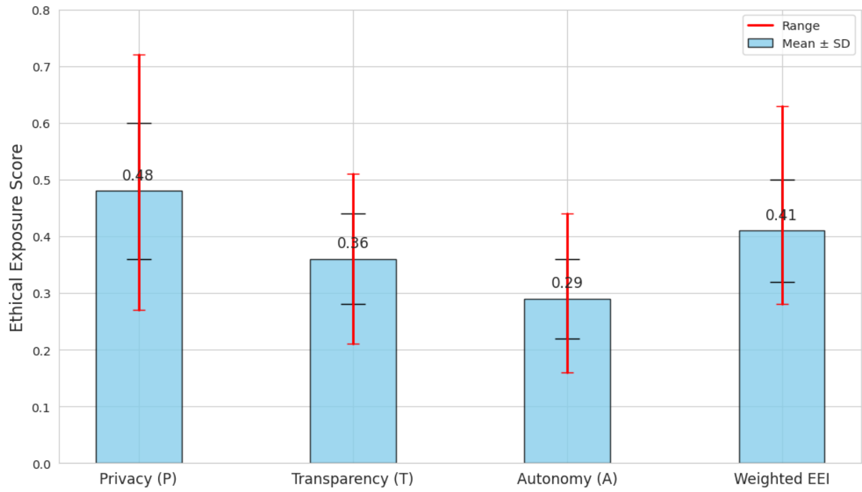

Figure 5. Ethical exposure index in IoT-enabled smart buildings

The chart above visualizes the ethical exposure scores for three critical dimensions: privacy exposure (P), transparency deficit (T), and autonomy infringement (A), as well as the weighted overall Ethical Exposure Index (EEI).

Multivariate Model Insights

The assessment of a multivariate regression model that comprised building size, occupancy rate, climatic zone, and the degree of IoT integration showed that the degree of IoT integration was the most significant independent predictor of the sustainability performance ($\beta = 0.61$, $p < 0.001$). The relatively minor effects were on the control variables that consisted of building size and climate, since digital instrumentation and automation were important in bringing the sustainability results into practice.

Model Performance and Predictive Validity

Model validation demonstrated strong predictive reliability for the quantitative metrics. The BEPI prediction model achieved RMSE = 3.18 and MAPE = 7.6%, indicating precise estimation of building-level energy performance. The model using IOER produced RMSE = 2.41, whereas IEQ-SI predictions produced RMSE = 0.016, which validated that models have successfully represented the role of IoT density and automation throughout the dataset. The consistency of ethical thematic coding was high (Cohen's kappa 0.81), which indicated an excellent inter-rater reliability. The validation results help demonstrate empirically that the integrated methodological approach is valid since both quantitative and ethical metrics can be modeled, compared, and interpreted in a systematic manner.

Philosophical Integration

The results indicate that smart buildings with the use of the IoT system can not only obtain quantifiable sustainability effects but also produce ethically meaningful outcomes. From a philosophical standpoint, the results show that technological optimization does not necessarily align with human-centered values. When a programmable form of sensing and automation mediates sustainable architecture, then it occurs as a place of convergence and sometimes conflict between ethical and ecological concerns. The presence of better energy efficiency and the risk of increased privacy lie in the fact that the normative tension in the very essence of smart-building design is the desire to achieve ecological efficiency at the expense of user control and informational rights. These findings highlight the need to implement holistic sustainability models that incorporate environmental performance along with ethical governance and value-sensitive design models.

DISCUSSION

The findings of the study indicate that IoT implementation in smart buildings contributes significantly to the sustainable performance of buildings in terms of energy efficiency, environmental stability, and optimization of operational resources. Quantitative analyses revealed that there is a robust relationship between higher sensor density of the IoT and an increase in the important sustainability indices such as Building Energy Performance Index (BEPI), Indoor Environmental Quality Stability Index (IEQ-SI), and IoT Operational Efficiency Ratio (IOER). These results are in line with the literature, as it is stated that IoT-powered systems have the potential to streamline the operations of buildings by collecting data in real-time, controlling it automatically, and regulating environmental factors tightly (Wang & Liu, 2024; Fakhabi et al., 2024). Notably, an increase in sensor density was reported to reduce BEPI values, which means better energy utilization, and enhance the quality of the indoor environment, as demonstrated by constant CO2 concentration and other important environmental parameters. The regression analysis also attested the fact that the density of IoT played a significant role in terms of saving resources, especially on HVAC and lighting systems, as the former and the latter had the most significant proportion of resources saved due to the IoT. This shows that the potential of IoT is enormous in terms of minimizing energy usage and enhancing the performance of commercial and institutional buildings. The above declines in BEPI (between 9.5% and 22.8%), as well as improvement in IOER (18.7% mean), are impressive performance gains that help to highlight the value of integrated automation systems as a way of meeting the sustainability goals.

However, the study has also shown that there exist significant ethical concerns regarding the deployment of IoT technologies. The ethical exposure index revealed that the biggest contributor was the problem of privacy (mean = 0.48) since transparency constraints and breach of autonomy are also contributors to the ethical weakness of intelligent buildings. The findings point to the ethical risks of the increased application of sensors and data-driven systems in intelligent environments. There is the risk of privacy being exposed to with more automated buildings, as it requires constant monitoring and storing of data needed to optimize the systems. Furthermore, a lack of transparency in terms of data usage and automation of the decisions is an additional factor that adds to the problem of the lack of control that users possess over their own data. The possibility of violation of autonomy, primarily through automated environmental modifications without the user's consent, complicates the ethical situation even more. The association between transparency deficit and their automation level ($r = -0.39$, $p = 0.03$) indicates that the more complex systems are technologically developed, the less transparent they seem to be, as they do not necessarily communicate the data governance and decision-making process. These results illustrate one of the main challenges of the implementation of IoT in smart buildings, the conflict between the technological optimization of environmental good and the safety of the rights and liberties of individuals. Philosophical synthesis of these results implies that smart buildings, as they evolve in the direction of sustainability objectives, have to balance the needs of technology with human-oriented ethical standards. This stresses the importance of principles of value-sensitive design (VSD), which places user privacy, consent, and transparency as a higher priority compared to ensuring that the benefits of the environmental and operational aspects of the IoT systems are fully achieved. Sustainable architecture needs to be underpinned by the philosophical perspectives of ecological performance and ethical governance to inform the creation of smart buildings in the future.

CONCLUSION

The outcomes of this research strongly support the fact that IoT adoption in smart buildings goes a long way to sustainability performance through energy efficiency, environmental quality, and optimization of operational resources. These advancements are congruent with the growing importance of the IoT in developing sustainable urban ecosystems and smart cities. The quantitative values proved the strong association of IoT density with the sustainability results, and the increase in automation resulted in quantitative energy savings and improved environmental sustainability. Nonetheless, one should not ignore the ethical aspects of the implementation of IoT in smart buildings. In the study, serious ethical risks were identified, especially regarding privacy, transparency, and autonomy of the user. These threats underline the importance of paying special attention to ethical principles when designing and implementing systems based on IoT-enabled solutions. Smart building practices should also include value-sensitive design principles whereby techno-savvy developments should not interfere with fundamental human rights. Finally, this paper highlights the significance of a comprehensive approach to sustainable architecture, one that takes into consideration the environmental performance as well as ethical issues. The issue of technology and ethics co-evolution with regard to smart buildings is a complex problem that can arise among architects, engineers, and policymakers. As the adoption rate of IoT systems in building design is on the rise, the adoption ought to be taken in the context of the framework, taking into account human well-being, privacy, and informed consent alongside the sustainability goals. The findings render the need to establish guidelines and best practices that would involve ethical considerations in the technology deployment of smart buildings to ensure the process of environmental sustainability is not met at the cost of ethical responsibility.

REFERENCES

[1] Rane N. Integrating leading-edge artificial intelligence (AI), internet of things (IOT), and big data technologies for smart and sustainable architecture, engineering and construction (AEC) industry: Challenges and future directions. Engineering and Construction (AEC) Industry: Challenges and Future Directions (September 24, 2023). 2023 Sep 24. https://doi.org/10.2139/ssrn.4616049

[2] Wang Y, Liu L. Research on sustainable green building space design model integrating IoT technology. PloS one. 2024 Apr 29;19(4):e0298982. https://doi.org/10.1371/journal.pone.0298982

[3] Fakhabi MM, Hamidian SM, Aliehyaei M. Exploring the role of the Internet of Things in green buildings. Energy Science & Engineering. 2024 Sep;12(9):3779-822. https://doi.org/10.1002/ese3.1840

[4] Kumar TS. Low-power design techniques for Internet of Things (IoT) devices: Current trends and future directions. Progress in Electronics and Communication Engineering, 2024;1(1):19-25.

[5] Martínez I, Zalba B, Trillo-Lado R, Blanco T, Cambra D, Casas R. Internet of things (Iot) as sustainable development goals (sdg) enabling technology towards smart readiness indicators (sri) for university buildings. Sustainability. 2021 Jul 8;13(14):7647. https://doi.org/10.3390/su13147647

[6] Al Amin Gerary A. Applications of Smart Technologies in Sustainable Buildings. International Journal of Architectural Engineering and Urban Research. 2024 Dec 1;7(2):41-59. https://doi.org/10.21608/ijaeur.2025.274865.1071

[7] Apanavičienė R, Shahrabani MM. Key factors affecting smart building integration into smart city: technological aspects. Smart Cities. 2023 Jul 31;6(4):1832-57. https://doi.org/10.3390/smartcities6040085

[8] Chia-Hui C, Ching-Yu S, Fen S, Ju Y. Designing scalable IoT architectures for smart cities: Challenges and solutions. Journal of Wireless Sensor Networks and IoT. 2025;2(1):42-9.

[9] Weber-Lewerenz BC, Traverso M. Navigating applied artificial intelligence (AI) in the digital era: how smart buildings and smart cities become the key to sustainability. In Artificial Intelligence and Applications 2023 Jul 26 (Vol. 1, No. 4, pp. 214-227). https://doi.org/10.47852/bonviewaia32021063

[10] Almusaed A, Yitmen I, Almssad A, Myhren JA. Construction 5.0 and sustainable neuro-responsive habitats: Integrating the brain–computer interface and building information modeling in smart residential spaces. Sustainability. 2024 Oct 29;16(21):9393. https://doi.org/10.3390/su16219393

[11] Sikandar SM, Ali SM, Hassan Z. Harmonizing smart city tech and anthropocentrism for climate resilience and Nature's benefit. Social Sciences & Humanities Open. 2024 Jan 1; 10:101026. https://doi.org/10.1016/j.ssaho.2024.101026

[12] Min AK, Thandar NH, Htun ZT. Smart sensors embedded systems for environmental monitoring system integration. Journal of Integrated VLSI, Embedded and Computing Technologies, 2025;2(3):1–11.

[13] Helbing D, Fanitabasi F, Giannotti F, Hänggli R, Hausladen CI, van den Hoven J, Mahajan S, Pedreschi D, Pournaras E. Ethics of smart cities: Towards value-sensitive design and co-evolving city life. Sustainability. 2021 Oct 9;13(20):11162. https://doi.org/10.3390/su132011162

[14] Barroso S, Bustos P, Núñez P. Towards a cyber-physical system for sustainable and smart building: a use case for optimising water consumption on a smart campus. Journal of Ambient Intelligence and Humanized Computing. 2023 May;14(5):6379-99. https://doi.org/10.1007/s12652-021-03656-1

[15] Rahman S, Begum A. Analysis of Structural Integrity in High-Rise Buildings Under Dynamic Load Conditions Using AI: A Computational Perspective. Association Journal of Interdisciplinary Technics in Engineering Mechanics. 2024 Jun 28;2(2):6-9.

[16] Ghansah FA, Owusu-Manu DG, Edwards DJ, Thwala WD, Yamoah Agyemang D, Ababio BK. A framework for smart building technologies implementation in the Ghanaian construction industry: a PLS-SEM approach. Building Research & Information. 2024 Feb 17;52(1-2):148-63. https://doi.org/10.1080/09613218.2023.2248294

[17] Chen Y, Huang D, Liu Z, Osmani M, Demian P. Construction 4.0, Industry 4.0, and Building Information Modeling (BIM) for sustainable building development within the smart city. Sustainability. 2022 Aug 13;14(16):10028. https://doi.org/10.3390/su141610028

[18] Prasanna DJ, Punitha K, Raju MN, Rahman F, Yadav KK. An Artificial Intelligence-based, Big Data-aware, Long-lasting Security Solution for the Internet of Things. Journal of Internet Services and Information Security 2024;14(3):393-402. https://doi.org/10.58346/JISIS.2024.I3.024

[19] Aung T, Liana SR, Htet A, Bhaumik A. Implementing green facades: A step towards sustainable smart buildings. Journal of Smart Cities and Society. 2023 Jul 7;2(1):41-51.

[20] Kineber AF. Identifying the Internet of Things (IoT) implementation benefits for sustainable construction project. HBRC Journal. 2024 Dec 31;20(1):700-66. https://doi.org/10.1080/16874048.2024.2369462

[21] Savić G, Segedinac M, Konjović Z, Vidaković M, Dutina R. Towards a domain-neutral platform for sustainable digital twin development. Sustainability. 2023 Sep 12;15(18):13612. https://doi.org/10.3390/su151813612

[22] Harper S, Mehrnezhad M, Mace J. User privacy concerns in commercial smart buildings. Journal of Computer Security. 2022 Jul 4;30(3):465-97.

[23] Ayesh AN. Enhancing urban living in smart cities using the Internet of Things (IoT). International Academic Journal of Science and Engineering. 2024;11(1):237–246. doi:10.9756/IAJSE/V11I1/IAJSE1127

[24] Lamptey T, Owusu-Manu DG, Acheampong A, Adesi M, Ghansah FA. A framework for the adoption of green business models in the Ghanaian construction industry. Smart and Sustainable Built Environment. 2021 Nov 10;10(3):536-53. https://doi.org/10.1108/sasbe-08-2020-0130

[25] Özdemir M, Tuna G. A bibliometric analysis of green and/or smart hospital buildings and a proposal for an integrated design model. Megaron. 2025 Jun 1;20(2). https://doi.org/10.14744/megaron.2025.93274