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Ecological Architectural Concepts of Museum Buildings in the Humid Tropics Case Study: Museum Gunungapi Merapi

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Abstract
Ecological architecture is the harmony between structural function and environmental function through the efficient usage of natural potential and adherence to eco-friendly principles. The purpose of this study is to see how ecological architecture is applied in the design of museum buildings. The object of this research is the Museum Gunungapi Merapi. The building is located in Yogyakarta, near Mount Merapi, a humid tropical area. This qualitative descriptive research illustrates the factual conditions of the museum, which later on will be associated with theories found in literatures. A building will be regarded as ecological if its design has met ecological architectural principles in the sense of having incorporated environmental consideration in its physical structure, harmonized its system with nature, used sustainable natural resources and energy efficiency, and applied spatial planning according to ecological values. The results have led to a conclusion that the museum has been built by considering the ecological architectural aspects of its structural arrangement, landscape utilization, and material usage.

Keywords*: eco-friendly; ecological architecture; humid tropics; museum*

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1. INTRODUCTION

Environmental damage is currently increasing over time. Rapid global warming due to the greenhouse effect, climate change, natural resources crisis, and environmental pollution have caused concern. Being located in the humid tropical region, Indonesia benefits and, at the same time, suffers from relatively high air temperatures, solar radiation, and humidity (Permana et al., 2017). One of the contributors to environmental damage is non-environmentally-friendly development due to function and aesthetic orientation.

Ecological architecture was born as a response to environmental damage. This type of architecture harmonizes constructions with their surrounding environment and utilizes natural potentials as efficiently as possible (Abdul et al., 2018). According to Frick (2007), ecological architecture promotes the use of natural materials, adjusts structural functions to environmental conditions, and creates a recycling system for construction waste. Ecological architecture focuses on environmental management through environmentally friendly usage of natural resources and technology (Sidik & Fauzi, 2016). This concept teaches about the mutual

relationship between living things and the environment for environmentally friendly architectural designs.

Indonesia is geographically located in the humid tropics. Therefore, buildings in this country must be designed accordingly to increase comfort for their inhabitants. As this research focuses on museum buildings, the use of artificial energy must be minimized so that natural lighting and ventilation are more impactful to visitors. Because the buildings are public places, green open spaces must be provided so that visitors can enjoy the museum's collections and at the same time enjoy the environment around them (Ghiyas et al., 2020). The application of ecological architecture to buildings is the optimal use of architectural elements for protection against the effects of climate. It is realized through spatial planning and building masses that pay attention to orientation, accessibility, circulation, and zoning (Suhada, 2018). In terms of spatial planning, the use of high-intensity materials must be minimized, while local values must be applied through the formation of building facades that protect people from solar radiation and wind while still maximizing natural lighting and ventilation (Chrisnesa, 2017). The concept of ecological architecture forms a complete cycle between supply and disposal that occurs in buildings by managing and taking care of the buildings. Ecological architecture is appropriate for building a sustainable environment through the construction of environmentally friendly buildings as it keeps people's interests in harmony with the surrounding environment and prevents damage to the environment.

According to the 2020 Cultural Statistics data, Indonesia has 439 museums; more than 50% of them need to be rebuilt to meet the minimum standard, as only 32 of them are in category A or excellent (Hadi, 2020). The primary aspect of a museum is the spatial comfort for visitors. However, museums are frequently designed by ignoring this comfort to pursue form and aesthetics, despite the fact that the quality of a museum is also determined by the level of visitors' interest to visit the museum and their comfort while enjoying the collections. Therefore, building efficiency is crucial for future museum management (Nugeraha, 2021). Based on the description above, research regarding the concept of ecological architecture in museum buildings using the case study of the Museum Gunungapi Merapi is necessary. This research can state how the museum's design responds to ecological concepts in the tropics to make its buildings environmentally friendly and comfortable for visitors. Therefore, the objective of this research is to describe the application of ecological architecture in the tropics, particularly in terms of the building site, its spatial planning, its facades, and the materials that it has used.

2. METHODS

This qualitative descriptive research uses inductive analysis by connecting the primary data taken from observations with the secondary data in the forms of theories obtained from literatures. This research results in a more in-depth explanation regarding the application of ecological architecture in the object of study (Figure 1). The analysis was performed using the theory proposed by Frick, Cowan & Ryn, and Yeang about ecological architecture. According to them, an ecological architectural approach to buildings can be applied through four principles: physical and environmental integration, harmony between building systems and nature, the use of sustainable natural resources and energy efficiency, and spatial planning that considers ecological values. Those principles were used as a reference for the analyses during the data analysis stage, which was conducted by classifying architectural ecological aspects using variables of climate, structure and construction, materials, vegetation, waste systems, ventilation and lighting systems, drainage systems, technology, spatial needs and dimensions, and user's activities.

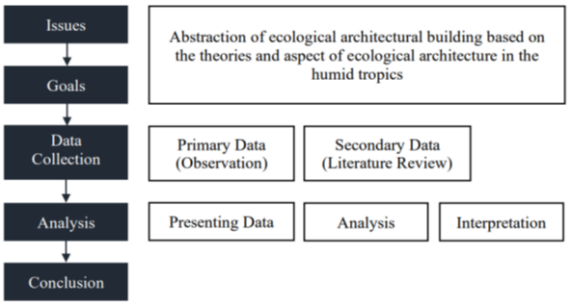


Figure 1. Research Process

3. RESULT AND DISCUSSION

Ecological architecture is a concept of environmental management that maximizes the existing natural resources through environmentally friendly designs. This architecture combines many aspects, but the main principle remains the continuity of the natural resource's carrying capacity. According to Ryn & Cowan (2002), the application of ecological architecture involves five principles: solution grows from the place, ecological accounting informs design, design with nature, everyone is a designer, and makes nature visible (Table 1).

Table 1. Ecological architecture theory according to Cowan and Ryn

Principle	Parameter
Solution Grows from Place	Harmony with the surroundings.
Ecological Accounting Informs Design	Design based on careful consideration and thought.
Design with Nature	Waste management and use of energy-efficient materials.
Everyone is a Designer	Involve users in the design process.
Make Nature Visible	Align design with natural processes.

Source: Ryn & Cowan, 2002

The concept of ecological architecture can be realized through a design that involves users as idea providers. The solution for design problems must be derived from the surrounding environment through ecological calculations by harmonizing the design and the surrounding environment, from which adverse impacts on the environment can be minimized.

According to Yeang (2006), the ecological approach in architecture can be defined as an ecological design that is bioclimatic, a design with the climate of locality, and a low-energy design (Table 2). The ecological architecture establishes relationships between local ecological conditions, climate, site conditions, building programs, design concepts, climate-responsive systems, and energy savings through passive design.

Table 2. Ecological architecture theory according to Ken Yeang

Principle	Parameter
Physical integration with the surrounding environment.	Locality factors that harmonize with natural conditions (climate, soil, topography, water, and vegetation).
System integration with nature.	Building utility factors (mechanical-electrical systems, fire protection, ventilation, lighting).
Integration of natural use.	The use of environmentally friendly materials, energy saving, and alternative materials.

Source: Yeang, 2006

Yeang (2006) also stated that ecological architecture focuses on integrating the biology of living things through harmonious relationships between natural ecosystems and that it emphasizes aspects of building management systems to create places that follow the local environmental conditions.

Ecological architecture is holistic, containing various fields that harmonize humans with nature. According to Frick (2007), the patterns of ecological architectural design apply building principles that optimize architectural elements and minimize energy consumption (Table 3). These building principles are implemented by adjusting to local environmental conditions and minimizing the use of non-renewable natural energy through the use of recyclable materials, the establishment of a balanced supply and disposal system for waste, and the use of appropriate technology.

Table 3. Ecological architecture theory according to Frick Heinz

Principle	Parameter
Adaptation to local environmental conditions.	Pay attention to the orientation of sunlight, wind direction, temperature changes, and the use of vegetation and water elements as climate regulators.
Conserve the use of non-renewable natural energy	Minimizing energy use and optimizing the use of non-renewable energy using

sources.	alternative energy.
Maintain environmental sources of air, soil, and water.	Avoid pollutants that interfere with water circulation, clean air, and soil.
Maintain and improve natural circulation.	The building pays attention to all natural ecosystems and does not damage them.
Reducing dependence on central energy and waste systems.	Management of optimizing electrical systems, building utilities, and waste use.
Possibility of users to produce their own daily needs.	Adjustment of space according to the needs and activities of users.
Utilizing natural resources around the site for building systems.	Use local materials and building access close to settlements to reduce vehicle gas emissions.
Use of simple technology.	Using technology that is easy to care for and maintain carpentry technology.

Source: Frick, 2007

Based on the opinion of the experts above, an ecological architectural approach to buildings can be applied through four principles; they are physical and environmental integration, harmony between building systems and nature, the use of sustainable natural resources and energy efficiency, and spatial planning that considers ecological values (Table 4). These principles are used in the analysis stage, which was done by classifying the ecological architectural aspects of climate, structure and construction, materials, vegetation, waste systems, ventilation and lighting systems, drainage systems, technology, spatial needs and dimensions, and user activity.

Table 4. Application of ecological architecture

Principle	Variables	Aspect
Physical integration with the environment.	Climate	Building orientation
		Facade
		Mass order
	Structure and construction	Foundation
		Beam column
		Roof
	Materials	Local materials
	Vegetation	Vegetation type
		Vegetation arrangement
		Vegetation function
Building System's Harmony with the Nature	Waste systems	Waste utilization
	Ventilation and lighting systems	Openings and ventilation
		Material Type and Color
	Utility systems	Space function
		Water sources
		Drainage
		Shelter system
Sustainable Natural Resource Usage and Energy Efficiency.	Materials	Alternative or recycled materials
		Environmentally friendly materials
	Technology	Eco-friendly technology
Spatial planning that considers ecological values.	Spatial needs and dimensions	Space zoning
		Organization and size of space
	Activity	Circulation

Ecological architecture in museum buildings is applicable in building arrangement that follows nature, in the use of renewable natural resources, in the use of environmentally friendly building materials, and building arrangement according to climatic conditions. Ecological architecture can save energy and costs. This impacts the survivability of humans, buildings, and the surrounding environment because integrating buildings with nature makes the buildings have a longer age, require less maintenance, provide higher comfort for the visitors, and be healthier for them, in addition to reduced impact of energy emissions.

The Museum Gunungapi Merapi, which is located in Kaliurang, Sleman, Yogyakarta, was used as the object of this case study to verify the theory of ecological architecture. This 4,470 m² museum building stands on 3.5 hectares of land. This museum serves recreational and educational purposes for studies about volcanoes and geological disasters (Figure 2).

Figure 2. Museum Gunungapi Merapi
Source: mgm.slemankab.go.id, 2022.

3.1 The Principle of Physical Integration with the Environment

Physical integration with the environment is a solution for environmental problems derived from local values and responsive to natural conditions. This principle aims to harmonize buildings with natural conditions such as climate, topography, soil, water, and vegetation (Yeang, 2006). The implementation of this be achieved through adjustments to local climatic conditions, applications of structural construction systems that suit the natural conditions, the use of local materials, and the use of vegetation responsive to natural conditions.

The influence of climate on building architecture can be seen from several aspects such as building shape and materials. The design of a building must consider harmony and conformity between people's needs, the surrounding environment, and local climate conditions. Therefore, the technology of nature-based materials can be applied to avoid damage to environmental sustainability and the surrounding ecosystem (Imran, 2013).

In humid tropics, the sun's exposure to buildings is affected by the building's orientation against the sun's path (Permana et al., 2017). Therefore, buildings should be according to east-west direction with openings facing north and south (Yeang, 2006). The mass composition of the museum building is arranged following the contour of the site's topographical conditions, with the building's orientation facing north-south (Figure 3). In response to these conditions, the outer walls of the building that receive direct sunlight function as service rooms and are given additional components in the form of overhangs (Figure 4).

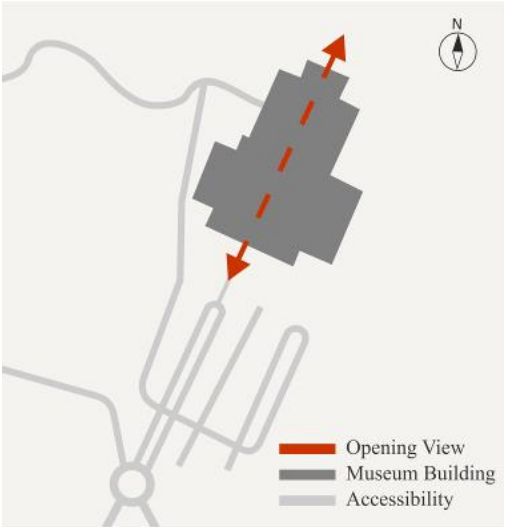


Figure 3. Orientation of the Museum Gunungapi Merapi

Figure 4. Roof overhangs

The museum is located in disaster-prone areas due to volcanic activity. Therefore, the structure must be reinforced to endure earthquakes by stiffening the building in a lateral direction (Adi & Ihsan, 2018). Its structure uses a pile foundation to respond to the site's soil characteristics, and a grid column-beam frame structure is used with the application of concrete construction. This reinforced concrete construction also embodies several characteristics of eruption activities, such as massive, hard, and smooth. The roof of the building is made of concrete combined with a sloping roof covering the building envelope (Figure 5).

Figure 5. Structure of the Museum Gunungapi Merapi
Source: Museum documents, 2022.

The use of local materials can support environmental sustainability, in addition to material sources preservation (Prasetyo et al., 2018). They are used also because they are easy to obtain, are not harmful to the environment, and are available around the site (Utami et al., 2017). The most common local materials are sand, rocks, bricks, wood, and bamboo. The building structures and envelopes are made of sand, cobblestones, and bricks, while bamboo and wood were used as the formwork. The outer space of this museum uses natural stone elements for ground cover and visual elements (Figure 6).

Figure 6. The pavement outside the museum

The museum's building forms a flat, elongated beam with an inner courtyard creating an open space large enough to provide sufficient space for vegetation. The vegetation on the museum's landscape is arranged based on function and location. In the parking area, the used vegetations are those which function as barriers and shades (Figure 7). The main entrance uses directional vegetation and space fillers to provide visual aesthetics. No vegetation is planted in the inner space of the museum, but some are grown in the inner court area for space filling.

(a) (b)

Figure 7. Vegetation of the Museum Gunungapi Merapi in area a. Parking, b. Inner courtyard

3.2 The Principle of Building System's Harmony with the Nature

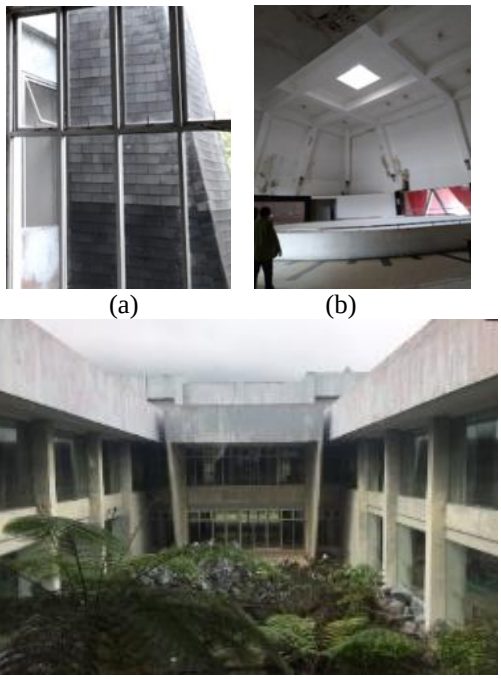
A Building system is the availability of facilities in a building that is used to provide security, comfort, convenience, and accessibility (Mutmainah et al., 2017). The harmony between the system and the environment is achieved through adjustments to environmental design. A building design must have an integrated system of plumbing, sanitation, fire prevention, ventilation, and waste management, by which things that have the potential of polluting the environment can be managed through a passive process to avoid environmental damage.

Maximizing natural lighting and ventilation can be achieved by adapting the design to the local climate. This adjustment is made by placing openings in the west-east direction, adding skylights to optimize natural lighting, and creating aerodynamic building masses to protect the structure from wind and optimize natural ventilation (Rahayu et al., 2016). The museum uses openings, skylights, and glass for natural lighting. The skylights are located in the lobby above the replica of Mount Merapi. The glass walls are used as barriers between the inside and outside of the museum. They are placed in the inner courtyard areas to let sunlight in. This museum uses artificial lighting as a supporting element to highlight museum collections and make them more attractive (Figure 8).

(a) (b)

Figure 8. The sources of lighting in the museum
a. Glass walls, b. Artificial lighting

Located in a humid tropical area, this museum has low temperatures and relatively high humidity, so it needs many openings to let light in and air well circulated. The ventilation is obtained from openings in the walls. The addition of building voids can affect wind circulation, accelerating the shift and change of wind in the building. The green area in the middle of the building makes way for cross ventilation, which blows air from the main entrance to the side entrance. Artificial ventilation is installed in specific areas, such as theaters and auditoriums, to improve air quality and regulate indoor humidity (Figure 9).



(a) (b)

(c)

Figure 9. Ventilation Sources in the Museum
a. Window, b. Skylight, c. Inner courtyard

Drainage sustainability can be created by optimizing water absorbed into the ground, which is done by making infiltration wells and biopore channels, using water-absorbing ground cover materials, and recycling the wastewater to prevent environmental pollution (Zeiher, 1998). The use of paving blocks in this museum is limited in certain areas. The parking lot is covered with asphalt, but infiltration lines are placed throughout the parking spot barriers. The entrance area uses natural stone hardening, and ponds are built for rainwater reservoirs. Access between masses is made of paving blocks to maximize water absorption, and gutters are placed to drain the wastewater into the reservoir (Figure 10).

Figure 10. The water element in the entrance area

3.3 The Principle of Sustainable Natural Resource Usage and Energy Efficiency

In the effort of meeting the needs of the building, the selection of environmentally friendly materials must be aligned with the effective and efficient use of technology. The objective is to integrate the characteristics of the building materials with the surrounding environment for energy efficiency and environmental sustainability. According to Cullen in Permana & Arsandrie (2021), environmentally friendly materials are chosen based on the material's characteristics. The suggested characteristics of the material are reusable, minimal in harmful air emissions, pollutant-free, durable, long service life, locally produced, and can be quickly restored.

The primary material for the museum's roof is concrete. For the building envelope, aluminum composite panels and bitumen-coated steel frames are used to form the sloping of the roof (Figure 11). The casing of this museum is dominated by concrete walls as they can withstand extreme weather and dampen sound and are corrosion free. The application of sloping concrete is difficult, requiring more cost and time in its construction.

(a) (b)

Figure 11. Aluminum composite panel at the Museum entrance

Wood panels are used in this museum to create barriers and to display museum collections. The floor is a combination of various types of flooring with different motifs that are adjusted to the function of the space. The use of glass walls as supporting elements in the museum adds an overall effect to the space in the building. The replica of Mount Merapi is made from environmentally friendly material, resin-based materials. The smoke effect coming out of the replica's crater is produced by a water combustion system that does not harm the environment (Figure 12).

(a) (b)

Figure 12. Interior space in the Museum
a. miniature of Mount Merapi b. Showroom
Source: mgm.slemankab.go.id, 2022.

The use of technology can save energy and minimize the negative impact on the environment. The usage also aims to facilitate this process by treating the waste of the museum's activities (Utami et al., 2017). Nowadays renewable energy can be classified into three categories, one of which is energy that has been developed commercially, such as biomass, geothermal, and hydropower. Barcodes are also used in this museum to replace paper and minimize waste. Commercial renewable energy has not been applied in this museum, reducing the ecological value of the building.

3.4 The Principle of Spatial Planning that Considers Ecological Values

In ecological architecture, the shape of spaces must be considered so that each of them can support the activities in the building (Utami et al., 2017) and so that there is no unused space. The more effective the design of the space, the more efficient the use of the space.

Space organization and zoning can significantly influence the space circulation of a building. The room layouts at the Museum Gunungapi Merapi are based on the pattern of user activities, and rooms are grouped by function and proximity. In this museum, zoning is made according to activities. The zones are reception (parking and entrance), management (office, warehouse, and others), museum (exhibition, mini theatre, thematic plaza), and service (prayer room and amphitheater). The zoning within the building is made based on its function and accessibility, such as public zones, semi-public zones, private zones, and service zones (Figure 13).

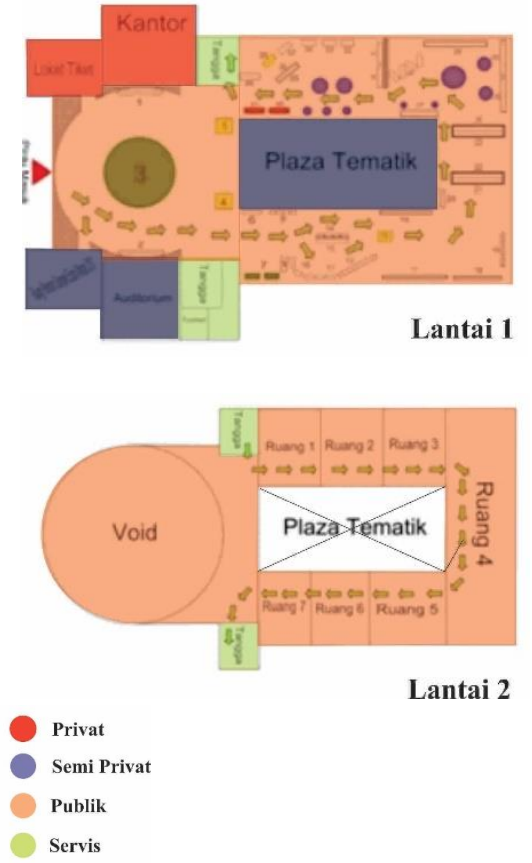


Figure 13. Spatial zoning at the Museum Gunungapi Merapi
Source: Adhiarta, 2012.

The zone division produces a circulation pattern of activities in the museum building. The initial circulation pattern of visitors begins with free circulation in the parking area. In the entrance area, the pattern is changed into a linear circulation that can be reached via a ramp or stairs. The lobby inside the building uses a centralized circulation on an interactive model of Mount Merapi. Then, in the exhibition space, the circulation changes linearly according to the museum's storyline (Figure 14).

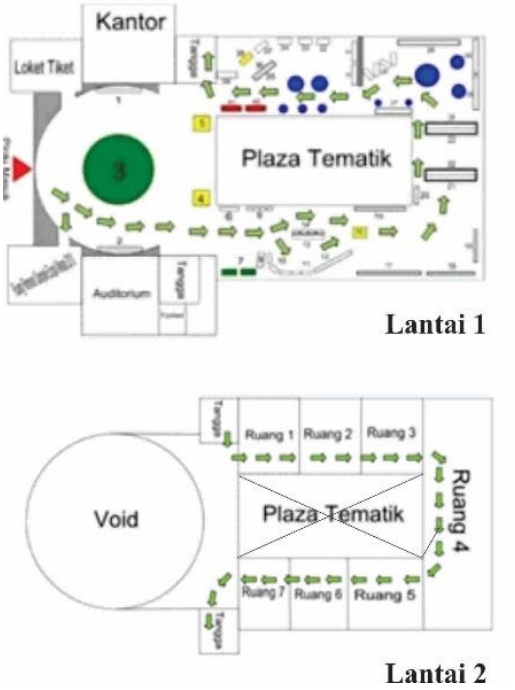


Figure 14. Circulation Patterns in Museums
Source: Adhiarta, 2012.

4. CONCLUSION

The concept of ecological architecture in buildings forms a reciprocal relationship between living things and their environment, which aims to create environmentally friendly architectural designs. A building will be considered ecological if its design has applied the four principles of ecological architecture. Several principles can be used to analyze the Museum Gunungapi Merapi's ecological architecture. The principle of physical integration with the local environment is applied by this museum in its north-south building orientation, its composition of elongated flat masses, and its structure that adapts to its existing conditions. The principle of harmony between the building system and nature is applied by creating many openings, presenting an inner courtyard, and optimizing water absorption into the ground. The principle of sustainable natural resources usage and energy efficiency is met by using readily available materials and environmentally friendly designs on the volcano replica. The principle of spatial planning that considers ecological values is achieved by dividing spaces according to their functions and user's activities, from which an effective circulation pattern is produced. Based on the research results, the Museum Gunungapi Merapi is declared fulfilling the aspects of ecological architecture. However, improvements still need to be made in the utilization of renewable energy. This can be done by the implementation of technology that processes waste from the museum's activities and by installing backup energy sources that utilize the environmental potential.

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