REVIEW ARTICLE

Smart Buildings in the Age of Internet Technology: Civil Engineering's Role in Shaping an Energy-Efficient Future

Arkar Htet [1]*, Sui Reng Liana[1], Theingi Aung[1], Amiya Bhaumik[1]

[1]Faculty of Business and Accounting, Lincoln University, 47301 Petaling Jaya, Selangor D. E., Malaysia

Corresponding Author: Arkar Htet: arkarhm@gmail.com
Received: 01 May, 2023, Accepted: 10 June, 2023, Published: 15 June, 2023

Abstract
The integration of Internet Technology, particularly the Internet of Things (IoT), is radically transforming several sectors, including civil engineering and construction. This article scrutinizes the transformative capacity of IoT technology in formulating and deploying energy-efficient smart buildings. These innovative structures are designed for optimum efficiency, sustainability, and user experience. Various challenges and opportunities emerging within this rapidly growing domain are examined, and the future direction of smart building technology is anticipated, taking into account recent progress and innovative research. Within the context of contemporary civil engineering, this detailed analysis highlights the most recent advancements, providing valuable insights for other researchers in the field. This article contributes to the ongoing dialogue about the role of IoT in civil engineering and its potential to foster an energy-efficient future in smart building design and implementation.

Keywords: Smart Buildings, Internet Technology, Civil Engineering, Energy Efficiency, Sustainability

Introduction

Civil engineering and construction sectors are undergoing a transformative shift, propelled by the rapid integration of Internet Technologies, notably the Internet of Things (IoT) (Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I., 2012). Among the prominent outcomes of this technological revolution is the emergence of "smart buildings". These structures incorporate IoT technology to maximize energy efficiency, sustainability, and user experience, symbolizing a new era of innovative architecture (Shah, S. F. A., Iqbal, M., Aziz, Z., Rana, T. A., Khalid, A., Cheah, Y.-N., & Arif, M., 2022).
Global urbanization trends and the concurrent increase in energy consumption necessitate sustainable solutions to minimize the environmental impact of expanding cities (Arkar, H., Sui-Reng, L., Theingi, A., & Amiya, B., 2023). With growing calls for energy-efficient and sustainable infrastructures, smart buildings have become critical in addressing the myriad challenges of urban environments (Hashem, I. A. T., Chang, V., Anuar, N. B., Adewole, K., Yaqoob, I., Gani, A., ... & Chiroma, H, 2016).
This comprehensive review paper explores the intersection of civil engineering and IoT within the context of smart buildings, highlighting the imperative need for energy efficiency in modern infrastructural development. Further, the adoption and application of emerging technologies such as artificial intelligence, machine learning, and big data analytics underscore the potential for the evolution and innovation in the construction industry, shaping the future trajectory of infrastructure development (Theingi, A., Sui-Reng, L., Arkar, H., & Amiya, B., 2023).
A "smart building" is a structure that leverages advanced Internet Technologies, particularly IoT devices, to monitor, control, and optimize various building systems, encompassing automation, security, and energy management (O'Donovan, P., Leahy, K., Bruton, K. & O'Sullivan, D. T. J., 2015). This optimization is facilitated

by an intricate network of sensors, actuators, and communication systems that collect and process data in real-time, allowing the building to adapt to its occupants' needs and preferences (Al-Obaidi, K.M., Hossain, M., Alduais, N.A.M., Al-Duais, H.S., Omrany, H., & Ghaffarianhoseini, A., 2022). The overarching goal of smart buildings is to enhance the performance and energy efficiency of the built environment while mitigating resource consumption and environmental impact (Dounis, A. I., & Caraiscos, C., 2009). Given the global emphasis on reducing greenhouse gas emissions and promoting sustainable practices, the role of Internet Technologies in developing energy-efficient smart buildings becomes ever more paramount. This paper, therefore, seeks to contribute to the growing body of literature on this topic and offers insights that could guide future research and innovations in this field (Bakri Hassan, M., Sayed Ali Ahmed, E., & Saeed, R. A, 2021)."

IoT Technologies in Smart Buildings

IoT integration in smart buildings has created new possibilities for tracking, managing, and improving a variety of building systems. Some of the key IoT technologies employed in smart buildings include sensors, actuators, communication protocols, and data analytics (Bashir, M.R., Gill, A.Q. & Beydoun, G., 2022). In this section, we will delve into these technologies and explore their applications in energy management, security, and automation.

Figure 1: IoT Technologies Interaction Flow in a Smart Building

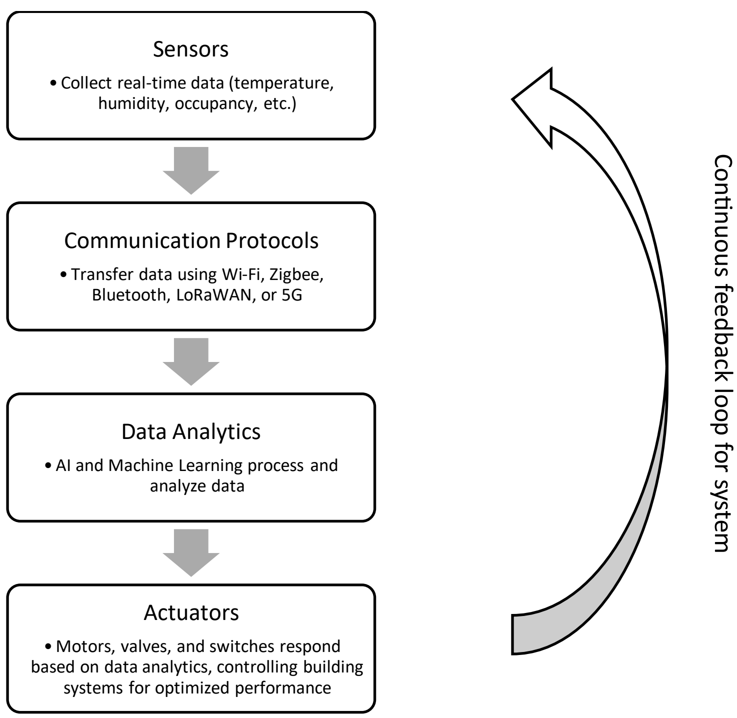


Figure 1 description: The flowchart presents the interaction of IoT technologies in a smart building. The process begins with sensors collecting real-time data, which is then transferred via various communication protocols. This data is processed and analyzed by AI and machine learning techniques in the data analytics stage. Based on these insights, actuators control various building systems for optimal performance, thus completing the feedback loop.

Sensors: In order to collect real-time data from the built environment, sensors are a crucial component of smart buildings (Kaligambe, A., Fujita, G., & Keisuke, T., 2022). In smart buildings, a variety of sensors are used, including temperature, humidity, occupancy, light, and air quality sensors. These sensors continuously monitor the building conditions, providing critical information for optimizing building performance and occupant comfort (Floris, A., Porcu, S., Girau, R., & Atzori, L. , 2021).

Actuators: Actuators are devices that convert an input signal into a physical action, allowing smart buildings to respond to the data collected by sensors (Roopa, H. S., & Jhansi, R. P. , 2017). Common actuators used in smart buildings include motors, valves, and switches, which control HVAC systems, lighting, and other building elements. By automating these controls, actuators enable real-time adjustments to building systems, resulting in improved efficiency and occupant comfort (Carli, R., Cavone, G., Ben Othman, S., & Dotoli, M., 2020).

Communication Protocols: Effective communication between IoT devices is critical for the seamless operation of smart buildings. Various communication protocols are used to facilitate data transfer between sensors, actuators, and other IoT devices. Some popular protocols include Wi-Fi, Zigbee, Bluetooth, LoRaWAN, and 5G (Jeongmi, S. & Yeonseung, R. , 2016). The selection of a communication protocol is influenced by variables such network topology, range, power consumption, and data rate (Jamuna, M., & Vijaya Prakash, A.M., 2021).

Data Analytics: The processing of the enormous amounts of data produced by IoT devices in smart buildings depends critically on data analytics. Increasingly, this data is being examined using machine learning and artificial intelligence (AI) approaches, allowing for the extraction of insightful conclusions and forecasts (Khan, R., Khan, S. U., Zaheer, R., & Khan, S., 2019). These findings can be applied to improve occupant comfort, lower energy usage, and optimize building efficiency (Ahmad, M.W., Mourshed, M., Yuce, B., & Rezgui, Y. , 2016) .

Applications of IoT Technologies in Smart Buildings:

Energy Management: The monitoring and optimization of numerous energy-consuming systems made possible by IoT technologies has substantially improved energy management in smart buildings (Sanya, W., Bajpai, G., Kombo, O., & Twahirwa, E., 2022). Smart thermostats, for instance, may automatically regulate the temperature based on user preferences and occupancy, minimizing energy waste (Gupta, R., & Gregg, M.,, 2022). Additionally, IoT-enabled lighting systems can adjust their brightness levels depending on natural light availability and occupant presence, further contributing to energy savings (Vodovozov, A. M., & Burtsev, A. V., 2021). These are examples of how IoT can aid in creating an energy-efficient infrastructure within smart buildings.

Energy Efficiency: Energy efficiency is at the forefront of sustainable design and operation in smart buildings. By integrating IoT technologies, buildings can optimize the use of energy resources, reduce operational costs, and decrease environmental impact. Advanced energy metering and monitoring systems, together with predictive algorithms, can identify energy wastage patterns and recommend or implement energy-saving actions. Building Energy Management Systems (BEMS) are an example of such IoT-enabled systems that lead to more efficient energy utilization, creating a smarter and more sustainable built environment (Pan, J., Jain, R., Paul, S., Vu, T., Saifullah, A., & Sha, M., 2015).

Security: IoT technologies enhance the security of smart buildings by providing advanced monitoring and access control capabilities (Elrawy, M., Awad, A. & Hamed, H., 2018). For instance, smart cameras can employ AI algorithms to detect and analyze unusual activities, enabling real-time response to potential security threats (Khan, R., Khan, S. U., Zaheer, R., & Khan, S., 2019). Moreover, IoT-enabled access control systems can use biometric authentication, RFID tags, or smartphone-based credentials to provide secure and convenient access to authorized individuals (Kanchana, 2019).

Automation: IoT technologies facilitate the automation of various building systems, improving efficiency and user experience. Examples of automation in smart buildings include automated HVAC systems, which adjust temperature and airflow based on occupancy and user preferences (Terence, K.L., Hui, R., Simon, S., & Daniel, D. S., 2017), and smart blinds, which can automatically adjust their position based on sunlight intensity and angle to optimize natural light utilization and reduce energy consumption (Seong, 2015). Furthermore, IoT-enabled elevators can analyze real-time traffic patterns and adjust their operation accordingly, reducing waiting times and improving overall efficiency.

IoT technologies, which have applications in energy management, security, and automation, are essential for improving the performance of smart buildings. As advancements in sensor technology, communication protocols, and data analytics continue to evolve, the potential for further improvements in smart building performance will likely increase. By harnessing the power of IoT, civil engineers and building professionals can create sustainable, efficient, and user-friendly built environments for the future.

Benefits of Smart Buildings

Smart buildings, which integrate IoT technologies to monitor, control, and optimize various systems, offer numerous advantages over traditional buildings. These advantages include enhanced efficiency, sustainability, and user experience, contributing to improved building performance and occupant well-being. This section will go over the possible advantages of smart buildings and provide illustrations of actual initiatives that have had good effects.

Enhanced Efficiency: Smart buildings can significantly improve energy and resource efficiency by utilizing IoT technologies to monitor and optimize the performance of various building systems (Shah, S. F. A., Iqbal, M., Aziz, Z., Rana, T. A., Khalid, A., Cheah, Y.-N., & Arif, M., 2022). For example, smart HVAC systems can adjust temperature and airflow based on occupancy and user preferences, reducing energy waste and lowering utility costs (Behdad, R., & Paul G. O'Brien, 2021). Additionally, IoT-enabled lighting systems can optimize energy consumption by adjusting brightness levels depending on natural light availability and occupant presence (Yuan-Ko, 2023). These efficiency improvements can result in substantial cost savings for building owners and operators.

Sustainability: By increasing energy efficiency and reducing resource consumption, smart buildings contribute to overall sustainability efforts. By controlling energy generation, storage, and distribution, IoT technologies allow smart buildings to more efficiently use renewable energy sources, such as solar or wind power (Singh, & Dhawan., 2023). Furthermore, smart water management systems can monitor water usage and detect leaks in real-time, preventing waste and conserving valuable resources (Fuentes, H., & Mauricio, D., 2020).

User Experience: IoT technology integration in smart buildings enables a more cozy and individualized user experience. Advanced monitoring and control systems can adapt building conditions to individual preferences, such as temperature, lighting, and air quality (Zafari, F., Papapanagiotou, I., & Christidis, K., 2016). Moreover, smart buildings can provide occupants with real-time information about building conditions, energy usage, and available amenities, fostering a sense of awareness and engagement in sustainable practices (Arditi, D., Mangano, G. & De Marco, A., 2015).

Real-World Examples of Smart Building Projects

The Edge, Amsterdam: The Edge, an office building in Amsterdam, is often cited as one of the world's most sustainable and innovative smart buildings. The building utilizes a variety of IoT technologies, including smart sensors, automated lighting, and energy management systems, to reduce energy consumption by 70% compared to traditional buildings. Additionally, The Edge employs a smart parking system that guides employees to available spaces and adjusts lighting and ventilation accordingly, further contributing to energy savings (The Edge, n.d.).

Salesforce Tower, San Francisco: The Salesforce Tower in San Francisco is another prime example of a smart building that leverages IoT technologies to enhance sustainability and user experience. The tower features an intelligent HVAC system that uses outside air for cooling and natural ventilation, reducing energy consumption by 30-50% compared to traditional systems (Hines, n.d.). Further energy savings are achieved via the building's smart lighting system, which modifies brightness levels in response to occupancy and the presence of natural light.

Siemens Headquarters, Munich: The Siemens headquarters in Munich, Germany, serves as an example of the potential of smart buildings to increase occupant comfort and energy efficiency. In comparison to typical structures, the building uses a combination of IoT technologies, such as smart sensors, energy management systems, and controlled shading devices, to reduce energy use by 90% and water usage by 75%. Additionally, the headquarters features a user-centric design that promotes well-being and productivity by providing occupants with personalized control over temperature, lighting, and air quality (Siemens, 2017).

In ultimately, smart buildings integrate IoT technology to monitor and regulate multiple building systems. These benefits include increased efficiency, sustainability, and user experience. Examples from the real world, including The Edge in Amsterdam, Salesforce Tower in San Francisco, and Siemens Headquarters in Munich, show how smart buildings have the ability to significantly improve a structure's performance and occupant well-being. The future of civil engineering and construction is anticipated to be significantly influenced by smart buildings as the need for environmentally friendly and user-friendly built environments continues to rise.

Challenges and Opportunities

Despite the numerous advantages associated with smart buildings, implementing IoT technology in these environments also presents several challenges. We'll address potential answers and chances for additional innovation and development in this section as we list some of the biggest obstacles to using IoT technology in smart buildings.

Interoperability: The lack of interoperability across diverse devices and systems is one of the main obstacles to deploying IoT technology in smart buildings (Javed, M. Y., Javaid, N., Qasim, U., Alrajeh, N., & Alabed, M. S, 2020). As different manufacturers and vendors develop their own proprietary technologies and communication protocols, integrating these disparate systems can be a complex and resource-intensive process. Potential solutions to this challenge include the development of standardized communication protocols and open-source frameworks that allow for seamless integration between different IoT devices and systems (Huang, C. Y., & Wu, C. H. , 2016). By promoting collaboration and information sharing among industry stakeholders, these initiatives can help overcome the interoperability challenge and drive further innovation in smart building technologies.

Security: The increasing reliance on IoT technology in smart buildings raises concerns regarding cybersecurity and data protection (Shah, S. F. A., Iqbal, M., Aziz, Z., Rana, T. A., Khalid, A., Cheah, Y.-N., & Arif, M., 2022). The security and privacy of building occupants may be jeopardized as a result of cyberattacks and illegal access as enormous volumes of data are collected and transmitted by smart building systems. To address this challenge, robust security measures, such as encryption, authentication, and intrusion detection systems, must be integrated into smart building solutions (Al-Turjman, F., Zahmatkesh, H., & Shahroze, R., 2022). Additionally, fostering a culture of cybersecurity awareness and promoting best practices among building stakeholders can contribute to creating a more secure environment for smart building implementation.

Privacy: The collection and analysis of occupant data in smart buildings can raise privacy concerns among users (Harper, Scott, Mehrnezhad, Maryam, & Mace, J., 2022). The collection, storage, and processing of this data must respect user privacy as IoT devices track numerous elements of occupant activity and preferences. Implementing stringent data governance regulations, anonymizing gathered data, and providing consumers with transparent information about data collecting and usage methods are all potential solutions to this problem (Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I., 2012). Smart building designers may increase user confidence and encourage a wider adoption of IoT technology in the built environment by resolving privacy issues.

Cost and Complexity: It can be expensive and difficult to install IoT technologies in smart buildings, especially when retrofitting existing structures (Al-Obaidi, K.M., Hossain, M., Alduais, N.A.M., Al-Duais, H.S., Omrany, H., & Ghaffarianhoseini, A., 2022). The installation and integration of IoT devices, sensors, and systems can require significant upfront investments and ongoing maintenance costs. To overcome this challenge, innovative financing models, such as public-private partnerships, can be explored to facilitate the deployment of smart building solutions (Mazhar, T., Irfan, H. M., Haq, I., Ullah, I., Ashraf, M., Shloul, T. A., Ghadi, Y. Y., Imran, & Elkamchouchi, D. H., 2023). Moreover, the development of low-cost, easily deployable IoT devices can help reduce the financial barriers to smart building implementation.

Skills Gap: The implementation of IoT technologies in smart buildings requires specialized knowledge and expertise in various domains, such as civil engineering, computer science, and data analytics (O'Donovan, P., Leahy, K., Bruton, K. & O'Sullivan, D. T. J., 2015). Addressing the skills gap in this interdisciplinary field can be a challenge, particularly as the demand for qualified professionals continues to grow. Potential solutions to this challenge include promoting educational and training programs that focus on the development of relevant skills and fostering collaboration between academia, industry, and government stakeholders to create a workforce capable of driving innovation in smart building technologies.

To summarize, while there are challenges associated with implementing IoT technology in smart buildings, such as interoperability, security, privacy, cost, and the skills gap, there are also numerous opportunities for innovation and development. The following table summarizes the main challenges and potential solutions discussed in this section:

Table 2: Challenges and Opportunities in Implementing IoT in Smart Buildings

Challenge	Description	Potential Solution
Interoperability	Different proprietary technologies and communication protocols from various manufacturers hinder system integration.	Development of standardized communication protocols and open-source frameworks.
Security	Increasing reliance on IoT technology exposes smart buildings to cybersecurity threats and data breaches.	Implementing robust security measures such as encryption, authentication, and intrusion detection systems.
Privacy	Collection and analysis of occupant data raise privacy concerns.	Implementing strict data governance policies, anonymizing collected data, and increasing transparency in data collection and usage.
Cost and Complexity	Implementation, particularly for retrofitting, can be expensive and complex.	Exploring innovative financing models and developing low-cost, easily deployable IoT devices.
Skills Gap	Implementation requires specialized knowledge in various domains, leading to a skills gap.	Promoting educational and training programs, fostering collaboration between academia, industry, and government stakeholders.

By addressing these challenges and promoting collaboration among stakeholders, the smart building industry can continue to evolve and contribute to the creation of more efficient, sustainable, and user-friendly built environments.

Future Trends and Developments

As the smart building industry continues to evolve, the role of IoT in shaping the future of civil engineering and construction will become increasingly significant. In this section, we will explore the future of smart buildings and discuss emerging technologies and research directions that may influence the evolution of these environments.

Artificial Intelligence (AI): The integration of AI and machine learning techniques into smart building systems offers significant potential for enhancing building performance, energy efficiency, and user experience (Farzaneh, H., Malehmirchegini, L., Bejan, A., Afolabi, T., Mulumba, A., & Daka, P. P., 2021). AI algorithms can analyze data collected from IoT devices to optimize building operations, predict equipment failures, and identify patterns in energy consumption. As AI capabilities continue to advance, we can expect increased adoption of AI-driven solutions in smart buildings, leading to more efficient and intelligent environments (Bakri Hassan, M., Sayed Ali Ahmed, E., & Saeed, R. A, 2021).

Data Analytics: The vast amount of data generated by IoT devices in smart buildings can be leveraged for deeper insights into building operations and occupant behavior (Hildayanti, A., & Machrizzandi, M. S., 2020). To find trends, spot abnormalities, and improve building performance, advanced data analytics techniques like big data processing and predictive analytics can be used. As data analytics technologies advance, we can anticipate them to play a bigger part in guiding decision-making and advancing smart building technology.

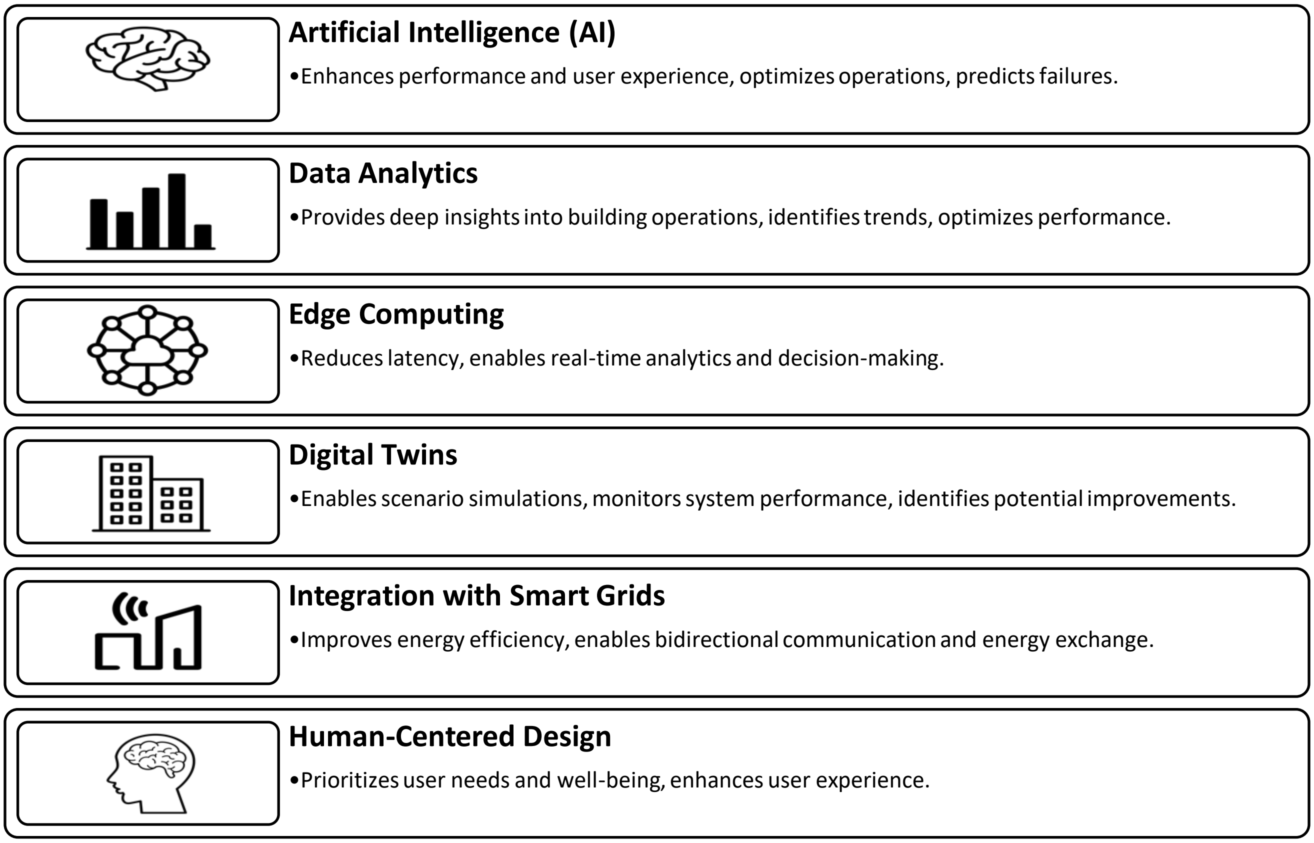
Edge Computing: As IoT devices proliferate in smart buildings, there is a rising need for processing power to handle and analyze data at the network edge (Shah, S. F. A., Iqbal, M., Aziz, Z., Rana, T. A., Khalid, A., Cheah, Y.-N., & Arif, M., 2022). Edge computing can help address this challenge by performing data processing tasks closer to the data source, reducing latency, and minimizing the reliance on centralized cloud resources. The integration of edge computing in smart buildings can enable real-time analytics and decision-making, contributing to more responsive and adaptive environments.

Digital Twins: A potent technique for maximizing the efficiency of smart buildings is the development of digital twins, which are virtual replicas of physical assets or systems (Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F., 2018). By creating a digital replica of a building, facility managers can simulate various scenarios, monitor the performance of building systems, and identify potential areas for improvement. As digital twin technology continues to advance, we can expect to see increased adoption of this approach in smart building management and operations.

Integration with Smart Grids: The future of smart buildings will likely involve increased integration with smart grid systems, enabling bidirectional communication and energy exchange between buildings and the grid (Thomas, M. L., Marie-Claude, B., Lieve, H., Gregor, H., Javad, M., Doug, N., Dieter, P., Shanti, P., & Richard, T. W., 2016). This integration can lead to improved energy efficiency, demand-side management, and increased adoption of renewable energy sources. As smart grids and smart buildings become more interconnected, there will be new opportunities for innovation and collaboration in the energy sector.

Human-Centered Design: As the focus on user experience in smart buildings continues to grow, we can expect to see increased attention on human-centered design principles (Alessandra, L. N., & Mauro, O., 2018). This approach prioritizes the needs, preferences, and well-being of building occupants, ensuring that smart building technologies are developed with the end-user in mind. Future smart building developments may incorporate biophilic design elements, improved indoor environmental quality, and more personalized control systems to create spaces that promote occupant health and well-being.

Figure 2: Future Trends and Developments in Smart Buildings



In conclusion, the development of new technologies and research areas, such as artificial intelligence (AI), data analytics, edge computing, digital twins, smart grid integration, and human-centered design, will have a significant impact on the future of smart buildings. As the industry continues to evolve, we can expect to see smart buildings becoming more intelligent, efficient, and user-friendly, offering significant potential for transforming the built environment and the way we live and work.

Conclusion

In this study, the authors explored the intersection of civil engineering and the Internet of Things (IoT) within the context of smart buildings. The use of IoT technology, such as sensors, actuators, and communication protocols, was discussed, underscoring their essential roles in energy management, automation, and security. The multitude of benefits offered by smart buildings, particularly in terms of energy efficiency, sustainability, and enhanced user experience, were examined.

This research also shed light on the complexities associated with the integration of IoT technology into smart buildings, including interoperability issues and security and privacy concerns. Despite these challenges, the research also highlighted the ample opportunities for innovation and enhancement in this rapidly growing field. In contemplating the future trajectory of smart buildings, the discussion extended to emerging technologies and methodologies, including artificial intelligence (AI), data analytics, edge computing, digital twins, and human-centered design.

The integration of IoT technology into smart buildings offers an exceptional opportunity to reshape the built environment towards an energy-efficient future. However, to effectively tackle the challenges and fully harness the potential of this rapidly evolving field, continuous research, collaboration, and innovation are integral. Emphasizing the role of civil engineering in the development of energy-efficient infrastructure, this study contributes to the body of literature focusing on IoT-driven smart buildings. The insights garnered serve as a guide for future research and innovations, steering us towards a future with smart buildings that are not only intelligent and user-friendly, but also increasingly energy-efficient and sustainable.

Future Studies

The development of more reliable and scalable IoT solutions that handle the issues of interoperability, security, and privacy may be the main topic of future study in the fields of smart buildings and civil engineering. Additionally, to further improve building performance and occupant well-being, researchers might look into novel integration strategies for cutting-edge technologies like edge computing, AI, and data analytics. Other potential directions for future research include examining the contribution of human-centered design to the creation of smart building technologies and the effects of biophilic design components on occupant productivity and health.

Declarations

Ethical Approval

Not applicable. This manuscript does not involve any human and/or animal studies.

Competing Interests

The authors declare that they have no competing interests of a financial or personal nature that could have influenced the work reported in this manuscript.

Authors' Contributions

Arkar Htet 1* and Theingi Aung 3 were the main contributors to the writing of the manuscript. Dr.Sui Reng Liana 2 and Dr. Amiya Bhaumik 4 supervised the manuscript. All authors reviewed the manuscript and gave their approval for the final version to be published. All authors agree to be accountable for all aspects of the work and will ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Availability of Data and Materials

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Acknowledgments

Our appreciation goes out to all the academics, experts, and organizations whose work has advanced our knowledge of smart buildings and the Internet of Things. Their dedication and innovation have paved the way for the advancements discussed in this article. We also acknowledge the support of our colleagues and institutions in conducting this research, as well as the valuable feedback provided by reviewers and editors. Their insights and expertise have significantly enriched the quality and depth of this article.

References

Ahmad, M.W., Mourshed, M., Yuce, B., & Rezgui, Y. . (2016). Computational intelligence techniques for HVAC systems: A review. *Building Simulation, 9*, 359–398. https://doi.org/10.1007/s12273-016-0285-4.

Al-Obaidi, K.M., Hossain, M., Alduais, N.A.M., Al-Duais, H.S., Omrany, H., & Ghaffarianhoseini, A. (2022). A Review of Using IoT for Energy Efficient Buildings and Cities: A Built Environment Perspective. *Energies, 15*, 5991. https://doi.org/10.3390/en15165991.

Al-Turjman, F., Zahmatkesh, H., & Shahroze, R. (2022). An overview of security and privacy in smart cities' IoT communications. *Emerging Telecommunications Technologies, 33(3)*, e3677. https://doi.org/10.1002/ett.3677.

Alessandra, L. N., & Mauro, O. (2018). Towards human-centred intelligent envelopes: A framework for capturing the holistic effect of smart façades on occupant comfort and satisfaction. *International Building Physics Conference 2018* (pp. NA. https://doi.org/10.14305/ibpc.2018.hf-2.05). Surface.

Arditi, D., Mangano, G. & De Marco, A. (2015). Assessing the smartness of buildings. *Facilities, 33(9/10)*, 553-572. https://doi.org/10.1108/F-10-2013-0076.

Arkar, H., Sui-Reng, L., Theingi, A., & Amiya, B. (2023). Green Facades and Renewable Energy:Synergies for a Sustainable Future. *International Journal of Innovative Science and Research Technology*, 219-223. DOI: 10.5281/zenodo.7937856.

Bakri Hassan, M., Sayed Ali Ahmed, E., & Saeed, R. A. (2021). Machine Learning for Industrial IoT Systems. In J. &. Zhao, *Handbook of Research on Innovations and Applications of AI, IoT, and Cognitive Technologies* (pp. 336-358. https://doi.org/10.4018/978-1-7998-6870-5.ch023). IGI Global.

Bashir, M.R., Gill, A.Q. & Beydoun, G. (2022). A Reference Architecture for IoT-Enabled Smart Buildings. *SN Computer Sceience, 3*, 493. https://doi.org/10.1007/s42979-022-01401-9.

Behdad, R., & Paul G. O'Brien. (2021). Evaluation of Smart Booster Fans and Dampers for Advanced HVAC Systems. *Journal of Green Building, 16(2)*, 115-127. https://doi.org/10.3992/jgb.16.2.115.

Carli, R., Cavone, G., Ben Othman, S., & Dotoli, M. (2020). IoT Based Architecture for Model Predictive Control of HVAC Systems in Smart Buildings. *Sensors, 20(3*, 781. https://doi.org/10.3390/s20030781.

Dounis, A. I., & Caraiscos, C. (2009). Advanced control systems engineering for energy and comfort management in a building environment—A review. *enewable and Sustainable Energy Reviews, 13(6-7)*, 1246-1261. DOI: 10.1016/j.rser.2008.09.015.

Elrawy, M., Awad, A. & Hamed, H. (2018). Intrusion detection systems for IoT-based smart environments: a survey. *Journal of Cloud Computing volume 7*, 21. https://doi.org/10.1186/s13677-018-0123-6.

Farzaneh, H., Malehmirchegini, L., Bejan, A., Afolabi, T., Mulumba, A., & Daka, P. P. (2021). Artificial Intelligence Evolution in Smart Buildings for Energy Efficiency. *Applied Sciences, 11(2)*, 763. https://doi.org/10.3390/app11020763.

Floris, A., Porcu, S., Girau, R., & Atzori, L. . (2021). An IoT-Based Smart Building Solution for Indoor Environment Management and Occupants Prediction. *Energies, 14(10)*, 2959. https://doi.org/10.3390/en14102959.

Fuentes, H., & Mauricio, D. (2020). Smart water consumption measurement system for houses using IoT and cloud computing. *Environmental Monitoring and Assessment volume, 192*, 602. https://doi.org/10.1007/s10661-020-08535-4.

Gupta, R., & Gregg, M.,. (2022). Building performance evaluation of low-energy dwellings with and without smart thermostats. *Building Services Engineering Research and Technology*, 297-318. doi:10.1177/01436244221077344.

Harper, Scott, Mehrnezhad, Maryam, & Mace, J. (2022). User Privacy Concerns in Commercial Smart Buildings. *Journal: Journal of Computer Security, 30(3)*, 465-497. DOI: 10.3233/JCS-210035.

Hashem, I. A. T., Chang, V., Anuar, N. B., Adewole, K., Yaqoob, I., Gani, A., ... & Chiroma, H. (2016). The role of big data in smart city. *International Journal of Information Management, 36(5)*, 748-758. https://doi.org/10.1016/j.ijinfomgt.2016.05.002.

Hildayanti, A., & Machrizzandi, M. S. (2020). The Application of IOT(Internet Of Things) for Smart Housing Environments and Integrated Ecosystems. *Nature: National Academic Journal of Architecture, 7(1)*, 80-88. https://doi.org/10.24252/nature.v7i1a6.

Hines. (n.d.). *Hines*. Retrieved from www.hines.com: https://www.hines.com/properties/salesforce-tower-san-francisco

Huang, C. Y., & Wu, C. H. . (2016). Design and Implement an Interoperable Internet of Things Application Based on The Extended OGC Sensorthings API Standard. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 12-19. doi:10.5194/isprsarchives-XLI-B4-263-2016.

Jamuna, M., & Vijaya Prakash, A.M. (2021). A Study of Communication Protocols for Internet of Things (IoT) Devices: Review. *Proceedings of the 3rd International Conference on Integrated Intelligent Computing Communication & Security (ICIIC 2021)* (p. NA. DOI: 10.2991/ahis.k.210913.033). Springer Nature.

Javed, M. Y., Javaid, N., Qasim, U., Alrajeh, N., & Alabed, M. S. (2020). Scalable IoT Platform for Heterogeneous Devices in Smart Environments. *IEEE Access, 8(204)*, 496-510. https://doi.org/10.1109/access.2020.3039368.

Jeongmi, S. & Yeonseung, R. . (2016). Sensitive Data Hiding Scheme for Internet of Things using Function Call Obfuscation Techniques.

International Journal of Security and Its Applications, 10 (10), 169-180. http://dx.doi.org/10.14257/ijsia.2016.10.10.16.

Kaligambe, A., Fujita, G., & Keisuke, T. (2022). Estimation of Unmeasured Room Temperature, Relative Humidity, and CO2 Concentrations for a Smart Building Using Machine Learning and Exploratory Data Analysis. *Energies, 15(12)*, 4213. https://doi.org/10.3390/en15124213.

Kanchana, S. (2019). Histogram of Neighborhood Tripatite Authentication with Ringerprint - Based Biometrics for IOT Services. *International Journal of Computer Networks & Communications (IJCNC), 11(5)*, 21-37.

Khan, R., Khan, S. U., Zaheer, R., & Khan, S. (2019). Future internet: The internet of things architecture, possible applications and key challenges. *In 2012 10th International Conference on Frontiers of Information Technology*, (pp. 257-260. https://doi.org/10.1109/FIT.2012.53).

Mazhar, T., Irfan, H. M., Haq, I., Ullah, I., Ashraf, M., Shloul, T. A., Ghadi, Y. Y., Imran, & Elkamchouchi, D. H. (2023). Analysis of Challenges and Solutions of IoT in Smart Grids Using AI and Machine Learning Techniques: A Review. *Electronic, 12(1)*, 242. https://doi.org/10.3390/electronics12010242.

Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I. (2012). Internet of things: Vision, applications and research challenges. *Ad Hoc Networks, 10(7)*, 1497-1516. https://doi.org/10.1016/j.adhoc.2012.02.016.

O'Donovan, P., Leahy, K., Bruton, K. & O'Sullivan, D. T. J. (2015). An industrial big data pipeline for data-driven analytics maintenance applications in large-scale smart manufacturing facilities. *Journal of Big Data, 2 (25)*, 1-26. https://doi.org/10.1186/s40537-015-0034-z.

Pan, J., Jain, R., Paul, S., Vu, T., Saifullah, A., & Sha, M. (2015). An Internet Of Things Framework For Smart Energy In Buildings: Designs, Prototype, and Experiments. *IEEE Internet Things Journal, 6(2)*, 527-537. https://doi.org/10.1109/jiot.2015.2413397.

Roopa, H. S., & Jhansi, R. P. . (2017). An Energy Efficient Decentralized Detection Of System For Structural Health Monitoring In Wireless Sensor And Actuator Networks. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, 355-360. .

Sanya, W., Bajpai, G., Kombo, O., & Twahirwa, E. (2022). Real-Time Data Analytics for Monitoring Electricity Consumption Using IoT Technology. *Tanzania Journal of Engineering and Technology, 41(1)*, 27-35. https://doi.org/10.52339/tjet.vi.770.

Seong, Y. B. (2015). HELIOS-EX: Blind control simulator and method with a consideration of adjacent buildings . *Indoor and Built Environment, 24(1)*, 37-51. doi:10.1177/1420326X13500976.

Shah, S. F. A., Iqbal, M., Aziz, Z., Rana, T. A., Khalid, A., Cheah, Y.-N., & Arif, M. (2022). The Role of Machine Learning and the Internet of Things in Smart Buildings for Energy Efficiency. *Applied Sciences, 12(15)*, 7882. https://doi.org/10.3390/app12157882.

Siemens. (2017). *Siemens*. Retrieved from press.siemens.com: https://press.siemens.com/global/en/feature/new-corporate-headquarters-munich

Singh, & Dhawan. (2023). Role of Building Automation Technology in Creating a Smart and Sustainable Built Environment. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 10(1)*, 412-420. https://doi.org/10.5109/6781101.

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. *The International Journal of Advanced Manufacturing Technology, 94(9-12)*, 3563-3576. https://doi.org/10.1007/s00170-017-0233-1.

Terence, K.L., Hui, R., Simon, S., & Daniel, D. S. (2017). Major requirements for building Smart Homes in Smart Cities based on Internet of Things technologies. *Future Generation Computer Systems, 76*, 358-369. https://doi.org/10.1016/j.future.2016.10.026.

The Edge. (n.d.). *The Edge*. Retrieved from edge.tech: https://edge.tech/developments/the-edge

Theingi, A., Sui- Reng, L., Arkar, H., & Amiya, B. (2023). Using Machine Learning to Predict Cost Overruns in Construction Projects. *Journal of Technology Innovations and Energy, 2(2)*, 1–7. https://doi.org/10.56556/jtie.v2i2.511.

Thomas, M. L., Marie-Claude, B., Lieve, H., Gregor, H., Javad, M., Doug, N., Dieter, P., Shanti, P., & Richard, T. W. (2016). Ten questions concerning integrating smart buildings into the smart grid. *Building and Environment, 108*, 273-283. https://doi.org/10.1016/j.buildenv.2016.08.022.

Vodovozov, A. M., & Burtsev, A. V. (2021). Intelligent Street Lighting System Based On the Internet of Things Paradigm. *Bulletion of Cherepovetsk State Universtiy*, 7-17. DOI: 10.23859/1994-0637-2021-3-102-1 .

Yuan-Ko, H. (2023). Design of a Smart Cabin Lighting System Based on Internet of Things. *Cloud Computing and Data Science, 4 (2)*, 112-121. DOI: https://doi.org/10.37256/ccds.4220232697.

Zafari, F., Papapanagiotou, I., & Christidis, K. (2016). Microlocation for Internet-of-Things-Equipped Smart Buildings. *IEEE Internet of Things Journal, 3 (1)*, 96-112. doi: 10.1109/JIOT.2015.2442956.