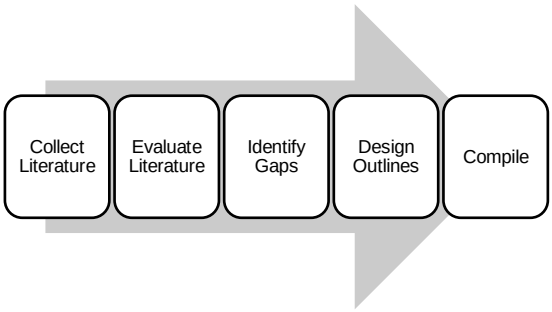
increasing energy demand, the pressure to use green energy, the vast potential of strategic airport locations, and the economic and operational advantages, Piezoelectric Energy Harvesting emerges as a relevant and promising solution. The design of this technology at airports can be a step forward in the effort to achieve greater sustainability and energy efficiency. It is expected to help save energy and reduce operational costs in the long run. The initial investment in this technology can be offset by reducing conventional energy costs and contributing to the company's sustainability goals. In addition, an additional sustainable energy source can improve the reliability of the energy supply at the airport.

Based on the background, problems can be formulated and discussed to build hypotheses for further research: 1) Does energy source affect piezoelectric energy harvesting? 2) Does Material Affect Piezoelectric Energy Harvesting? 3) Does design affect Piezoelectric Energy Harvesting? This article discusses the influence of Energy Sources, Materials, and Design on Piezoelectric Energy Harvesting, a literature review study in energy harvesting technology. This research is expected to provide an overview of what factors need to be considered when implementing Piezoelectric Energy Harvesting at the airport in terms of energy sources, types of materials, and designs following the characteristics of airport activities.

METHOD

This research is a literature review that studies the theory and the relationship between variables: energy source, material, and design. The literature review is a method that can be employed to carry out research endeavors. The literature review is considered the most authoritative form of evidence. Literature reviews are a systematic process employed to collect information or strategies for addressing specific issues. They entail a systematic procedure that generates reports to conduct research or concentrate on a specific topic. Nevertheless, the evidence suggests that conducting a literature review might be difficult because researchers must thoroughly understand how to investigate a specific issue to compile a review. According to Zed's research (Kartiningrum, 2015), the literature review is needed as preliminary research to understand emerging societal issues better. Using this research, the researchers hope to gain a deeper insight into the potential application of piezoelectric nanogenerators at airports. In his 2018 research, Cronin states that to create a comprehensive literature review effectively, a writer must meticulously adhere to five distinct steps during the preparation and writing (Cahyono et al., 2019).



This research collects scientific articles from trusted publisher journals with indexes. The library studies are structured and grouped to approach methodological assumptions. The library study is presented inductively and exploratory to provide a clear overview of current literary references to the theme of piezoelectric energy harvesting.

RESULT AND DISCUSSION

Piezoelectric Energy Sources in Airports

Energy sources for piezoelectric energy are ambient energy sources, usually solar, heat, and vibrational energy. Among these energy sources, vibrational energy is continuously present in nature and man-made structures (Safaei et al., 2019). Mechanical energy generated by the pressure of people or objects has also been shown to be a source of PEH (Abadi et al.,

2018; Sharma et al., 2022; Yulia et al., 2016). The Energy Source indicator for ambient energy is a stable source and transduction mechanism that can convert vibrational energy into useful electrical energy.

Energy sources are produced by flexible piezoelectric devices that harvest wind energy (Orrego et al., 2017). Energy source indicators include wind stability and Piezoelectric Energy Harvesting design. Energy Source for piezoelectric energy harvesting uses direct energy conversion from vibration and mechanical deformation into electrical energy. Piezoelectric Energy Harvesting is a promising technique for supplying power sources in standalone electronic devices, wireless sensor nodes, micro-electronic devices, etc (Kang et al., 2016). Energy Source indicators are simple structural designs and materials influencing higher energy conversion efficiency. Energy Sources obtained from noise and vibration include noise from aircraft near airports, vibrations from jet and supersonic aircraft, aircraft engine tests, aircraft runway noise, and supersonic booms (Kováciková et al., 2023). Indicators of energy sources are the intense vibrations that are produced.

The energy source is obtained from the flexible airfield pavement structure, the pressure generated by aircraft activity on the aircraft runway (Zhao & Wang, 2020). The indicators of the Energy Source are the strength of the pressure generated and the stackable design of the piezoelectric system embedded in the flexible pavement. Energy sources have been studied extensively by previous researchers, including (Altabey & Kouritem, 2023; Bairagi et al., 2023; Febrawi & Wonoyudo, 2013; Mohammadpourfazeli et al., 2023; Nechibvute et al., 2012; Sarker et al., 2022).

Airport characteristics can be a potential Piezoelectric Energy Harvesting source as places with intensive activities generate much wasted mechanical energy. This energy comes from various sources, such as passenger and visitor traffic, vehicle movement, elevator and conveyor use, and aircraft activity on runways and taxiways (Lee & Youn, 2011; Safaei et al., 2019; Sekhar et al., 2023). In addition, airside wind speeds and vibrations generated by building structures also offer an additional energy source. Converting mechanical energy into alternative electrical energy through piezoelectric technology can improve airport operations' energy efficiency and sustainability.

Piezoelectric Materials in Airports

The materials used in energy harvesting activities are divided based on the type of effect used, namely piezoelectric (PENG), triboelectric (TENG), and pyroelectric (PyENG), which was first developed by Wang in 2006 (Indira et al., 2019). The indicators are the energy source, material characteristics, and implementation based on the type of effect selected. Materials that utilize the piezoelectric effect are divided into three types: polymers, ceramics, and composites (Sekhar et al., 2023). These material indicators are energy sources, properties, and characteristics appropriate to the application's location.

Polymer-type materials are usually selected with a focus on the flexibility and malleability of inorganic, polymeric, and bio-piezoelectric materials, explaining their properties for monitoring physiological signals, motion detection, and force sensing (Mohammadpourfazeli et al., 2023), where (Y. Wu et al., 2021) Therefore, PLLA/PDMS, electro-spun PVDF, and ZnO/PVDF have a higher elastic modulus and are more suitable for wearable devices. The dimensions or indicators of the material are the types of polymers and composites that match human skin as the modulus of elasticity. The lead zirconate titanate or PZT ceramic type material is most widely used because of its durability (Kang et al., 2016) because it is considered to have the highest piezoelectric effect even though the

characteristics of PZT are classified as stiff and brittle (Habib et al., 2022). The power generated from this type of Piezoelectric Energy Harvesting is capable of biasing several electronic devices at once (Ambrosio et al., 2011). PZT material dimensions or indicators are material characteristics capable of providing optimal performance, as evidenced by the resulting power output.

Composite materials have advantages compared to ceramic and polymer materials because the nature of the material is easy to modify, both in structure and composition (Fabiani et al., 2019; Habib et al., 2022. For example, piezoelectric polymer nanofibers were successfully embedded in composite laminates for self-sensing applications, as mentioned in the research (Selleri et al., 2022). Material indicators are the flexibility of structure and composition. Many studies related to materials have been conducted by previous researchers, including (Habib et al., 2022; Liu et al., 2018; Safaei et al., 2019; Sekhar et al., 2023).

The type of materials has to match the airport's energy source. The airport's energy source character can be found based on the activities that generate much wasted mechanical energy. Ceramic materials have strong piezoelectric properties but are stiff and brittle. Where PZT has the highest piezoelectricity compared to others. In addition, the modified BaTiO3 and KNN also have suitable piezoelectric constants. However, AlN and LiNbO3 are better choices at high temperatures. Therefore, all ceramic piezoelectric materials in this study have high Young's modulus values, making them unlikely to be employed in applications requiring large deflection, except microfabricated PZT. Although polymer materials are lighter and more flexible than ceramic materials, they do not exhibit excellent piezoelectric performance. Cellular PP, likewise categorized as a ferroelectric, is the exception. It has been determined that composite materials combine the best qualities of ceramic and polymer materials with the flexibility to change their composition and structure to achieve the desired results.

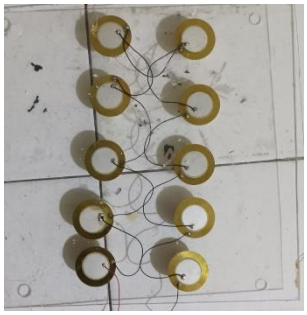


Figure 1. PZT material and design for footstep (source: owner documentation)

In addition, each material's advantages vary depending on the application. Composite materials are better suited for tactile sensors and energy harvesting from gait, polymer materials for electronic textiles and biomedical devices, and ceramic materials for underwater sonar and MEM resonators.

Piezoelectric Design in Airports

The design by (Diniardi et al., 2017) combines a piezoelectric membrane and solar cells as a medium for producing electrical energy from the influence of compressive or impact forces originating from raindrops and sunlight-based regions in Indonesia. The design dimensions or indicators are designed accurately, which includes accuracy in calculating forces, distance between piezos, and the stress obtained. The design by (Sivasubramanian et al., 2021) combines photovoltaic hybrid cells and nanogenerators as a medium for producing electrical energy. The design indicators are the design structure and the resulting energy output. Piezoelectric designs sourced from energy from footsteps were reviewed by (Sharma et al., 2022). Several Piezoelectric Energy Harvesting designs are embedded in building floors and state that the dimensions or design indicators lie in the installation mechanism and electronic circuit design specified.

The piezoelectric design (Nuh & Hendrowati, 2017) took the form of a Piezoelectric Energy Harvesting prototype, which was tested in the laboratory using a case study on ocean waves. These design dimensions or indicators are related to the energy harvesting mechanism and the amount of input generated from sea waves. The design has been extensively researched by previous researchers, including (Ambrosio et al., 2011; Bairagi et al., 2023; Diniardi et al., 2017; Febrawi & Wonoyudo, 2013; Nechibvute et al., 2012; Orrego et al., 2017; Selleri et al., 2022). Based on the result above, we can describe the three relations of piezoelectric energy harvesting with an energy source, material, and design, as stated below.

Influence of Energy Source on Piezoelectric Energy Harvesting in Airport

Energy Sources influence Piezoelectric Energy Harvesting where the indicators of energy sources in airports include stable sources and transduction mechanisms that can convert vibrational energy into valuable electrical energy, influencing indicators of Piezoelectric Energy Harvesting in research (Bairagi et al., 2023; Febrawi & Wonoyudo, 2013; Mohammadpourfazeli et al., 2023; Nechibvute et al., 2012) which is determined by the size and stability of the energy source obtained (Safaei et al., 2019).

Another source of Piezoelectric Energy Harvesting comes from sea tides (Nuh & Hendrowati, 2017), requiring stability of the energy source and several stages of testing to obtain design accuracy. We can find a water flow in the airport in the water treatment system. It is necessary to identify a harvest location for energy sources that is stable, large enough, and equipped with the necessary design and testing stages in order to maximize the potential for adopting piezoelectric energy harvesting by paying attention to energy sources (Orrego et al., 2017).

Piezoelectric Energy Harvesting in Airports may influenced by the type of energy sources used. Employing the appropriate technology to collect energy sources will generate a Piezoelectric Energy Harvesting effect. It may be inferred that mechanical energy sources notably influence its performance. The findings indicated that vibration was piezoelectric energy harvesting's most efficient energy source, surpassing other mechanical energy sources. The results of this study have consequences for the development and improvement of systems, particularly in applications that necessitate energy utilization. This aligns with the research (Covaci & Gontean, 2020; Liu et al., 2018; Pradeesh et al., 2022; Sapkal et al., 2022).

Influence of Material on Piezoelectric Energy Harvesting in Airports

Materials influence Piezoelectric Energy Harvesting in airports, where indicators of mechanical energy sources originating from vibration, pressure, friction, wind, and waves influence indicators of the amount of electrical energy output produced. To improve Piezoelectric Energy Harvesting by paying attention to energy sources, the correct selection of materials must be made, which influences higher energy conversion efficiency (Kang et al., 2016).

Materials influence Piezoelectric Energy Harvesting. Suppose the material has appropriate energy harvesting characteristics. In that case, this will improve quality and provide optimal performance, as evidenced by the power output produced by Piezoelectric Energy Harvesting (Ambrosio et al., 2011; Habib et al., 2022).

Materials influence Piezoelectric Energy Harvesting conclusions obtained from previous research results show the significant impact of piezoelectric materials on Piezoelectric Energy Harvesting performance in airports. The results show that PZT is the most effective

material for Piezoelectric Energy Harvesting in airports, followed by lead zirconate and barium titanate. The findings of this research have implications for the design and optimization of Piezoelectric Energy Harvesting systems, especially in applications that require mechanical energy. The results of this research align with research conducted by (Habib et al., 2022; Safaei et al., 2019; Sekhar et al., 2023).

Influence of Design on Piezoelectric Energy Harvesting

Design influences Piezoelectric Energy Harvesting where the indicators of Energy Sources in airports resulting from vibration, pressure, friction, wind, and waves influence the indicators of Piezoelectric Energy Harvesting, design accuracy, which includes accuracy in material selection, calculation of force, distance between piezo, and stress obtained (Diniardi et al., 2017). In order to enhance Piezoelectric Energy Harvesting in airports, it is crucial to focus on the design, installation mechanism, and design of the specific electronic circuit that fits the situation of the airport. These factors have a direct impact on the energy output that is obtained (Sivasubramanian et al., 2021).

Design influences implementation in airports; if a stable energy source is supported by a transduction mechanism that can convert vibration energy into electrical energy, this will improve the quality of Piezoelectric Energy Harvesting (Kang et al., 2016). Design is proven to affect Piezoelectric Energy Harvesting in airports; conclusions from previous research results show that energy harvester design significantly affects its performance. The size, the material properties, and the distance between the piezo, the transducer, and the rectifier for maximizing the voltage obtained should be appropriately calculated to make the best performance of the energy harvesting system in airports.

The design of piezoelectric energy harvesting systems at airports must consider several critical (Sivasubramanian et al., 2021) factors. These include placing piezoelectric sensors in areas with the highest vibration frequencies, integrating with airport electrical systems, and ensuring long-term maintenance and durability. The design must also ensure that the sensor installation does not interfere with normal airport activities and adheres to strict safety standards. An efficient energy management system is also needed to store and distribute the energy produced. This significantly influences the accuracy of Piezoelectric Energy Harvesting and plays an essential role in determining its performance. This conclusion is in line with research conducted by (Ambrosio et al., 2011; Bairagi et al., 2023; Diniardi et al., 2017; Febrawi & Wonoyudo, 2013; Nechibvute et al., 2012; Orrego et al., 2017; Selleri et al., 2022; Sharma et al., 2022).

The conceptual framework is structured based on problem formulation, theoretical study, relevant research, and discussion related to the influence between variables x1, x2, and x3, thus obtaining the framework of thinking below.

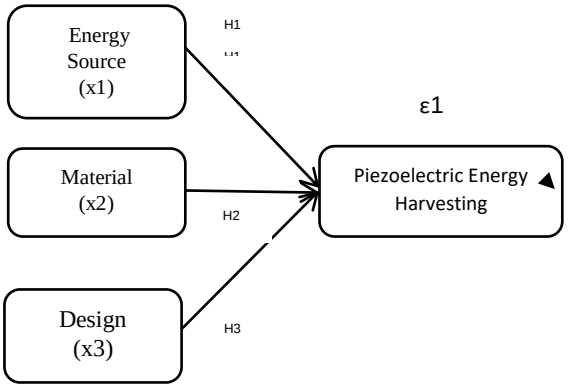


Figure 1. Conceptual Framework

Based on the conceptual framework above, Energy Sources, Materials, and Design influence Piezoelectric Energy Harvesting in airports. In addition to the three exogenous variables that affect Piezoelectric Energy harvesting, many other variables influence it, including a) x4: System testing steps by (Arimurti et