2nd Proceeding of International Conference on Science and Technology UISU (ICST)
"Engineering for Suistanable Future: Innovation in Renewable Energy, Green Technology, and Circular Economy"
ISSN:3063-7929 (Online)
DOI: https://doi.org/10.30743/icst

Development of Smart and Green University Towards a Sustainable and Environmentally Friendly Campus: Case Study at Universitas Sumatra Utara

Fahmi Fahmi[*)], Hermansyah Alam[1)]
[*)]Department of Electrical Engineering, Universitas Sumatera Utara Medan Indonesia
[1)]Department of Electrical Engineering Universitas Islam Sumatera Utara Medan Indonesia
correspondence author: fahmimn@usu.ac.id* ; hermansyah.alam@ft.uisu.ac.id

Abstract—Sustainable urban development is critically needed in tropical regions facing unique challenges, including extreme heat, high humidity, and intense rainfall. This study examines the implementation of smart and green building concepts at Universitas Sumatera Utara (USU), Indonesia, as a case study to illustrate strategies for creating environmentally friendly campuses. USU has integrated digital technologies and sustainable design principles into its infrastructure, notably through smart buildings that employ IoT sensors and AI-based management systems. These technologies ensure efficient energy use, improved indoor air quality, and reduced resource consumption. Green building strategies, such as passive architectural design, natural ventilation, shaded courtyards, and renewable energy systems, are implemented to mitigate the impacts of tropical climate conditions. Key initiatives include the use of solar panels, wind turbines, biomass pyrolysis, and innovative transportation solutions, such assmart garbage electric vehicles (Smart GeV) and free campus bicycles.Additionally, USU's waste management strategy, highlighted by the establishment of the USU Circularity Centre (UCC), effectively promotes resource circularity by converting waste into compost and alternative fuels. Collaboration with international institutions has further enriched local expertise and facilitated the dissemination of best practices. However, the study identifies critical barriers hindering broader adoption, including fragmented governance, limited financial incentives, insufficient skilled human resources, and a lack of tailored climate-specific standards. Strategic recommendations to overcome these challenges involve improving regulatory coherence, enhancing financial support mechanisms, investing in capacity-building initiatives, and strengthening interdisciplinary collaborations. The study concludes that USU's experience provides a replicable model for other tropical universities, highlighting the pivotal role educational institutions can play as pioneers of urban sustainability and thereby contributing significantly to global environmental objectives.

Keywords—Smart Building, Green Building, Sustainable Campus, Tropical Climate, Circular Economy

1. INTRODUCTION

Sustainable and smart development in urban areas, particularly in tropical regions such as Indonesia, is facing significant challenges due to the unique climatic conditions, including high humidity, intense heat, and heavy rainfall [1,2]. These challenges significantly affect urban infrastructure, architectural design, and energy systems. Buildings contribute substantially to environmental degradation, consuming approximately 40% of public resources and significantly contributing to greenhouse gas emissions and pollution, thereby exacerbating the impacts of climate change [3,4]. Consequently, transitioning to green and smart buildings is crucial for sustainable urban living, enhancing public health, reducing environmental impacts, and improving resource efficiency [5,6].

The integration of green and smart buildings with sustainable urban planning concepts offers robust solutions to urban environmental problems. Green buildings focus on reducing negative impacts throughout their lifecycle, emphasizing energy efficiency, resource conservation, and environmental management [7,8]. Conversely, smart buildings utilize digital technologies, such as the Internet of Things (IoT) and Artificial Intelligence (AI), to optimize building operations, thereby enhancing energy efficiency, security, and user comfort [9,10]. Sustainable urban design combines these approaches, emphasizing pedestrian-friendly streetscapes, ecological resilience, and efficient urban resource management [11,12].

Universitas Sumatera Utara (USU), located in Medan, North Sumatra, Indonesia, exemplifies these principles through its strategic integration of smart and green building concepts, aiming to establish a sustainable campus environment [13,14]. USU's commitment involves practical innovations, including smart electric garbage trucks, waste management centers, and the implementation of renewable energy. The campus infrastructure promotes natural ventilation, optimal daylight utilization, and passive cooling, thereby significantly reducing energy consumption and enhancing indoor environmental quality [15, 16].

Despite USU's initiatives, broader implementation faces obstacles such as fragmented governance structures, insufficient funding mechanisms, limited skilled human resources, and inadequate climate-specific standards [17,18]. Thus, addressing these gaps through robust policy frameworks, interdisciplinary collaboration, and adaptive technological innovation is critical. This research aims to evaluate USU's initiatives as a model for sustainable urban development, highlighting effective practices in the deployment of smart and green infrastructure, and providing strategic recommendations applicable to other tropical universities.

ISSN:3063-7929 (Online)
DOI: https://doi.org/10.30743/icst

2. MATERIALS AND METHODS

Smart Building

Smart buildings integrate digital technologies to manage environmental control systems efficiently [19]. At USU, smart buildings utilize IoT sensors to monitor temperature, humidity, lighting, and air quality, which are essential in tropical climates to maintain indoor comfort and energy efficiency [20]. The campus utilizes advanced Building Management Systems (BMS) that integrate AI to automate HVAC systems and dynamically optimize energy use [21]. Real-time energy management using predictive analytics reduces energy consumption significantly by aligning operational parameters with actual occupancy and environmental conditions [22].

Green Building

The Green building concepts at USU focus on passive architectural strategies to mitigate the harsh tropical climate [23]. Buildings feature designs such as cantilevered floors and shaded inner courtyards to minimize solar heat gain. The use of natural lighting through strategic building orientations and large glazed windows reduces reliance on artificial lighting, thus cutting electricity usage [24]. Moreover, the Teaching Hospital at USU features a "hot chimney" design, which facilitates natural air circulation, significantly improving indoor air quality and comfort without the need for mechanical cooling [25].

USU adheres to certification standards, such as Greenship, which is developed specifically for Indonesia's humid tropical conditions [26]. Greenship emphasizes energy efficiency, water conservation, and indoor comfort, aligning closely with local climatic and cultural contexts. USU buildings meet or exceed Greenship criteria, ensuring their sustainability performance aligns with national benchmarks [27].

Development of Sustainability Campus

The Sustainability Campus Initiative at USU integrates renewable energy solutions and sustainable transportation systems [28]. Renewable energy projects include solar panels with capacities up to 21 kWp, wind turbines, biomass pyrolysis, and kinetic energy capture from speed bumps. These diversified energy sources significantly reduce campus reliance on conventional energy, contributing to substantial reductions in carbon emissions [29].

Transportation sustainability is enhanced through the provision of free campus bicycles and shuttle bus services, which significantly reduce the carbon footprint associated with campus mobility [30]. Additionally, USU promotes extensive green open spaces, occupying approximately 88% of the campus, which serve ecological functions and provide recreational amenities for students and faculty, enhancing overall campus livability [31-33]

3. RESULTS AND DISCUSSION

USU exemplifies best practices in smart and green university development through various innovative initiatives. One notable project is the Smart Garbage Electric Vehicle (Smart GeV v1.0), as shown in Figure 1, a sustainable waste collection vehicle powered entirely by electricity, which significantly reduces emissions and operational costs compared to conventional vehicles. Electric garbage trucks, also known as electric refuse collection vehicles, transform the waste management process by prioritizing sustainability, efficiency, and minimizing environmental impact. Unlike traditional diesel-powered trucks, it operates on electric power, significantly reducing greenhouse gas emissions and noise pollution.

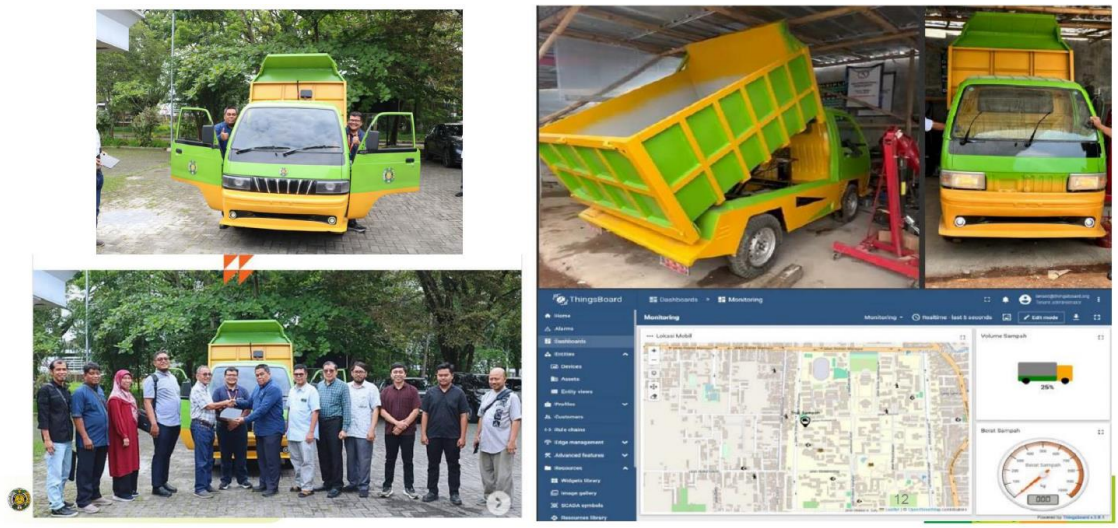

Figure 1. USU Smart Garbage Electric Vehicle (Smart GeV ver 1.0)

2nd Proceeding of International Conference on Science and Technology UISU (ICST)
"Engineering for Suistanable Future: Innovation in Renewable Energy, Green Technology, and Circular Economy"
ISSN:3063-7929 (Online)
DOI: https://doi.org/10.30743/icst

Their future adoption contributes to cleaner air, especially in densely populated areas, and aligns with global efforts to combat climate change. Lower maintenance costs and fuel savings make them a financially viable long-term solution for municipalities and organizations. USU successfully designed a smart electric garbage vehicle for campus settings, supporting the circular economy. The proposed vehicle enhanced waste collection efficiency and sustainability by integrating advanced technologies, including AI-powered sorting, route optimization software, and regenerative braking. Smart sensors and automated waste categorization improved recycling processes, ensuring proper material separation and reducing landfill waste.

To optimize energy consumption, the vehicle incorporates smart charging infrastructure and vehicle-to-grid (V2G) capabilities, allowing it to interact with the local power grid. The implementation of fast-charging stations will ensure seamless operations, minimizing downtime. By developing an intelligent and eco-friendly waste collection system, campuses can serve as a model for sustainable urban environments. This initiative not only reduces carbon footprints but also fosters awareness and responsibility toward environmental conservation, demonstrating how smart technology can revolutionize waste management for a greener future.

Complementing this, the USU Circularity Centre (UCC) effectively processes campus waste, converting organic waste into compost and utilizing plastic waste for fuel production, exemplifying a closed-loop waste management model as shown in Figure 2. The USU Circularity Centre (UCC) stands as a pioneering initiative at Universitas Sumatera Utara dedicated to implementing effective, innovative waste management strategies aligned with sustainability and circular economy principles. By strategically processing diverse campus waste streams, the UCC significantly reduces the volume of waste directed to landfills, thereby minimizing the environmental footprint of university operations. At the heart of its operations is the transformation of organic waste generated from campus activities—such as food scraps from cafeterias, landscaping residues, and agricultural waste—into nutrient-rich compost. This compost not only contributes to soil health and fertility for campus green spaces but also supports university-led agricultural research and sustainability projects. This systematic composting practice effectively mitigates greenhouse gas emissions commonly associated with uncontrolled organic waste decomposition, directly aligning USU's waste management strategy with global climate change mitigation goals.

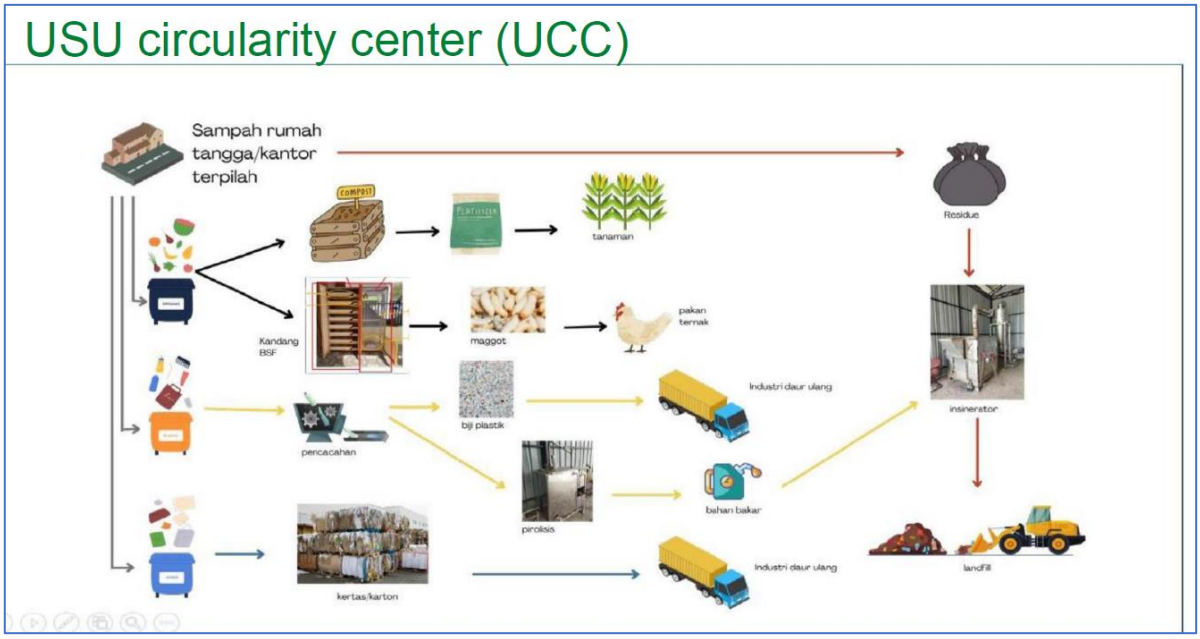

Figure 2. USU Circulatory Centre (UCC)

Simultaneously, the UCC addresses the growing challenge of plastic waste by pioneering its conversion into alternative fuels. Plastic waste generated on campus is collected, sorted, and processed using advanced pyrolysis technology, which breaks down plastic into valuable hydrocarbons. This innovative approach produces a usable fuel that can partially replace traditional fossil fuels in campus operations, such as powering generators, heating facilities, and potentially fueling campus transportation systems. By converting plastic waste into energy resources, the UCC exemplifies a closed-loop, resource recovery model that significantly reduces the university's reliance on external energy sources.

Furthermore, the UCC's circularity approach fosters a holistic sustainability culture across campus, encouraging active participation from students, faculty, and staff in waste segregation and recycling practices. Through continuous education and engagement programs, the UCC emphasizes the importance of individual and collective responsibility in sustainable resource management, effectively raising environmental awareness across the campus community.

ISSN:3063-7929 (Online)
DOI: https://doi.org/10.30743/icst

Thus, the USU Circularity Centre not only demonstrates effective waste management practices but also serves as a replicable model for other institutions, reinforcing the university's broader commitment to sustainable development, environmental stewardship, and innovation in addressing waste management challenges.

The integration of smart and green principles in campus buildings, such as the use of natural ventilation, passive shading, and renewable energy integration, demonstrates significant operational efficiencies [34,35]. The Teaching Hospital and other facilities have showcased significant reductions in electricity and water consumption through innovative architectural and technological interventions, as shown in Figure 3.

Figure 3. USU Hospital

Collaborative initiatives with government and international institutions, such as Universiti Sains Malaysia (USM), have bolstered USU's capabilities in implementing sustainable infrastructure through knowledge exchange and joint research endeavours [36]. These collaborations enhance local expertise and support the dissemination of best practices within the regional context [37].

The successful implementation of smart and green initiatives at USU highlights essential strategies for sustainable urban development in tropical climates [38]. The effective combination of passive architectural design, renewable energy integration, and innovative waste management systems provides a replicable model for other institutions seeking sustainability [39]. However, overcoming existing implementation barriers requires strengthening regulatory coherence, enhancing financial incentives, and developing skilled human resources to foster broader adoption [40].

In conclusion, USU's experience underscores the critical role universities play as pioneers in urban sustainability [41]. Continued investment in adaptive technology, interdisciplinary collaboration, and robust policy frameworks will be vital to scaling these initiatives, ultimately contributing significantly to achieving broader sustainability and environmental objectives in tropical regions [42]

.

4. CONCLUSION

Universitas Sumatera Utara (USU) demonstrates the successful integration of smart and green concepts in campus infrastructure, presenting an effective model for sustainable university development in tropical climates. USU's initiatives include the innovative use of digital technologies, such as IoT and AI, for efficient building management, renewable energy utilization, and comprehensive waste management through the USU Circularity Centre. The adoption of passive architectural designs, such as natural ventilation, shaded courtyards, and optimized daylighting, has significantly enhanced indoor comfort and reduced environmental impacts. Collaborative efforts with international institutions have further enriched knowledge exchange, improving local expertise and fostering wider implementation.

However, critical challenges persist, primarily related to fragmented governance, limited financial incentives, lack of climate-specific regulatory standards, and insufficient skilled human resources. Addressing these barriers requires robust regulatory frameworks, strengthened interdisciplinary collaborations, enhanced financial mechanisms, and focused human resource development strategies. Future implementation should prioritize the creation of adaptive, context-specific building standards and policies tailored explicitly to tropical climates.

Looking forward, universities must assume leadership roles in sustainability, driving transformative change that extends beyond their campus boundaries. Investments in advanced smart technologies, expanded renewable energy projects, and circular economy practices will continue to be crucial. Emphasis should also be placed on

ISSN:3063-7929 (Online)
DOI: https://doi.org/10.30743/icst

community engagement, fostering awareness and active participation among stakeholders, and ensuring the sustainability initiatives are culturally and socially relevant. Regular monitoring, evaluation, and transparent reporting are necessary to track progress and maintain accountability. Ultimately, the long-term vision for USU and similar institutions must include becoming centres of excellence in sustainability, serving as hubs for research, innovation, and the dissemination of best practices. Through sustained commitment and proactive action, tropical universities can significantly contribute to achieving broader global environmental and sustainability objectives

ACKNOWLEDGEMENT

We would like to thank the Faculty of Engineering at Universitas Sumatra Utara for its support of this article. We also extend our gratitude to Prof. Hilma Tamiami, as head of the Centre of Excellence for Green Building and Urban Environmental Quality, and to Dr. Zaid Perdana, Head of USU UCC. Some parts of this paper were developed with the help of OpenAI [43]

REFERENCES

[1] Alexandri, E. (2007). Green cities of tomorrow. Sustainable Construction, Materials and Practices, 710-717.
[2] Chao, A. L., et al. (2020). Indicators Framework for Sustainable Urban Design. Atmosphere, 11, 1143.
[3] Sharma, S., et al. (2020). Effect of restricted emissions during COVID-19 on air quality in India. Science of the Total Environment, 728, 138878.
[4] GBCI. (2021). Net Zero Healthy. Green Building Council Indonesia.
[5] Bijimi, C. K. (2013). The Relevance of Good Urban Design in Managing Urban Sprawl in Nigeria. International Journal of Technology Enhancements and Emerging Engineering Research, 1(4), 123-125.
[6] Stauskis, G. (2013). Green Architecture Paradigm: From Urban Utopia To Modern Methods Of Quality Assessment. Science – Future Of Lithuania, 5(3), 181-188.
[7] USGBC. (2020). LEED Certification System. U.S. Green Building Council.
[8] IFC. (2019). EDGE Certification System. International Finance Corporation.
[9] Al-Azzawi, W., et al. (2018). Radio-friendly building for efficient signal distribution. IEEE International Conference.
[10] Tushar, W., et al. (2018). IoT for green building management. arXiv preprint arXiv:1805.10635.
[11] Carmona, M. (2009). Sustainable Urban Design: Definitions and Delivery. International Journal for Sustainable Development, 12(1), 48-77.
[12] Rehan, R. M. (2012). Sustainable streetscape as an effective tool in sustainable urban design. HBRC Journal, 9, 173-186.
[13] Fachrudin, H. T., et al. (2023). Green Street Design Approach to Realize Green City. Future Cities and Environment, 9(1), 8.
[14] Fachrudin, H. T., et al. (2024). Sustainable Streetscape Design Based on Functional Aspects. E3S Web of Conferences, 519, 03004.
[15] Warman, E., et al. (2018). Energy cost unit of street lighting system. IOP Conference Series.
[16] GBCI. (2022). BSD Green Office Park Certification Profile.
[17] Fitriana, D., et al. (2022). Cross-sectoral policy integration for sustainable urban governance.
[18] Hasmawaty, et al. (2022). Building green smart city capabilities. Sustainability, 14(13), 7695.
[19] Bibri, S. E., & Krogstie, J. (2023). Smart sustainable cities. Journal of Cleaner Production, 166, 234-248.
[20] Liu, Z., et al. (2024). IoT-Based Smart Energy Framework. Frontiers in Public Health, 12.
[21] Nabaei, S. H., et al. (2025). Multimodal data integration for sustainable indoor gardening. arXiv preprint arXiv:2503.21932.
[22] Xu, H., et al. (2024). Leveraging generative AI for urban digital twins. arXiv preprint arXiv:2405.19464.
[23] Zhu, S., et al. (2022). Urban green infrastructure morphology. Building and Environment, 207, 108449.
[24] Andric, I., et al. (2020). Efficiency of green roofs and walls in climate change mitigation. Energy Reports, 6, 2472-2489.
[25] Susca, T. (2019). Green roofs energy performance. Building and Environment, 162, 106273.
[26] GBCI. (2016). Greenship Existing Building Version 1.1. Green Building Council Indonesia.
[27] Pradipta, et al. (2022). Contextualizing Greenship certification. Journal of Environmental Management.
[28] Kali, M., et al. (2019). Urban warming causes and adaptation. Journal of Architecture and Urbanism Research, 3(1).
[29] Fachrudin, H. T., et al. (2023). Green infrastructure and urban resilience. Urban Ecology Journal.
[30] KLHK. (2020). Program Kampung Iklim (ProKlim).
[31] Garde, F., et al. (1998). Quality standards for natural cooling. Building and Environment, 34(1).
[32] Alwetaishi, M., & Balabel, A. (2020). Thermal performance of passive strategies. Journal of Building Engineering, 30.
[33] Bibri, S. E. (2018). Integration of IoT technology in buildings. Sustainable Cities Journal.
[34] Narada Gunawan, K., et al. (n.d.). Optimization of Urban Thermal Environment. Urban Climate Modeling.
[35] Nabaei, S. H., et al. (2025). AI-based predictive maintenance in buildings. Sustainable Engineering Review.
[36] Etzkowitz, H., & Leydesdorff, L. (2000). The Triple Helix model. Research Policy, 29(2).

ISSN:3063-7929 (Online)
DOI: https://doi.org/10.30743/icst

[37] Lubis, M. D., et al. (2021). Application of green concept. IOP Conference Series.
[38] Nguyen, T. T. H., et al. (2024). Smart city frameworks. Cities, 121.
[39] Setyowati, A. B. (2020). Smart grid innovations in Indonesia. Energy Research & Social Science, 71.
[40] Prasetiyo, W. H., et al. (2021). Nature-based solutions in urban planning. Environmental Science & Policy, 126.
[41] Dewi, O. C., et al. (2020). Sustainable urban management policies. Earth and Environmental Science, 448.
[42] Pérez, G., et al. (2018). Vertical greenery systems. Energy and Buildings, 173.
[43] OpenAI. (2025). *ChatGPT* (4.5 version) [Large language model]. https://chat.openai.com/chat