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What Architecture Students Learn About IoT and Energy Efficiency

Bangun I.R. Harsritanto[1], Arnis Rochma Harani[2], Resza Riskiyanto[3], Sri Hartuti Wahyuningrum[4]

[1,2,3,4]Department of architecture, Engineering Faculty, Universitas Diponegoro, Semarang, Indonesia
Email: bangunirh@lecturer.undip.ac.id

Abstract

Energy consumption has become a major concern within academic communities, affecting everyone from undergraduate students to senior professors. In response, architectural schools in Indonesia have begun incorporating energy efficiency education into the curriculum for first-year students across various courses. One of the newest mandatory courses at the university is the Internet of Things (IoT). In the architecture department, this course not only covers the fundamentals of IoT but also emphasizes designing IoT solutions that support energy efficiency. This article describes the process by which architecture students integrate energy efficiency concepts into their IoT designs. A case study conducted during the Spring semester of 2025 in IoT classes for second-year students, using the updated teaching syllabus, highlights the positive outcomes. The results demonstrate that early-stage architectural education can significantly raise awareness of energy efficiency in both IoT and building design.

Keywords: Energy Efficiency, Internet of Things, Architecture Education, Sustainable Design, IoT Integration

1. INTRODUCTION

The role of higher education in advancing sustainable development remains an evolving concept, with many institutions still not fully recognizing the importance of integrating the United Nations Sustainable Development Goals (SDGs) into their curricula, research, and teaching practices. This integration has been identified as a key factor for boosting student engagement and ensuring that graduates are well-prepared to address global sustainability challenges. Research shows that promoting quality education not only improves individual lives but is also crucial in advancing sustainable development on a global scale. Higher education institutions, through their academic programs, can play a significant role in shaping the future of sustainability by equipping students with the necessary skills and knowledge to address the challenges of a rapidly changing world [1][2].

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In an ideal scenario, higher education institutions should aim to directly align their programs with the global sustainability agenda, ensuring that all students are exposed to sustainability-related issues beyond their specific disciplines. This includes curricular, extra-curricular, and co-curricular activities that raise awareness about pressing sustainability challenges. Such programs should help students understand sustainability not just in terms of their individual fields of study but also at a societal level, as they will be both affected by and responsible for contributing to these issues in the future. This broader approach encourages critical thinking and fosters a sense of responsibility toward sustainable practices in everyday life and professional practice [3].

From the perspective of sustainability, universities play a vital role in society as key drivers of change. By educating future professionals and leaders and fostering research that addresses sustainability issues, universities can contribute significantly to global sustainability efforts. Moreover, universities can act as living laboratories for sustainable practices, where students, staff, and faculty members collaborate to develop and implement innovative solutions. By engaging with local and international communities, universities have the potential to drive sustainable development both within their campuses and in the broader society. As such, higher education institutions are positioned to serve as models for sustainability, demonstrating how to integrate sustainability into institutional practices and curricula [4].

In response to the need for more focused energy efficiency education, the Bachelor's program at DAFT Undip introduced an energy efficiency curriculum for first-year students. The current curriculum, created in 2020, has been identified as insufficient in promoting awareness of energy efficiency in building design, as building physics is introduced only in the third semester, coinciding with the first building design studio. This delay in introducing energy efficiency concepts creates a gap in students' understanding of sustainable design practices at an early stage in their academic careers. To address this, DAFT Undip has decided to adopt an interdisciplinary approach to energy efficiency education by incorporating it into the mandatory Internet of Things (IoT) course. This innovative approach aligns with the growing recognition that interdisciplinary education is essential for addressing the complexities of sustainable development [4].

This article focuses on how the integration of energy efficiency education into the IoT course has been implemented and adapted in the context of architecture students' learning. The study involves four classes: A1, A2, B1, and B2 comprising 180 students in total. Over the course of 14 meetings, students participated in three assignments that combined IoT concepts with energy efficiency efforts. By analyzing this approach, the article seeks to highlight the potential of interdisciplinary education in fostering sustainable development practices, particularly in the field of architecture. The findings from this study will contribute

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to the broader discussion on the importance of early exposure to sustainability education and the role of universities in preparing students for the challenges of a sustainable future.

2. METHOD

This study adopts an experimental educational approach to examine how integrating energy efficiency education within the Internet of Things (IoT) curriculum influences students' awareness and perspectives on sustainable design. The aim of this research is to investigate the process through which students develop a deeper understanding of energy efficiency in IoT design, from the delivery of lecture materials to the completion of assignments. This section details the structure of the educational intervention, which includes the development of lecture content, the design and execution of assignments, and the analysis of students' evolving understanding of IoT's role in promoting energy efficiency.

The study is based on three progressive assignments designed to enhance students' understanding of energy efficiency in relation to IoT. The first assignment, titled "Personal Daily Activities Reflection," requires students to reflect on their daily habits and identify areas where energy is consumed inefficiently. This reflection serves as an introductory exercise to raise awareness of energy consumption and its environmental impacts. Students track and analyze their activities, fostering self-awareness and helping them connect their personal energy use to broader sustainability issues.

Building on the first assignment, the second task, "Responding to Energy Wasting in Daily Life," challenges students to identify and address energy inefficiencies within their daily environments. Students explore potential energy-saving solutions using IoT devices, positioning them to view IoT not just as gadgets, but as tools capable of mitigating energy waste and supporting sustainability. This assignment encourages critical thinking about real-world applications of IoT technology to solve energy efficiency problems in various contexts, including homes, workplaces, and public spaces.

The final assignment, "Group Project of Designing IoT," serves as a culminating project in which students collaborate in teams to design an IoT-based solution to a specific energy-related issue. In this group setting, students are tasked with applying the knowledge and insights gained from the previous assignments to create a prototype or conceptual design for an energy-efficient IoT device. The group project emphasizes collaboration, creativity, and practical application, allowing students to synthesize their learning and innovate solutions that integrate energy efficiency with IoT technologies.

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To assess the impact of the intervention, students' perspectives on IoT and energy efficiency were evaluated before and after completing the assignments. Initially, many students perceived IoT primarily as consumer gadgets for convenience. However, by the end of the study, students demonstrated a significant shift in perspective, recognizing IoT as a powerful tool for enhancing energy efficiency and supporting sustainable development. These findings suggest that the interdisciplinary approach of integrating energy efficiency concepts into the IoT curriculum effectively fostered a deeper understanding of sustainability and technological innovation.

3. RESULT AND DISCUSSION

3.1. Learning Materials for IoT Classes

The course syllabus, initially developed in 2017, as shown Figure 1, was revised and updated for the 2025 academic year to reflect the evolving focus on sustainability in IoT. The new curriculum incorporates advanced topics such as smart buildings and smart cities, as shown Figure 2, emphasizing the integration of energy efficiency with IoT technologies. The first assignment is designed to help students understand their own habits related to energy consumption and explore how IoT can support energy efficiency.

RENCANA PEMBELAJARAN		
Pertemuan	Materi	Materi (Inggris)
1	Pendahuluan: - Sistem perkuliahan, pengertian IoT. - Kuis interaktif pengenalan IoT	Preliminary: - Lecture contract, understanding IoT. - IoT introduction interactive quiz.
2	Dasar-dasar perangkat Internet Regulasi terkait Informasi dan Transaksi Elektronik Dasar-dasar penggunaan internet untuk menunjang pendidikan: E learning, Video conf, survei/pengumpulan data	Internet device basics Electronic Information and Transaction Regulations The basics of using the internet to support education: E learning, Video conf, survey/data collection
3	Internet untuk menunjang setiap proses arsitektur: (1)Perencanaan, (2)Perancangan, (3)Pemasaran, (4)Konstruksi, (5)Operasional bangunan.	Internet to support every architectural process: (1)Planning, (2)Design, (3)Marketing, (4)Construction, (5)Building operation.
4	Penggunaan Internet dalam perencanaan arsitektur: pencarian referensi dan cek similarity/plagiarism.	Use of the Internet in architectural planning: reference search and check similarity/plagiarism.
5	Penggunaan Internet dalam perencanaan arsitektur: survei, kuesioner, pengumpulan data menggunakan platform internet atau search engine.	Use of the Internet in architectural planning: surveys, questionnaire, data collection using several platforms or search engines.
6	Penggunaan Internet dalam perencanaan arsitektur: reference manager dalam perencanaan arsitektur (software mendeley)	Use of the Internet in architectural planning: reference manager in architectural planning (Mendeley software)
7	IoT untuk perancangan arsitektur: cek tapak, pencarian preseden, upload/download 2D/3D dari big data, mengetahui BIM.	IoT for architectural design: site check, precedent search, 2D/3D upload/download of big data, knowing BIM.
8	UTS	Mid-term examination
9	Penggunaan internet dalam pendekatan green architecture (EDGE platform) Pembahasan hasil mid semester	The use of the internet in the green architecture approach (EDGE platform) Discussion of mid -semester results
10	Penggunaan internet untuk pemasaran arsitektur: e-commerce, start up arsitektur (contoh: video operasional)	Internet use for architectural marketing: e-commerce, start-up architecture (example: operational videos)
11	IoT untuk proses konstruksi: Bangunan 3D printing.	IoT for the construction process: 3D printing buildings
12	IoT untuk operasional bangunan: Pollution control, Smart cameras, smart parking, Energy efficiency, Bardi Smart Home, etc	IoT for building operation: Pollution control, Smart cameras, smart parking, Energy efficiency, Bardi Smart Home, etc

Figure 1. The syllabus of 2017 IOT class

The changes made in the 2025 syllabus reflect a broader sustainability agenda that permeates both the content and the teaching-learning process. In this updated

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framework, students are encouraged to assess their personal energy consumption habits and use IoT technology to mitigate energy waste. These adjustments align with global trends toward sustainability in higher education, where more universities are incorporating green practices into their operations and curricula [5]. By embedding sustainability into the IoT curriculum, this approach aims to foster a deeper understanding of how architectural design can contribute to energy conservation and environmental responsibility.

The third assignment takes a different approach by allowing students to apply their knowledge independently. Rather than being directly instructed on energy-efficient IoT design, students are tasked with utilizing their previous understanding of energy efficiency concepts to devise their own solutions. This shift in responsibility encourages critical thinking and innovation, allowing students to fully engage with the subject matter [1]. The move from structured guidance to independent project development exemplifies the progression from knowledge acquisition to practical application, an essential element in fostering a deeper understanding of sustainability.

Figure 2. The new teaching material of 2025 IOT class

3.2. Results of Assignments

The first assignment, focusing on students' personal use of electronic devices, provided valuable insights into their energy consumption habits. Students reported using various electronic devices throughout their day, but often failed to recognize the cumulative energy consumption associated with multiple devices. A common observation was that they would forget to include devices that were left on while they used others, such as leaving lamps or chargers plugged in while using smartphones or laptops. Some students generalized the energy consumption issues by using terms like "many tools usage" or "unplugged problems," which indicates a lack of precision in their awareness of the energy impact of individual devices.

This assignment served as an eye-opener for many students, revealing how habits such as leaving devices on unnecessarily contribute to overall energy waste. In the second assignment, which focused on addressing these energy-wasting habits,

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students exhibited more refined thinking. Many students linked their previous reflections to actionable solutions, suggesting IoT-based applications for energy management. The logic behind their solutions demonstrated an emerging understanding of the potential for IoT devices to mitigate energy waste. Their proposals often involved using IoT technology to monitor and control energy consumption, such as integrating communication devices with energy management systems.

The results from these assignments indicate that students were beginning to recognize that excessive use of electronic devices, particularly communication gadgets, significantly contributes to energy consumption. In response, they proposed IoT applications designed to monitor and optimize the energy usage of multiple devices. Some students, for example, suggested integrating communication gadgets with electricity controllers, leveraging internet connectivity to enhance energy efficiency. This shift toward practical IoT applications underscores a growing awareness of the role of technology in reducing energy consumption. Furthermore, the findings align with previous studies that show communication devices are particularly energy-intensive and that IoT can provide effective solutions to mitigate such inefficiencies [6].

In the third assignment, students worked in groups to design IoT-based solutions to energy-related problems. Building on their earlier assignments, students expanded their ideas beyond simple IoT devices like smartphones to more complex systems incorporating sensors, automation, and control mechanisms. The designs presented by the groups incorporated Internet-connected modules, allowing them to monitor and regulate energy consumption in real time (Figure 3). This group collaboration demonstrated how students were synthesizing their learning and applying it to more sophisticated solutions, showing significant growth in both their technical and conceptual understanding of IoT for energy efficiency.

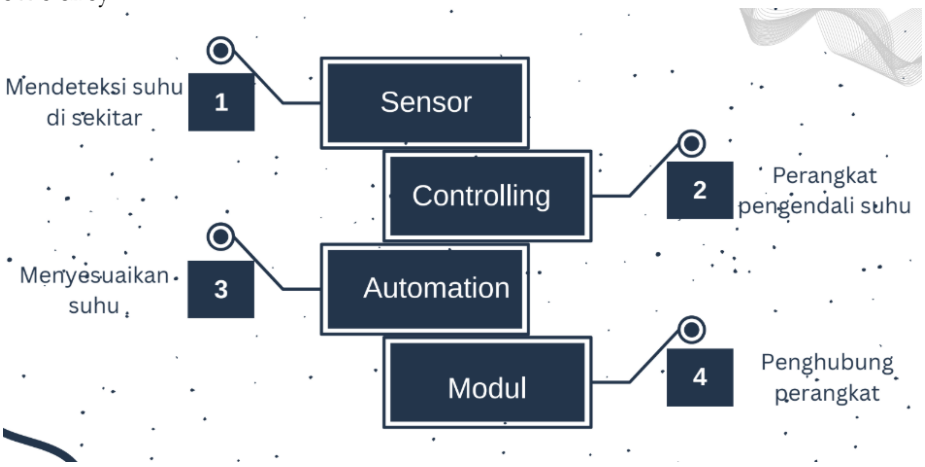

Figure 3. The 3rd assignment result in group discussion

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3.3. The Process of Understanding Energy Efficiency Toward IoT

As digitalization continues to expand, so does the demand for energy, creating a paradox in which the very technologies designed to optimize our lives also contribute to greater energy consumption [7]. This challenge has prompted concerns about balancing the use of IoT technologies during both the design and operational phases of architecture [8]. In this study, students demonstrated a growing awareness of energy demand and the potential role of IoT in mitigating it. However, a recurring theme in their feedback was the belief that sustainability should not be confined to a single course but should be integrated into architectural studios throughout the design process [9]. While this perspective is important, the lack of IoT integration in the architectural design process in the early semesters illustrates a gap between theoretical knowledge and practical application. For instance, the designs presented in the third-semester architectural studio did not incorporate IoT systems, despite earlier exposure to energy efficiency concepts (Figure 4). This suggests that while students understood the importance of energy efficiency, they were not yet applying it consistently in their design work.

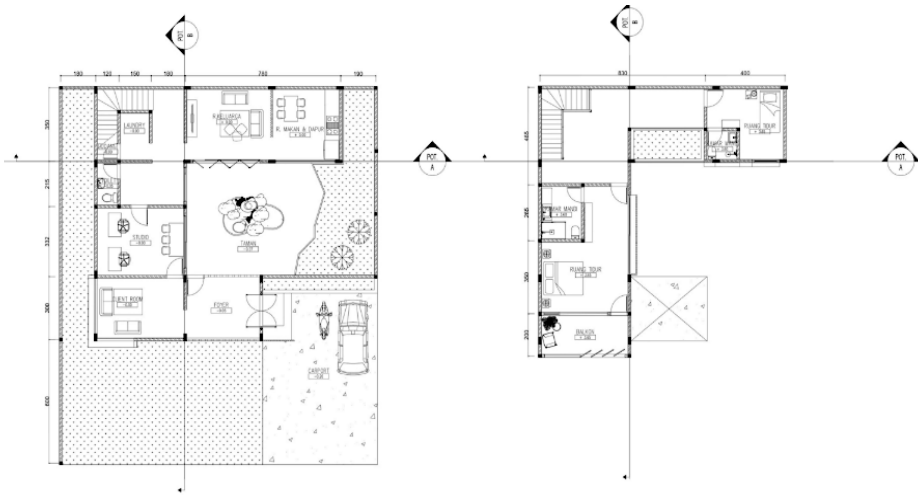

Figure 4. The 3rd semester student architectural studio plan

To address this gap, it is crucial that energy efficiency through IoT applications becomes a mandatory part of architectural design at every stage. This can be achieved by explicitly requiring the integration of IoT technologies in early design concepts. For example, students should be encouraged to include sensor-control-automation systems in their design process from the outset (Figure 5). Such integration would help to solidify the importance of energy efficiency in students' thinking and design practices.

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Figure 5. Leading scheme of IoT applications

Another challenge identified in this study is that students may need continual reminders to incorporate energy-efficient IoT solutions in their architectural designs. Incorporating a checklist or structured prompts into design studios—such as filling out an IoT application box during the concept development stages (weeks 1–6)—could ensure that students consistently address energy efficiency in their work. Encouraging students to approach building design with IoT concepts in mind would help them envision more sustainable, energy-efficient solutions. Given that students today are native to IoT technologies, they are well-positioned to design buildings that integrate energy-efficient systems seamlessly, creating a future where technology supports environmental sustainability naturally.

3.4. Discussion

The results from this study underscore the significance of integrating energy efficiency education into the IoT curriculum, particularly in the context of architecture students. By updating the syllabus for 2025 to include new topics such as smart buildings and smart cities, the course has evolved to reflect global trends toward sustainability. This shift is not just about teaching new material; it's a broader move to embed sustainability into the core curriculum. By encouraging students to reflect on their daily energy consumption and explore how IoT can help mitigate energy waste, the program fosters a deeper understanding of how architectural design can contribute to a more sustainable world. These changes align with a growing trend in higher education to make sustainability a foundational principle in curricula, which is critical in preparing future professionals to tackle pressing environmental challenges [10-12].

The progression of assignments in the study highlights how students' perceptions of energy efficiency and IoT evolved over time. The first assignment, focused on personal energy consumption, acted as an eye-opener, revealing how often students failed to consider the cumulative energy use of multiple devices. This initial reflection allowed students to connect their personal habits with broader sustainability issues, which set the stage for more targeted problem-solving in the second assignment. In this task, students demonstrated a more refined understanding of how IoT could be used to solve real-world energy inefficiencies. Their solutions ranged from creating applications to monitor energy consumption in homes to integrating IoT devices with electricity controllers. These practical ideas reflect an emerging awareness of IoT's potential to support sustainable living, demonstrating a shift from viewing IoT as merely a collection of gadgets to recognizing it as a tool for energy conservation.

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The third assignment, where students worked in groups to design IoT-based solutions, showcased their ability to apply their newfound knowledge in more sophisticated ways. By incorporating sensors, automation, and real-time energy monitoring, students moved beyond simple device ideas and began to consider integrated systems that could optimize energy use on a larger scale. This shift toward complex, system-based thinking demonstrates that students are internalizing the concept of energy-efficient design and recognizing how IoT can play a pivotal role in achieving it. Their designs for smart, IoT-connected systems suggest that they are not only grasping the theoretical underpinnings of energy efficiency but are also starting to envision how these concepts can be applied in real-world architectural practice.

Despite the positive developments in the students' understanding of IoT and energy efficiency, the study also highlighted some critical gaps, particularly in the application of these concepts within architectural design. While students demonstrated a clear understanding of the importance of energy efficiency through IoT in the context of their assignments, the architectural designs in the third semester did not reflect this integration. This gap suggests that while students are learning about sustainability, they are not yet consistently applying it in their design work. To address this, the integration of IoT and energy efficiency should be made a mandatory part of the design process from the outset, not just in specialized courses. Encouraging students to include IoT systems in their early design concepts could help reinforce the importance of energy-efficient design and ensure that these ideas become ingrained in their approach to architecture.

The findings also suggest that students may need ongoing reminders and structured prompts to keep sustainability at the forefront of their design process. Including specific checkpoints, such as a dedicated IoT application section in the early weeks of design studios, could ensure that students continue to incorporate energy-efficient solutions throughout their projects. Given that today's students are digital natives, they are uniquely positioned to design buildings that integrate IoT technologies seamlessly. The challenge lies in ensuring that sustainability is not just a concept discussed in the classroom but a practical tool that guides their design decisions from the very beginning of their academic journey. In conclusion, this study reinforces the importance of integrating sustainability into the core of architectural education and demonstrates how interdisciplinary approaches, such as combining IoT with energy efficiency education, can empower students to become the sustainability leaders of tomorrow.

4. CONCLUSION

This study demonstrates the potential of integrating energy efficiency education within the Internet of Things (IoT) curriculum to significantly enhance students' understanding of sustainable design. By aligning course content with global

sustainability goals and encouraging students to apply IoT concepts to real-world energy efficiency challenges, the program fosters a deeper awareness of how technology can contribute to environmental sustainability. While there are still gaps in the consistent application of these concepts in architectural design, the findings underscore the importance of making sustainability an integral part of the design process from the outset. This interdisciplinary approach not only equips students with the necessary skills to address global sustainability challenges but also prepares them to be future leaders in creating energy-efficient, sustainable built environments.

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