Enhancing Energy Efficiency and Sustainability in Public Transportation: A Study on Kinetic Floor Tiles at Surabaya Gubeng Station

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2060年までの二酸化炭素排出実質ゼロを目指すインドネシアで、通行人の歩行圧を電気に変換するkinetic floor tilesの有効性を検証する社会実験がスラバヤの鉄道駅で行われた。その結果を分析し、その可能性を探った。

Abstract

The rapid urban growth and increasing awareness of environmental issues have spurred research efforts to develop innovative solutions that combine renewable energy with energy efficiency. One intriguing solution is the utilization of Kinetic Floor Tiles to revitalize and connect public transportation infrastructure, such as Surabaya Gubeng Station, which is bustling with visitors and passengers. This research aims to explore the potential of Kinetic Floor Tiles in enhancing energy efficiency and environmental sustainability at this Station. The research methodology encompasses qualitative and quantitative methods. The qualitative methods involve site visits and interviews with stakeholders to understand their perceptions of this technology and the impact on the surrounding environment. Meanwhile, the quantitative method involves basic physics calculation to measure the amount of energy generated by Kinetic Floor Tiles when interacting with user activities in public spaces at the station. Apart from that, it will also carry out modeling and simulations to anticipate the potential energy savings that can be obtained by implementing this technology. The results of this research are expected to provide an alternative energy source based on the comparison of energy generated currently with the presence of Kinetic Floor Tiles in public spaces at Surabaya Gubeng Station. By providing alternative solutions in the context of station revitalization and connecting it with environmental sustainability, this research aids in the endeavor to revitalize public transportation infrastructure frequented by visitors and passengers, while converting kinetic energy generated by floor movement or pressure into electrical energy that can be used as needed.

Keywords energy efficiency, environmental sustainability, kinetic floor tile, renewable energy, Surabaya Gubeng Station

Introduction

In the last few decades, technological advancements have played a crucial role in shaping and transforming societal dynamics. Indonesia, being a country rich in natural resources like oil, gas, and coal, faces challenges in managing technology, especially in the energy sector. The Human Development Index (HDI) data reflects that Indonesia's HDI is below the global average, with a value of 0.718, while the global average is 0.737 (Ministry of Research and Technology/National Research and Innovation Agency, 2021). Indonesia is ranked 107th out of 189 countries, with a competitiveness index of 64.629, placing it 40th out of 140 countries. This situation increases Indonesia's dependence on foreign energy technology, posing a threat to national security[1]. This dependence is evident in Indonesia's need to import equipment and machinery for power generation and other energy industries.

The reliance on electric power in Indonesia remains high, primarily on fossil fuels like crude oil. Despite the significant potential of renewable energy (RE), such as Solar Power Plants (PLTS) with 92% utilization by PT

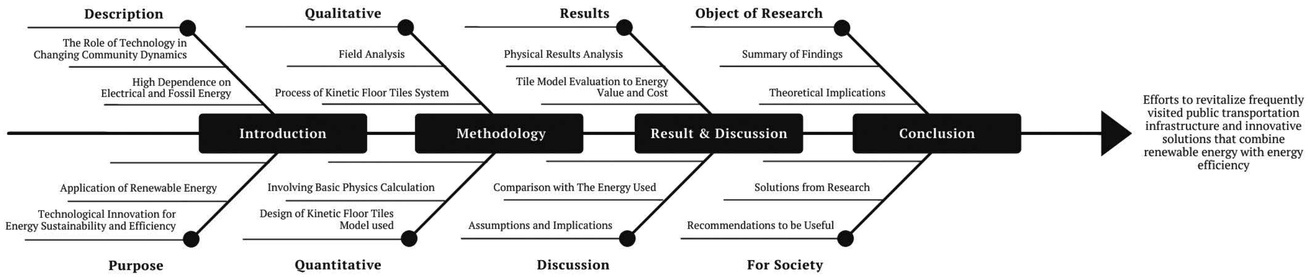

Fig. 1. Fishbone diagram.

Perusahaan Listrik Negara (PLN) consumers, Indonesia still faces challenges in adopting this technology widely[2]. In achieving the Net Zero Emission target by 2060, the implementation of RE in Indonesia becomes crucial. Dependency on fossil energy makes Indonesia vulnerable to fluctuations in oil prices in the global market[3]. The Indonesian government recognizes the need to expand the use of RE and low-carbon energy[4]. Amid global challenges related to climate change and limited natural resources, it is essential to explore and implement innovative technologies that can have a positive impact on energy sustainability.

Technologies like kinetic floor tiles, also known as “paving tiles” or “energy-harvesting floor tiles,” are innovative solutions that can help increase the use of renewable energy and reduce dependence on external resources[5]. Kinetic floor tiles are designed to generate electricity from the mechanical energy produced by human movement. They use technologies such as piezoelectric generators and electromagnetic generators to convert kinetic energy into electrical energy that can be used to power various applications within public spaces, such as lighting, displays, or charging stations[6], [7]. This technology offers an innovative and sustainable way to generate electricity by harnessing human footsteps, making it suitable for application in areas with high pedestrian traffic, such as jogging, running, or dance activities[8]. By strategically placing kinetic floor tiles in high-traffic areas like train stations, airports, malls, or pedestrian walkways, public spaces can effectively generate electricity from the movement of individuals, contributing to sustainable energy practices and reducing reliance on traditional power sources[7], [9]. Additionally, the interactive and engaging nature of kinetic floor tiles can enhance user experience, raise awareness about energy consumption, and promote eco-friendly behaviors in public settings[10].

Surabaya Gubeng Station, a focal point frequently visited by both city and out-of-town residents, was chosen as the research location due to its status as one of the largest and busiest stations. This study aims to optimize the use of electric energy within the station by leveraging the high number of visitors, allowing the station to generate its electricity without relying on external energy purchases. The integration of kinetic floor tile technology is one step toward enhancing energy efficiency and sustainability at the station.

Methodology

This study utilizes a fishbone diagram which can be seen in Figure 1, often referred to as the cause-and-effect diagram. The Fishbone (Ishikawa) Diagram[11], is a visual aid for problem-solving that divides possible causes of an issue into groupings such as machine, technique, material, man or mind power, and measurement or medium. When there is a lack of quantitative data and difficulty understanding problems, this picture is especially helpful. This diagram helps to address the underlying cause of an issue rather than merely its symptoms by graphically grouping potential causes and establishing cause and effect links. It is frequently used to pinpoint problem areas and their underlying causes in lean and six-sigma transformations.

The methodology combines qualitative methods like field analysis and a literature review with quantitative methods involving kinetic floor tile design models and physical calculations. The results and discussion section involves calculations at Surabaya Gubeng Station, comparing costs and values of generated electrical energy. The conclusion suggests that kinetic floor tile technology is a viable, innovative solution for Surabaya Gubeng Station, providing its own energy source, enhancing efficiency, and benefiting both the community and station management. The research aims to accomplish its goals through a well-organized sequence of information.

Field Analysis

Based on field analysis and information from office employees in the building of Surabaya Gubeng Station, it is known that the station operates 24 hours a day as it serves as a public service facility. However, according to the train departure schedule, the likelihood is that there are no passengers throughout the entire 24 hours. Employees explain that if the station's operational continuity is considered beneficial, trains will operate without time restrictions. Conversely, if the situation is unfavorable or there are few passengers, it is ensured that no trains will operate to avoid operational cost losses.

Table 1. Schedule of maximum train operating hours for Surabaya Gubeng Station.

Type of Train	Maximum Operating Hours
Westbound long distance train	20 : 00 WIB
Eastbound long distance train	23 : 50 WIB
Local train	18 : 00 WIB

From Table 1, the operating hours of trains at the station peak only until 23:50 WIB. Therefore, it is estimated that people are likely to visit the station from 05:00 AM to 00:00 AM. It can be concluded that between midnight (00:00 AM) and morning (05:00 AM), there are no arrivals, except for specific purposes related to supporting facilities available in the public area inside the station building.

Considering the layout of Surabaya Gubeng Station shown in Figure 2, it can be observed that the Old Surabaya Gubeng Station Area has an area of about 400 m², with a semi-public area of 330 m² and a public

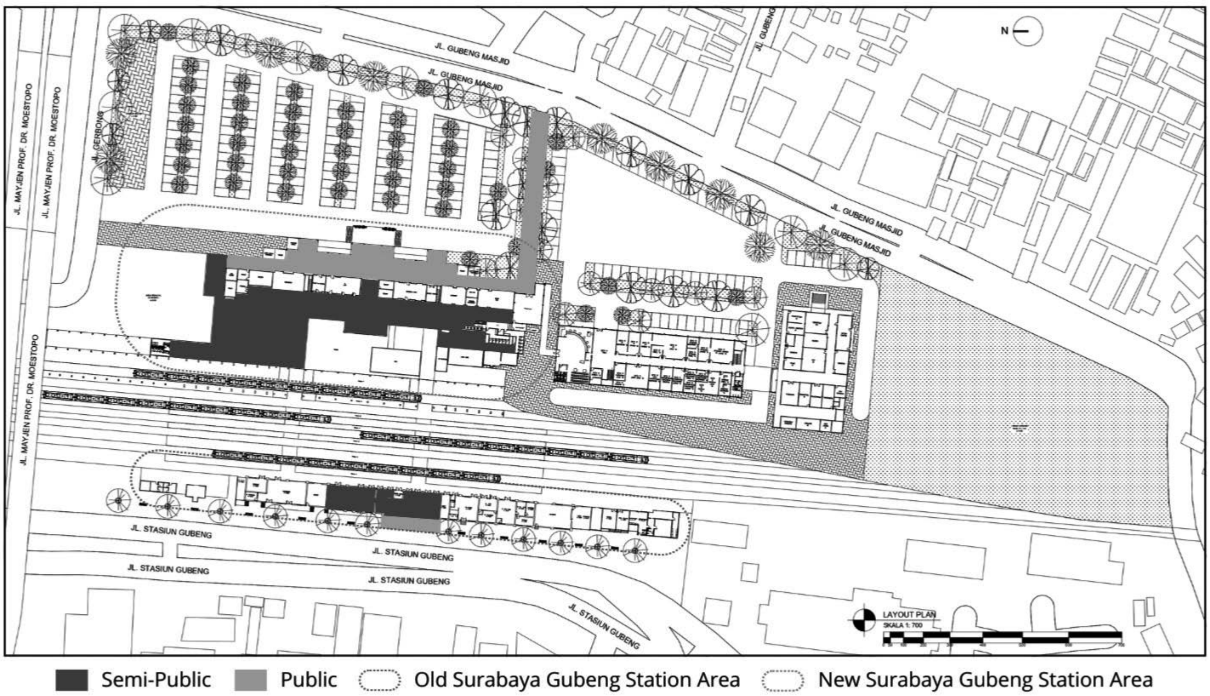

Fig. 2. Layout plan of Surabaya Gubeng Station for semi-public and public.

Source: Taken from reference data of PT. KAI Daop 8 developed by the author area of 170 m². Meanwhile, the New Surabaya Gubeng Station Area has an area of about 2.700 m², with a semi-public area of 1.700 m² and a public area of 1.000 m². Overall, the total area accessed by passengers and visitors inside the station building is approximately 3.100 m².

Process of Kinetic Floor Tiles System

In Figure 3, there's a diagram illustrating the process of converting mechanical energy generated by human movement or pressure on the floor into electrical energy. Here's a general overview of the kinetic floor system process[5], [8]:

1) Footstep Pressure, when a person steps on the Genpath floor tile, the pressure from the foot causes the tile to move or deform slightly, initiating the energy harvesting process.
2) Translation to Rotation, the Genpath system features a movement-converter mechanism that translates the linear movement of the floor tile, induced by a footstep, into rotational motion. This conversion process is essential for effectively transferring mechanical energy to the subsequent stages of energy harvesting.
3) Energy Harvesting Mechanism, commonly utilizing technologies such as piezoelectric generators or electromagnetic generators. These mechanisms capture and convert the mechanical energy from the user's movement into electrical energy.
4) Voltage Induction, as the EM generator rotates, it generates voltage through electromagnetic interactions within the system. This voltage signifies the electrical power harvested from human footsteps.
5) Power Manegement System, the electrical voltage and power produced by the EM generator are managed by a Power Management and Storage (PMS) circuit. This circuit controls and stores the harvested power, enabling efficient utilization to power electronic devices.
6) Energy Usage, the acquired power can be flowed to a switch or room that requires electricity.

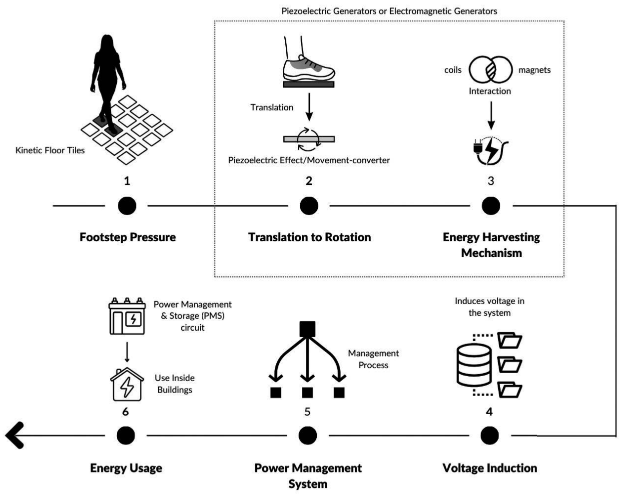

Fig. 3. Energy conversion process from human footsteps.

In summary, the Genpath energy harvesting floor system effectively captures the kinetic energy from human footsteps, converts it into electrical power using an electromagnetic generator, and manages the harvested energy for practical applications, showcasing an innovative approach to sustainable energy generation in high-traffic areas.

Design of Kinetic Floor Tiles Model used

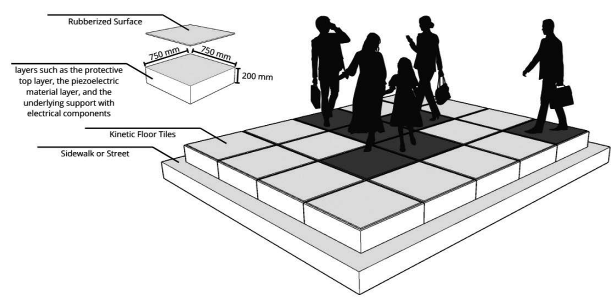

Fig. 4. Details of the kinetic floor tiles model used.

Kinetic Floor Tiles come in various sizes and voltages, depending on the design and technical specifications of the manufacturer or developer. As shown in Figure 4, the research employs tiles with dimensions of 750 mm × 750 mm × 200 mm, a commonly adopted size[12]. These tiles use piezoelectric technology to convert kinetic energy generated from human activities like walking, running, or jumping into electrical energy[13], [14]. For instance, a specific model called "The Dancer" can produce energy ranging from 25 to 35 watts per module[15]. Therefore, the research uses an average power of 30 watts per module, considering various tile models with energy-generating capacities between 25 and 35 watts per module.

Involving Basic Physics Calculation

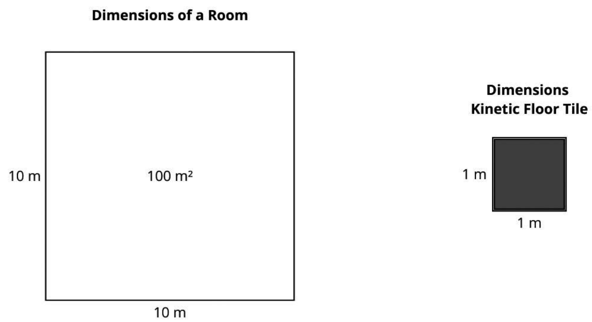

Fig. 5. Assume a room dimension and the kinetic dimensions of the floor tiles.

This research delves into the calculation of the energy that can be derived from kinetic floor tile technology. The study involves a combination of mathematical calculations to estimate the energy generated by these tiles. While basic physics calculations often rely on theoretical assumptions, this research aims to provide a more practical and accurate assessment of the energy output achievable through kinetic floor tiles. By utilizing mathematical models and real-world data, the study offers insights into the potential energy yield of these innovative tiles, contributing to a better understanding of their efficiency and effectiveness in generating electricity from human movement[16].

The kinetic floor tiles used in the design model have dimensions of 750 mm × 750 mm × 200 mm with a power of 30 watts per module. This means each module is 750 mm long, 750 mm wide, and 200 mm deep. Considering an area of 0.75 m × 0.75 m (square-shaped) generating 30 watts, each module covering 0.5625 m² can produce 30 watts. Thus, it is assumed that 1 m² has a maximum power of 60 watts.

Figure 5 shows assumptions about room dimensions and kinetic floor tiles. For example, if a room of 100 m² is equipped with kinetic floor tiles, then 100 m² × 60 watts will produce 6.000 watts in that space. It is assumed that each person requires 1.600 cm² of space for one tile (40 cm × 40 cm) and calculated as below,

$$\frac{\text{Room area}}{\text{One person per tile}} = \frac{10.000\ cm^2}{1600\ cm^2} = 6{,}25 \approx 6 \text{ people}$$

This means that 1 m² can be stepped on by 6 people per tile. Thus, for a room of 100 m², a maximum of 600 people is needed to generate 6.000 watts in a day. For example, it is assumed that the room is walked on by 400 people every hour, the generated power can be calculated as follows :

$$\frac{Number\ of\ people\ present}{Maximum\ number\ of\ people} \times \text{Maximum power generated}$$

$$\frac{400\ people}{600\ people} \times 6.000 \text{ watt} = \frac{4}{6} \times 6.000 = 4.000 \text{ watt}$$

The result shows that the presence of people are 400 every hour in the room, it generates 4.000 watts of electric power. This electric power can be converted into a monetary value to assess the potential cost savings for electricity in that room and assumed as following paragraph.

This study uses Surabaya Gubeng Station as the research location. It is a government facility subject to the electricity tariff set by PLN as an electric power company in this area. Since the government office, it needs (P-1/TR) with a power range of 6.600 VA to 200 kVA and the electricity tariff is estimated at $0,10 per kWh. This tariff is explained in reference[17]. The electric power produced by proposed kinetic floor tiles can be calculated as follows,

1 kWh = $0,10
Produced electric power per hour: 4 kW.
And per day : 4 kW × 24 hours = 96 kWh
Electricity price per day :
96 kWh × $0,10 = $9,94

It can be concluded that the electric power cost produced by proposed kinetic floor tiles is approximately \$298 per month. With calculations such as these, the result and ensuing discussions promise to demonstrate efficient energy production effectively.

Result

On April 14, 2023, PT. KAI Daop 8 officially announced that Surabaya Gubeng Station recorded the highest number of passengers boarding and alighting in East Java. The announcement stated that there were 69.378 passengers boarding and 74.698 alighting, totaling 144.076 passengers[18]. These figures do not include visitors accompanying, picking up, or visiting for purposes such as dining or using station facilities. Therefore, it can be concluded that the actual number of people coming to the station is likely to be even higher than the total number of train passengers.

Based on the data obtained, crowding of passengers and visitors at Surabaya Gubeng Station does not occur throughout the 24-hour period. This is due to the operational hours of trains at this station, which only run from 05:00 AM to 12:00 AM. Thus, it can be concluded that passenger and visitor activities occur for 19 hours, even though the station remains open 24 hours. Therefore, electricity usage will occur throughout the 24 hours.

In the next calculation, if passengers and visitors come during the 24-hour period, we can take the hourly average. If on that day the total number of passengers boarding and alighting is 144.076 people, then there will be around 6.000 people per hour. Therefore, the total estimated electrical energy used by Surabaya Gubeng Station, which has a total area of 3.100 m² and using the previously assumption, produced the electric power and electricity cost can be calculated as follows :

$$6.000 \text{ people per hour} : 3.100 \text{ m}^2 = 1{,}93 \approx 2 \text{ people}$$

$$\frac{2}{6} \times 60 \text{ watt} = \frac{1}{3} \times 60 \text{ watt} = 20 \text{ watt}/m^2$$

$$3.100 \text{ m}^2 \times 20 \text{ watts/m}^2 = 62.000 \text{ watts}$$

$$62.000 \text{ watts} : 1.000 = 62 \text{ kW}$$

$$62 \text{ kW x } 24 \text{ hours} = 1.488 \text{ kWh}$$

$$1.488 \text{ kWh x } \$0{,}10 = \$154/\text{day}$$

It is assumed that one tile can accommodate or be stepped on by about 2 people, and from these 2 people divided by 6 people (based on the previous assumption that 1 m² will cover 6 people for one tile) and multiplied by the power of 60 watts for 1 m². Then the total area of Surabaya Gubeng Station reaching 3.100 m², it will generate the electric power of about 62.000 watts.

This result can be converted into a monetary value with a total electric power obtained of 1.488 kWh in a day, with a cost of approximately \$4.623 per month just for passengers boarding and alighting. If added to visitors, assume the number of visitors coming to Surabaya Gubeng Station is around 3,000 people per hour (half of the number of passengers boarding and alighting). Then, the total electrical energy added by visitors is as follows :

$$170 \text{ m}^2 + 1.000 \text{ m}^2 = 1.170 \text{ m}^2$$

$$3.000 \text{ people} : 1.170 \text{ m}^2 = 2{,}56 \approx 3 \text{ people}$$

$$\frac{3}{6} \times 60 \text{ watt} = \frac{1}{2} \times 60 \text{ watt} = 30 \text{ watt}/m^2$$

$$1.170 \text{ m}^2 \times 30 \text{ watts/ m}^2 = 35.100 \text{ watts}$$

$$35.100 \text{ watts} : 1.000 = 35{,}1 \text{ kW}$$

$$35{,}1 \text{ kW x } 24 \text{ hours/day} = 842{,}4 \approx 842 \text{ kWh}$$

$$842 \text{ kWh x } \$0{,}10 = \$87/\text{day}$$

The area accessible to visitors in this station in the public area has a total area of about 1.170 m². If added to the total area of the public area in the old and new Surabaya Gubeng Station, the result is around \$2.612 per month for visitor areas. If added to the passenger area, it will result in a total cost of approximately \$7.208.

Discussion

This discussion will explore the main findings of the research, delving into the context of kinetic floor tile technology at Surabaya Gubeng Station, and providing interpretation and significance. These findings contribute significantly to understanding the potential implementation of this technology and its impact on energy efficiency in a crowded station environment. Furthermore, this discussion will compare the electricity consumption from the current external source with the electricity generated by kinetic floor tile technology.

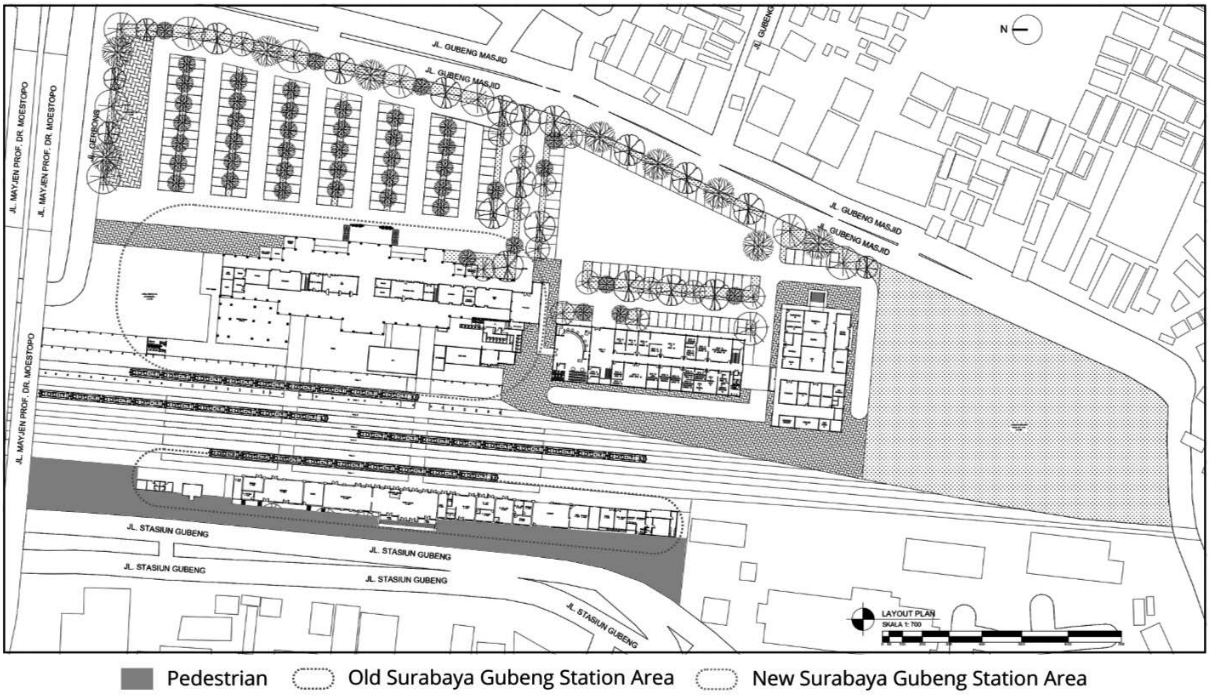

Fig. 6. Layout plan of Surabaya Gubeng Station for pedestrian.

Source: Taken from reference data of PT. KAI Daop 8 developed by the author

The architectural characteristics of kinetic floor tiles offer a range of benefits that can significantly enhance architectural spaces, especially in bustling areas like Surabaya Gubeng Station. These tiles introduce movement, animated patterns, textures, and visual effects that respond to user interaction or programmed sequences. Beyond being dynamic design elements, kinetic floor tiles create interactive environments, enhance aesthetics, enable spatial transformations, and provide innovative design solutions. They function as versatile architectural materials that add dynamism, interactivity, and aesthetic appeal to spaces, fostering creative and innovative design expression[19]. In busy pedestrian areas or streets, these tiles can transform the walking experience into an enjoyable and creative interaction, making them valuable additions to architectural spaces seeking to engage users in a unique and interactive way.

If Surabaya Gubeng Station currently uses 60 kW of electricity from PLN. If calculated, this consumption would reach :

60 kW x 24 hours = 1.440 kWh

1.440 kWh x $0,10 = $148/day

In one month, the cost of electricity taken from PLN reaches $4.454, a significant and burdensome amount. However, with the implementation of kinetic floor tiles, these electricity costs can be fully covered, even with the potential for surplus.

The kinetic floor tile are applied in the station's pedestrian area, as seen in figure 6, covering an area of 2.500 m² and passed by around 9.000 people every hour, the potential electricity generated can be calculated as follows :

9.000 people : 2.500 m² = 3,6 ≈ 4 people

$$\frac{4}{6} \times 60 \text{ watt} = \frac{2}{3} \times 60 \text{ watt} = 40 \text{ watt}/m^2$$

2.500 m² × 40 watts/m² = 100.000 watts

100.000 watts : 1.000 = 100 kW

100 kW x 24 = 2.400 kWh

2.400 kWh x $0,10 = $248/day

Thus, the implementation of kinetic floor tiles in this area can generate $7.426 per month, exceeding the total electricity costs spent on passenger and visitor areas.

Conclusion

This research aims to improve energy efficiency and environmental sustainability in public transportation, particularly at Surabaya Gubeng Station, by implementing kinetic floor tile technology. The research method involves a combination of qualitative and quantitative methods, including field analysis, stakeholder interviews, basic physics calculations, modeling for product companies or literature, and simulation.

The electrical energy generated from passengers boarding, alighting, and public areas (visitors), based on the daily activities of passengers and visitors at Surabaya Gubeng Station, amounts to 1,488 kWh + 842 kWh = 2,330 kWh. When converted into rupiah, this would yield $7.208. It is assumed that the electrical energy consumption of Surabaya Gubeng Station is approximately 60 kW or 1,440 kWh, which incurs a cost of $4.454 from PLN. This cost can be fully covered by the electricity generated in the semi-public and public areas if kinetic floor tile technology is implemented.

Additionally, if the pedestrian area, which is a high-traffic zone around the station, is also equipped with kinetic floor tile technology, it would generate 2,400 kWh of electrical energy, costing $7.426. This indicates that the electrical energy generated from the semi-public and public areas alone can cover the cost of electricity from PLN, and if the pedestrian area is also equipped with kinetic floor tiles, the output will be significantly higher. This surplus energy can be sold or donated to the surrounding community (the entire residential area around the station), creating a broader positive impact in environmental and social contexts.

The implementation of kinetic floor tiles at Surabaya Gubeng Station can create its own energy source, improve efficiency, and support sustainability. Furthermore, this technology is effective not only in promoting physical activity and enhancing user experience but also in showcasing its potential to promote healthier lifestyles[20]. In addition, the economic implications are significant in this study case. By comparing the current electricity consumption from PLN with the potential electricity generation from kinetic floor tiles, the financial feasibility of adopting this technology becomes evident. The calculation demonstrates that the electricity costs incurred from PLN can be fully covered, and even exceeded, by the electricity generated through kinetic floor tiles. This not only offsets the station's energy expenses but also presents an opportunity for surplus energy production, which can help reduce operational costs or create additional revenue streams.

Furthermore, the architectural attributes of kinetic floor tiles play a crucial role in enhancing the station's aesthetic appeal and user experience. The dynamic design elements and interactive features not only create visually stimulating environments but also foster creative and innovative design expressions. Therefore, beyond the energy-saving potential, the integration of kinetic floor tiles contributes significantly to the station's overall ambiance, reinforcing its identity as a modern and engaging transportation hub.

Thus, this research provides a valuable contribution in supporting the revitalization of public transportation infrastructure, integrating it with sustainable technology, and offering an energy alternative to reduce dependence on external resources while enhancing environmental sustainability in the future.

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