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The Impact of Carbon Footprints and Restoration Efforts on Temples Using Andesite Stone Materials

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Abstract

The various carbon footprints present in the environment can inevitably have a significant impact on cultural heritage sites. In fact, preserving cultural heritage buildings, including those made of andesite stone, is of paramount importance. This research aims to provide a clear understanding of the impact of carbon footprints generated by the degradation of temple buildings constructed with andesite stone. It also examines several strategies for restoring these structures as part of the broader effort to safeguard cultural heritage sites. The study's results indicate that the carbon footprint has resulted in the release of various chemical gases that have adversely affected the andesite stone, leading to structural issues. To address this, restoration efforts can be implemented through the establishment of a drainage system to control temple humidity and the improvement of concrete slabs to strengthen the temple foundations, which have eroded due to the impact of carbon footprints.

Keywords: *Temple, andesite stone, carbon footprint, gas emissions, cultural heritage*

1. Introduction

The 21st century is marred by distortions resulting from environmental pollution caused by natural gases, emissions from volcanic eruptions, and other particles released during such events, leading to ongoing pollution. Furthermore, the atmosphere is being polluted by greenhouse gases (GHGs), raising growing concerns for the future of human life. This pollution of gases will have an impact on the increase in the earth's average surface temperature, also known as global warming. The rise in the earth's surface temperature is driven by the heat energy from the sun, which should be reflected into the atmosphere but is instead absorbed by greenhouse gases that accumulate in the lower atmosphere. This, in turn, leads to the trapped heat causing an increase in the Earth's surface temperature (Pratama & Parinduri, 2019).

Global warming is an ongoing issue that continues to be studied due to its far-reaching impact on various aspects of human life and the environment. One of the most visible consequences of global warming is the melting of the ice caps in the North and South poles, leading to a rise in sea levels across the Earth's surface. Additionally, global warming intensifies extreme weather phenomena, leads to the extinction of various fauna species, alters animal habitats, and even triggers new disease outbreaks (Utina, 2009). Human activities play a significant role in the accumulation of greenhouse gases, which have a profound impact on the earth's atmosphere. The amount of gas emissions resulting from excessive daily activities or product usage is often referred to as a "carbon footprint." These activities encompass the use of fossil fuels, food consumption, and electricity usage. The more humans engage in such activities, the greater the energy consumption, resulting in a larger carbon footprint (Zhang & Cheng, 2009).

The carbon footprint is a measure of the environmental impact caused by human activities. The more activities humans engage in, the higher the level of emissions they produce. This highlights the connection between human activities and air quality in the atmosphere. The quantity of carbon emissions generated by an organization, event, product, or human activity is referred to as a carbon footprint, expressed in units of tons of carbon or tons of carbon dioxide equivalent. In their daily activities, everyone that utilizes energy generates carbon dioxide (CO2) emissions, and the more active a person is, the more energy they consume, resulting in a larger carbon footprint. In today's world, the human inclination to seek maximum comfort often leads to habits that impact the environment. Practices like using private vehicles, particularly cars over public transportation, air travel, and the use of air conditioning or heating in rooms, as well as the utilization of electronic devices such as computers, television, radio, and other entertainment gadgets, all contribute to higher carbon footprint values (Admaja, et al., 2018).

The various carbon footprints across the universe can inevitably have a significant impact on cultural heritage sites. Cultural heritage buildings, in fact, are essential elements to be preserved over time. Cultural heritage represents a valuable and immovable asset, not limited to specific nations but present in societies (Juliarini & Lestyowati, 2016). The efforts to preserve cultural heritage buildings must continue with a preservation approach that involves various elements. In Indonesia, the preservation of buildings and cultural heritage sites has become an important issue, particularly since the 1990s in the context of spatial planning (Herlambang, et al., 2019). The concerning carbon footprint further emphasizes the importance of maintaining cultural heritage buildings, such as temple structures. In Indonesia, temple sites commonly employ two main types of stone as primary materials in their construction: brick and andesite stone. Brick material in temples is typically made from molded clay, then fired. This type of stone is effective in retaining heat. Red brick has been widely used as a building material in Indonesia throughout its history. On the other hand, andesite stone is known for its high artistic value due to its specific composition and sculpt able textures. These stones are usually found in areas with high volcanic activity, typically associated with tectonic subduction environments. Andesite stones are generally dark or black in color. Due to their durability and low porosity, they are resistant to becoming dirty (Alam, 2020).

Despite being considered a stone with high artistic value and resistant to getting dirty, andesite rock, the material used in temple construction, faces a crisis when exposed to the carbon footprints dispersed throughout the environment. Carbon footprints have various detrimental impacts, including damage from corrosive reactions caused by the acids carried by chemical gas emissions. Consequently, this research seeks to provide a comprehensive understanding of the impact of a carbon footprint resulting from the degradation of temple structures constructed with andesite stone. Additionally, it explores efforts that can be undertaken by various stakeholders, including government and related agencies, and the community to restore these structures as part of preserving cultural heritage buildings, ensuring their longevity in the face of the continuing increase in carbon footprints in the future.

2. Methods

The study adopts a methodology primarily based on a comprehensive literature review. A literature review encompasses a systematic collection of data from various library resources, extensive reading, note-taking, and meticulous management of research materials (Zed, 2008). By meticulously cross-referencing a multitude of previously conducted studies that explored the impact of carbon footprints on cultural heritage sites and the corresponding restoration efforts, the research synthesizes findings from these relevant past research endeavors to offer an intricate and in-depth analysis of the subject matter at hand.

3. Results and Discussion

3.1 Factors Contributing to Temple Deterioration and Restoration Strategies

Understanding the factors contributing to the deterioration of cultural heritage objects, particularly temples, requires an examination of the interplay between various causal elements (Li et al., 2021). These elements encompass both internal and external factors. Internal factors are inherent to cultural heritage objects, encompassing aspects such as building materials, soil composition, geographical location, and local climate. External factors include environmental components such as flora, fauna, human activities, and natural disasters. Within the scope of this study, an effort is made to delineate the restoration strategies for andesite rock-based temples suffering from damage due to carbon footprints. It is important to recognize that the impact of carbon footprints is intricately connected to other natural processes. Temples with porous andesite rock foundations are susceptible to a range of issues, including damage and weathering, triggered by various factors, both biotic and abiotic (Yanuardi, 2009).

Biotic factors contributing to damage are primarily associated with the presence of macroscopic organisms, including algae, moss, lichens, and herbaceous plants such as spermatophytes and pteridophytes. Abiotic conditions, on the other hand, are influenced by various climate factors, both at micro and macro levels. These include air temperature, humidity, radiation, evaporation, and carbon footprints, such as air pollution, which have both direct and indirect impacts on temple structures. It is essential to note that damage to temple buildings is not solely attributed to human activities. The sheer volume of visitors can also pose a significant risk to the condition of these structures. For instance, the Borobudur Temple, with its large number of visitors, can contribute to the gradual subsidence of the temple structure into the land. Moreover, carbon footprints have the potential to play a substantial role in the process of temple damage. Among the various carbon footprints, global warming factors are noteworthy. Several factors contributing to global warming include the greenhouse effect, ozone layer depletion, and deforestation (Mulyani, 2021).

Other seemingly trivial issues, often dismissed as the byproducts of human activities, include elevated levels of SO_2 air pollution surrounding the temple. This air pollution results from vehicle emissions, decaying waste, chemical discharges, and the reduction of green spaces. Such pollution poses a significant threat to the preservation of temple buildings. Additionally, natural factors, compounded by activities contributing to global warming, lead to a surge in extreme temperatures within temple areas (Kasiyati & Brahmantara, 2010). When temperatures soar above 35°C - 37°C or higher, the integrity of the rock deteriorates. Furthermore, global warming triggers extreme climate variations, such as acid rain, which can induce various symptoms of diseases capable of harming temple structures with andesite foundations. Unlike global warming, the carbon footprint left behind by human activities can also induce chemical reactions that negatively impact the physical condition of andesite rocks, serving as the foundation for the temple.

Activities involving factory waste emissions, which may lead to acid rain, can corrode rocks, particularly andesite rocks. Similarly, the carbon footprint resulting from volcanic emissions, such as volcanic gases, can also cause substantial damage to temple rocks. When volcanic gas, generated during volcanic eruptions, comes into contact with water, it produces corrosive acids. These acids may include carbonic acid, sulfuric acid, and nitric acid, originating from the dissolution of gases like CO_2, SO_2, and NO_2 from volcanic emissions. These corrosive acids can react with various minerals, like feldspar or plagioclase, which constitute the primary components of andesite rocks, widely used as the foundational material for temple buildings. Chemical reactions that can occur in feldspar or plagioclase minerals encompass hydration, hydrolysis, and carbonation. The hydration reaction involves the mineral's formation of a hydrated compound, which entails the binding of water molecules to the mineral's surface within rocks. This process occurs when rocks are submerged in water, causing the saturation of surface planes, corners, and edges of the crystals by water molecules, forming a water mantle. This coating can damage the crystal structure, releasing binding energy, leading to cracks and breakage, thereby inflicting significant harm on andesite rocks. Hydrolysis, on the other hand, is a reaction facilitated by the presence of water and accelerated by the presence of acids. In this reaction, minerals undergo an alkali exchange with hydrogen ions from water and acids, with the acids providing a greater quantity of hydrogen ions than water. This hydrolysis reaction results in the formation of aluminosilicates, silicic acid, and the liberation of alkali hydroxides or alkali salts, leading to damage in the mineral's crystal structure. Meanwhile, the carbonation reaction involves the interaction of minerals with carbonic acid (H2CO3), which can originate from the dissolution of CO2 gas in water. An example of this event is the carbonation of feldspar, leading to the formation of kaolin, salt, and silica (Wahyuni, 2011).

These reactions lead to a common outcome, where minerals transform into other materials that are more susceptible to decomposition, along with the deposition of salt. The consequences of these reactions include stone cracking, breaking, salting, and weathering. As a result of the carbon footprint process, which introduces destructive chemicals, stone conditions known as pustules (closed stone sores) can emerge and develop into alveoli (open stone sores) after undergoing biochemical processes and salt deposition from water mixed with moss protonema (Price, 1996). Chemical substances, such as air pollutants containing chemical-laden dust particles, adhere to the temple walls. When these chemical substances come into contact with rain or experience acid rain, they rapidly induce reactions that result in the deterioration of the temple rocks. The restoration process must be meticulously planned to effectively preserve the temple.

3.2 Temple Building Restoration Efforts

In fact, temple restoration efforts have been actively carried out since the Dutch colonial era in the Dutch East Indies. The colonial government initiated large-scale restoration efforts for the temples during this period. An example is the Prambanan Temple, which was lost for several decades before being rediscovered by Sir Thomas Stamford Raffles. It was subsequently restored to its current, almost intact condition (Pramumijoyo, et al., 2009). Similarly, the Department of Archaeology has undertaken comprehensive planning for the meticulous restoration of andesite rock temples, ensuring the preservation of these monuments for at least the next 1,000 years.

Restoration efforts have been implemented with a focus on various aspects, including the correction of sloping walls to ensure their upright installation and the restoration of collapsed sections, especially in tourist-accessible temples such as Borobudur Temple. Furthermore, measures are taken to address sloping rock floors and any signs of deterioration to maintain structural integrity. Of utmost importance is the construction of foundations for Andesite rock temple buildings that not only guarantee long-term stability but also effectively control the flow of rainwater, preventing further weathering and damage (Ardika, 2005). These restoration efforts should align with the guidelines outlined in the Cultural Heritage Law, ensuring the preservation of heritage buildings damaged by time and impacted by carbon footprints. Restoration and repair of damaged Cultural Heritage Buildings and Cultural Heritage Structures should be conducted in accordance with Article 77, No. 11 of 2010, Paragraph 5, which details the process of restoring their physical condition through repair, strengthening, and preservation, encompassing reconstruction, consolidation, rehabilitation, and restoration work (Indonesia, 2014).

Before embarking on the restoration of a temple with an andesite foundation, it is essential to identify several key factors, including the type and properties of materials, the systematic behavior of structures, types of damage, and soil conditions (Tucci & Marconi, 2015). Various parameters of damage manifest in temple buildings, such as patterns of cracking, breaking, and rock collapsing, and these patterns can offer early insights into the potential causes of the damage. This damage often presents as rocks that are cracked or fragmented into multiple pieces. It is important to note that visual observations of the temple's rock surface are limited to one or two visible areas, as other rock surface areas are situated on the interior and remain unseen.

Before commencing the restoration process for damaged temple buildings, several sectoral officers are responsible for its execution. The Archaeological and Architectural Sector specializes in field surveys related to scientific and building sciences. The Techno-Archaeology Sector is responsible for dismantling and reinstalling temple stones, along with overseeing all technical aspects of reconstruction. Furthermore, the Civil Engineering Sector is tasked with planning and executing the stabilization of temple foundations through concrete work, managing the construction of office buildings, providing water resources, and managing electricity within the preservation area. It is also crucial to acknowledge the significant role played by the Preservation Sector in the temple restoration process due to the impact of carbon footprints.

The preservation sector plays a crucial role in maintaining andesite stones, which serve as the primary foundation of the temple, by preventing the growth of organisms like moss and lichen. This process is essential as moss growth can lead to severe temple damage, including the formation of pustules (lesions on the temples) and alveoles (holes in the stones) over time, ultimately causing illness and deterioration of the temple stones. Moreover, this sector is responsible for addressing fungus growth, treating stones affected by chemical damage or carbon footprints, conducting research to discover preservation methods for temple stones, repairing broken stones, and collecting meteorological data, such as rainfall, temperature, humidity, wind, and other factors that pose significant threats to the integrity of the andesite stones in the temple (Soekmono, 1973).

The restoration process can be divided into three stages. Firstly, there's the evaluation phase, where the goal is to assess the extent of the temple stones that still exist or can be recovered. Secondly, there's the conceptual restoration phase. This process involves two-dimensional reconstruction, which is a crucial aspect of restoration. It relies on the results of matching stones to one another to create a comprehensive picture of the entire structure. The final stage is the culmination of the restoration process, involving on-site restoration, cleaning, and restoration of the actual andesite rock foundations (Chawari, 2005).

The arrangement and formation of rocks in andesite temples generally result in issues related to water infiltrating the temple terrace hill and then exiting through rock crevices at lower levels, carrying various chemical elements. This can lead to damage to the stones in the temple, including the andesite stones, which are soft and less dense, making them susceptible to erosion from rain, heat, or biological and chemical factors. To maintain the condition of the temple rocks and prevent corrosive reactions due to the presence of acidic elements from carbon traces, a drainage system is essential. This drainage system involves creating a protective layer, such as a filter layer, to prevent water seepage onto the outer stone surface. This layer is placed along the concrete slab attached to the temple's ground. Additionally, a drainage pipe is used to remove rainwater and water seepage from the filter layer (Soediman, 1976).

The completion of this restoration involved finalizing the custom concrete slabs height, which was then covered with a cast curing compound made from wax to slow down the drying process. The day after this, the slab was sealed with layers of stone fillings of the same thickness. These filler stones must be kept wet during the first few weeks to protect them from rapid temperature changes. The temporary stones initially installed on the main wall were subsequently replaced with the original stone coating. In the hallway's floor, these temporary stones were left in place at first. Once an adequate period passed, they were replaced with permanent stones two days after casting the plate. Following this, the process involved reinstalling the plate with the stones (Achmad, 2018).

Certainly, the temple restoration process also brings benefits to the local community surrounding the temple. This is primarily because unskilled laborers from the area around the temple are employed. This restoration project requires the assistance of hundreds of unskilled workers to support the experts, thus contributing to the local economy. Involving the residents living in the vicinity of the temple fosters their sense of ownership of the temple structure, ensuring that restoration efforts become an enduring part of preserving this cultural heritage for centuries to come. Community engagement in the preservation of cultural heritage is a crucial priority that must be upheld in every conservation-oriented cultural heritage utilization activity (Wirastari & Suprihardjo, 2012).

4. Conclusion

The carbon footprint left by human activities triggers chemical reactions that can harm the physical condition of the andesite rock foundation of the temple. Activities such as factory waste emissions that can lead to corrosive acid rain and pose a threat to temple rocks underscore the need to promote restoration efforts in accordance with the Cultural Heritage Law. The goal is to preserve heritage structures affected by time and impacted by carbon footprints. Restoration of damaged Cultural Heritage Buildings and Cultural Heritage Structures should follow the guidelines set forth in Article 77 No. 11 of 2010, particularly paragraph 5, which addresses the restoration of physical conditions through repair, reinforcement, and preservation via methods like reconstruction, consolidation, rehabilitation, and restoration work. It is also crucial to clean the temple rocks from dust deposited by pollutants and other gas emissions that may react with water. Additionally, the establishment of an effective drainage system is necessary to regulate the humidity of the temple rocks, while perfecting the concrete slab is essential to fortify the temple structure.

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