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NeoHada: Adaptive Urban Building based on Solar-Piezoelectric and Rooftop Farming to Realize Resilient Cities in Preventing Floods and Food Crises

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ABSTRACT

Urban development, driven by increasing population density, significantly impacts the physical environment, leading to issues such as flooding, food crises, and energy shortages. In response to these challenges, particularly in the context of urban flooding in Indonesia, the implementing team proposes the NeoHada solution. NeoHada is an adaptive design concept that integrates Solar-Piezoelectric technology and Rooftop Farming to create resilient and sustainable cities. This concept is based on three key principles: Climatic Architecture, Energetic Architecture, and Productive Architecture. The principle of Climatic Architecture is implemented through a Rain Harvesting System, where building rooftops serve as rainwater reservoirs to prevent flooding and provide an alternative water source. The Energetic Architecture principle combines solar panels and piezoelectric technology to generate independent electrical energy, alternating between rainy and dry seasons. The Productive Architecture principle emphasizes the development of rooftop farming as a means of achieving urban food self-sufficiency. The NeoHada solution is expected to realize the Sustainable Development Goals (SDGs) related to Zero Hunger, Clean Water and Sanitation, Affordable and Clean Energy, Sustainable Cities and Communities, and Climate Action. By integrating innovative technology and adaptive design, NeoHada aims to mitigate the negative impacts of urban growth and promote city resilience against various disaster and crisis scenarios. It is hoped that this solution will serve as a guide for the development of cities in Indonesia towards sustainable sustainability.

Keywords: NeoHada, Solar-Piezoelectric, Resilient Cities, SDGs

1. Introduction

The escalating urbanization driven by population growth has resulted in substantial implications for the physical environment. Urban areas, serving as vital hubs of habitation, have exhibited a tendency towards disorder and challenging management, affecting their physical, social, and economic aspects (Irwan, 2004) [1]. This evolution in the urban landscape has been marked by the emergence of various catastrophes such as floods, food crises, and energy shortages, leading to significant losses for the cities.

For instance, data from the Bank Indonesia Representative Office in DKI Jakarta revealed that the flood damage during the New Year of 2020 led to the displacement of 31,232 individuals, causing an estimated loss of one trillion Indonesian rupiah [2]. Furthermore, Indonesia's hunger level is at 17.9, ranking third highest in the ASEAN region [3]. It is also a well-known fact that Indonesia still imports a substantial amount of electricity, reaching 1,417 GWh, and is projected to increase to 1,842.31 GWh by 2024 [4].

The issue of urban flooding can be addressed through the implementation of rainwater harvesting systems, with each building in the city equipped with rainwater collection roofs. For instance, in a city with a maximum rainfall of 14,644 mm per hour and a planned flood discharge of 5,646 m^3 per second, it is estimated that the occurrence of flooding can be prevented if approximately 43,054 buildings in the city each have a minimum 514-liter water storage capacity [5].

Furthermore, achieving energy independence in urban areas can be realized by harnessing the two distinct seasons in Indonesia, namely the rainy season and the dry season. During heavy rainfall, with an intensity of 50 mm to 100 mm over five hours, 156 watts of electrical energy can be generated per hour through 120 points of piezoelectric technology. Similarly, during the dry season, an estimated solar irradiance of 4.5 kWh per square meter per day can produce 183 watts of electricity per hour through solar panels measuring 54 cm x 64 cm x 3 cm [6]. Therefore, during days with both rain and sunshine, it is possible to generate 339 watts of electricity per hour.

In conjunction with the shrinking availability of land, urban areas have the potential for food self-sufficiency through the implementation of rooftop farming. This approach enables the production of various fresh food products atop city buildings.

Based on the aforementioned context, and in pursuit of achieving the Sustainable Development Goals (SDGs) outlined in points 2 (Zero Hunger), 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), 11 (Sustainable Cities and Communities), and 13 (Climate Action) [7], while also addressing Indonesia's concerning issue of flood disasters, the implementing team introduces the proposed solution titled "NeoHada: Adaptive Urban Buildings Based on Solar-Piezoelectric and Rooftop Farming to Realize Resilient Cities in Preventing Floods and Food Crises." The aim of this solution is to foster the growth of resilient and sustainable cities in Indonesia, thereby creating suitable and productive living environments for its inhabitants.

2. Methodology

The chosen research method is qualitative descriptive, which illustrates the approach used to present comprehensive information about existing issues [8]. In the context of this research, the focus is to provide in-depth descriptions of the phenomena of flooding, the level of hunger, and the dependence on electricity imports in Indonesia.

By employing this approach, the research aims to offer a clear and detailed picture of the root problems, enabling the development of appropriate and sustainable solutions, as understood in the context of descriptive research. Building upon the theoretical explanations found in the literature, this study aims to comprehensively analyze and describe the environmental challenges faced by urban areas, along with the social and economic impacts arising from these issues. Moreover, the research also attempts to provide suitable and effective solutions through a deep understanding of the concepts found in relevant literature sources. All the processes and research outcomes were carried out by collecting data in the form of words, representing an understanding of the interaction between concepts being empirically studied, as understood in qualitative research.

Data collection was conducted through two main approaches, namely observation and literature review. Observation was conducted by directly examining the flooding issues and their impacts, including the level of infrastructure damage and the social repercussions for affected communities. Additionally, observations were made to understand the prevalence of hunger in society and its impact on social well-being. Meanwhile, the literature review involved a comprehensive search of scientific journals and textbooks related to the topics of flooding, hunger, and dependence on electricity imports. Through in-depth analysis of the literature, this research seeks to build a strong understanding of the issues under investigation and develop effective solution concepts based on the available evidence.

3. Result and Discussion

3.1 Concept

The term "NeoHada" is derived from the term "Neo-" in the Indonesian Dictionary (KBBI), which means new or updated. The word "Hada" is taken from the name of the traditional Nias house, "Omo Hada," which holds a philosophical meaning that the house serves as a boat during floods [9]. Thus, NeoHada is expected to become a solution for urban building design that can renew the philosophical spirit of Omo Hada, aiming to achieve resilient cities against floods and food crises. In the general understanding, resilient cities in this context are perceived as a concept of robust cities that have a resilience system against various disruptions, especially flood disasters, energy, and food crises. In its implementation, this design concept adheres to three main principles: Climatic Architecture, Energetic Architecture, and Productive Architecture.

The concept of Climatic Architecture focuses on designing buildings that can adapt to the changing climate conditions and effectively address challenges like flooding. Through the integration of innovative rainwater harvesting systems and efficient water management techniques, the buildings are equipped to mitigate flood risks and utilize rainwater as an alternative water source. Energetic Architecture emphasizes the utilization of renewable energy sources such as solar and piezoelectric technologies. By incorporating solar panels and piezoelectric elements into the building's infrastructure, NeoHada aims to generate clean and sustainable energy independently, thus reducing the city's dependency on external power sources. Additionally, Productive Architecture emphasizes the integration of urban farming practices, particularly rooftop farming, to promote local food production and enhance the city's self-sufficiency in food resources. By utilizing available rooftop spaces, NeoHada seeks to foster a productive environment that contributes to the city's food security and sustainability. Through the integration of these three core principles, NeoHada strives to establish a transformative urban design solution that not only addresses immediate challenges but also fosters long-term resilience and sustainability in urban environments.

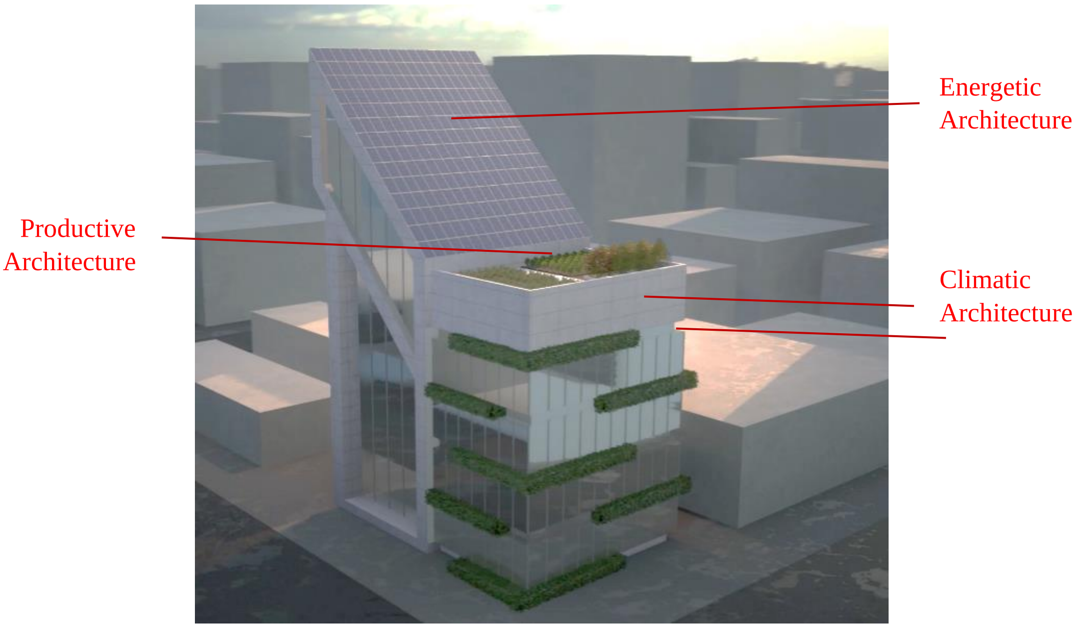

Figure 1 Design of NeoHada Building
Source: Personal Documentation

In its application, this design concept adheres to three main principles, namely Climatic Architecture, Energetic Architecture, and Productive Architecture.

3.2 Climatic Architecture

The principle of Climatic Architecture in NeoHada emphasizes building design as an adaptive solution to climate change, utilizing the building's roof as a rainwater harvesting system through the implementation of a Rain Harvesting System. Consequently, rainwater, which would typically flow directly onto the ground and through runoff drainage, is now captured on each building's roof, effectively preventing flooding [10]. The collected rainwater on the building's rooftops can be filtered to serve as an alternative water source, catering to the daily needs of the inhabitants. This approach not only mitigates flood risks but also promotes sustainable water management practices, ensuring the efficient use of water resources within the urban environment. Furthermore, the integration of green infrastructure elements within the building's design facilitates natural drainage and contributes to the overall resilience of the urban ecosystem in the face of climate variability and extreme weather events.

Figure 2 NeoHada’s Climatic Architecture
Source: Personal Documentation

The planned flood discharge (Q) is the maximum flow in a river or natural channel with a predefined return period, which can be conveyed without endangering irrigation projects and the stability of the structures [11]. This calculation is crucial to determine the necessary capacity required by a city to prevent flooding. Additionally, it is essential to understand the duration of time needed for the floodwaters to recede. This is why it is necessary to determine the time of concentration (tc). By multiplying these two pieces of information, the total capacity of the city's entire reservoirs can be determined to prevent flooding. Considering the goal of providing flood-free solutions based on independent building-by-building approaches, it is necessary to ascertain the total number of buildings owned by a city (n).

Subsequently, we can determine the minimum capacity required for each building to accommodate rainwater and prevent flooding. This comprehensive understanding of the city's hydrological dynamics and the potential impacts of rainfall allows for the effective design and implementation of flood prevention strategies tailored to the specific needs and characteristics of the urban environment. If illustrated, the calculation can be depicted as follows.

If assume the following data:

- Planned flood discharge (Q) = 5,646 m3/second = 338,760 liters/minute
- Time of concentration (tc) = 1.087 hours = 65.22 minutes
- Number of buildings in a city (n) = 43,054 [12]

Therefore, the volume capacity of the roof reservoir is obtained as:

$$V = \frac{Q\ x\ tc}{n} = \frac{338.760\ x\ 65{,}22}{43.054} = 514 \text{ liters per unit}$$

Thus, the minimum capacity of the roof reservoir is determined to be 514 liters per building.

3.3 Energetic Architecture

The principle of Energetic Architecture in NeoHada entails designing buildings that promote the generation of clean and renewable energy. This is implemented through the use of solar panels and piezoelectric technology, capable of producing electricity alternately during both sunny and rainy weather.

Piezoelectricity is a technology that harnesses kinetic energy in the form of pressure and converts it into electrical energy in the form of voltage [13]. These piezoelectric panels are designed to capture the impact of rainfall and transform it into electricity. On the other hand, solar panels operate by converting sunlight into electricity. When sunlight hits the cells, it causes electrons in the semiconductor material to move, creating an electric current [14]. When combined, these two renewable power generators will produce self-sustaining energy.

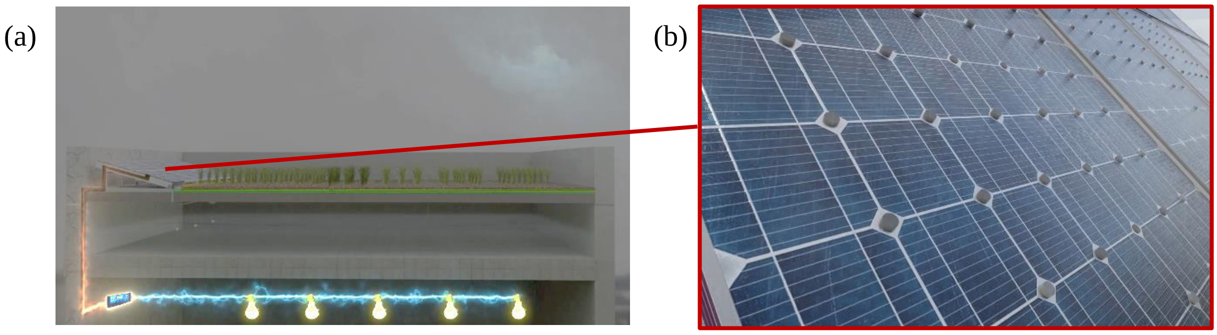

Figure 3 (a) Energetic Architecture of NeoHada's Building (b) Solar-Piezoelectric Panel
Source: Personal Documentation

Having two electricity generators results in two variations of power generation. During sunny weather, the solar panel operates to produce electricity. A 50-watt solar panel with dimensions of 54x64x3 cm can generate an output power of 50 Watts. However, not all of the received solar energy can be fully utilized due to system losses, including manufacturing losses (3%), dirt losses (5%), module temperature losses (5.7%), and cable losses (5%) [15].

Based on this data, the resulting output power is 40.65 watts. Therefore, if the solar radiation in Indonesia is known to be 4.5 kWh per day per square meter [16], the energy obtained from the solar panel is as follows.

$$\frac{40{,}65\text{wp}}{1000\text{W/m}^2} \times 4500 \text{ Wh day/m}^2 = 183 \text{ Wh} \quad (1)$$

When it rains, the solar panel stops functioning, and its role is replaced by the piezoelectric system, which harnesses the pressure from the rainfall to generate electrical energy. The power generated by the piezoelectric system is as follows:

Piezoelectric PVDF size 1 x 1 cm (2)
Piezoelectric voltage = 0.15 V [22] (3)
Solar Panel voltage = 18 V (4)

Since the voltage of the solar panel and the piezoelectric system are not the same (3) and (4), they need to be balanced first by increasing the number of piezoelectric components and connecting them. For this purpose, 120 pieces of PVDF piezoelectric materials, each measuring 1 x 1 cm, are required to be arranged in series. These 120 piezoelectric components are divided into two groups, namely Group 1, with a rhombus-shaped surface measuring 4 x 4 cm, and Group 2, with a rhombus-shaped surface measuring 2 x 2 cm. Each group is placed at 6 different points, as shown in Figure 1 below.

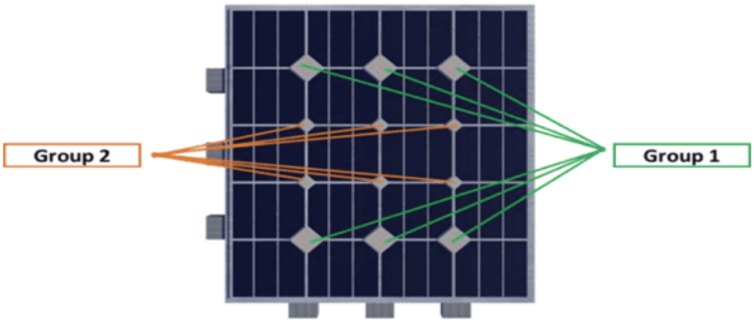

Figure 4 The Position of Piezoelectric on Solar Panel
Source: Personal Documentation

For Group 1, there are 6 subgroups, each measuring 4 x 4 cm. Since each piezoelectric component has a size of 1 x 1 cm, Group 1 can accommodate 16 piezoelectric components for 1 point. Therefore, the power generated by it is as follows:

$$P=\frac{V^2}{R}=\frac{(16\times 0,15)^2}{1}=5,76 \text{ Watt} \quad (5)$$

As there are 6 subgroups (5), then:

$$5.76 \times 6 = 34.56 \text{ watt} \ (6)$$

For Group 2, there are 6 subgroups, each measuring 2 x 2, and since 1 piezo measures 1 x 1 cm, Group 2 can accommodate 4 piezoelectric components for 1 point. Therefore, the power generated by Group 2 is as follows:

$$P=\frac{V^2}{R}=\frac{(4\times 0,15)^2}{1}=0,36 \text{ Watt} \quad (7)$$

As there are 6 groups (7), then:

$$0.36 \times 6=2.16 \text{ watt} \ (8)$$

Thus, for the total 120 piezos, they can generate a power of (6) and (8) 36.72 watts assuming heavy rainfall with an intensity of 50 mm-100 mm for 1 hour. If heavy rain occurs for 5 hours in a day with the same intensity, the power generated would be 183.6 watts. The power generated by the piezoelectric system cannot be directly supplied to household devices as it is in DC form. Therefore, the power must first be converted to AC, and the power must be reduced by 15% due to losses in its DC power [17]. Thus, the output energy from the piezoelectric system is as follows:

$$183.6\times 15\%=27.54 \text{ Watt} \ (10)$$
$$183.6 - 27.54=156.06 \approx 156 \text{ Watt} \ (11)$$

So, the electrical energy generated during sunny weather by the solar panel is 183Wh, and the electrical energy generated by the piezoelectric system during rainfall is 156Wh in a single day. The distribution of electrical energy from the combination of the solar panel and the piezoelectric system can be seen in the following figure.

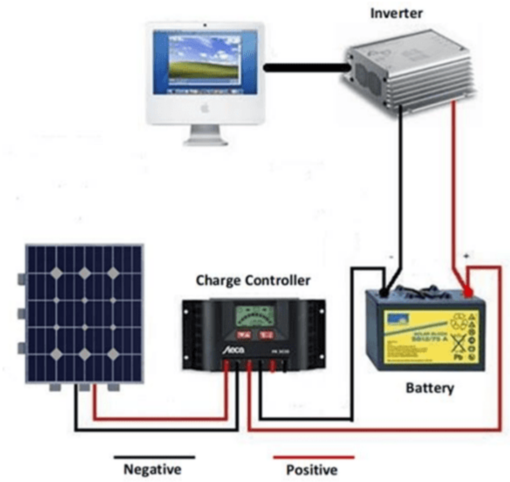

Figure 5 The Scheme of Energy Conversion from Solar-Piezoelectric Panel
Source: Personal Documentation

3.4 Productive Architecture

The principle of Productive Architecture in NeoHada focuses on the existence of agricultural land on the rooftops of urban buildings (rooftop farming). Eventually, various food products such as chili, shallots, garlic, tomatoes, mustard greens, water spinach, and others will be produced from the rooftops of urban buildings [18]. Rooftop farming serves as a sustainable and innovative approach to address food security concerns and promote self-sufficiency within urban areas.

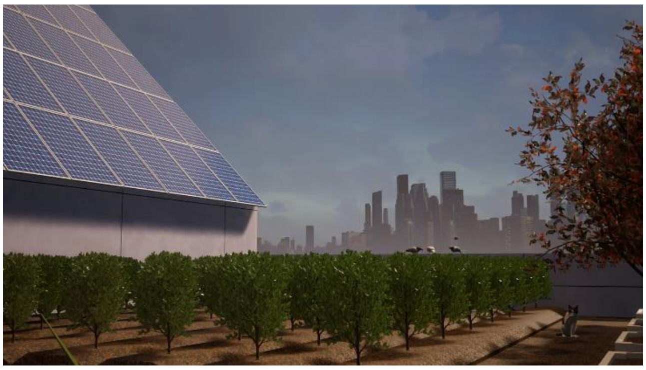

Figure 6 NeoHada's Productive Architecture
Source: Personal Documentation

By utilizing underutilized spaces on rooftops, the concept aims to integrate green spaces into urban environments, fostering local food production and promoting community engagement in sustainable farming practices. Through the implementation of efficient irrigation systems and appropriate farming techniques, rooftop farming contributes to enhancing the overall resilience and sustainability of cities, mitigating the adverse effects of food crises and promoting a more environmentally friendly urban landscape.

4. Conclusion

The proposed solution, "NeoHada: Adaptive Urban Buildings Based on Solar-Piezoelectric and Rooftop Farming to Realize Resilient Cities in Preventing Floods and Food Crises," aims to address the pressing urban challenges faced by Indonesia, particularly related to flooding, food crises, and energy dependency. By integrating the principles of Climatic Architecture, Energetic Architecture, and Productive Architecture, NeoHada presents a comprehensive approach to building design, emphasizing adaptability, sustainability, and self-sufficiency. By effectively implementing these strategies, NeoHada strives to foster resilient and sustainable urban environments that not only address immediate challenges but also pave the way for long-term environmental and social stability. Ultimately, the integration of these principles is crucial in achieving the Sustainable Development Goals (SDGs) outlined by the United Nations, emphasizing the significance of sustainable urban development and environmental resilience.

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