Sustainability concept as climate change adaptation in the vernacular house in Aceh

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Abstract. The vernacular residential adapted to climate change in various ways. Some studies showed that vernacular residential which is associated with traditional houses own its genius loci to climate change adaptation. This study aims to investigate the sustainability concept obtained in the Aceh vernacular residential in its attempt to adapt to climate change. This study was based on the data that been collected from observation and literature analysis. The result showed that the climate change adaptation of the vernacular residential in Aceh demonstrated in material, construction, form, orientation, space configuration, opening, ventilation, and infiltration. All those aspects covered the aspect of vernacular, which are technical, cultural, and environmental. The concept of sustainable architecture was raised based on these aspects. Further research should be conducted to extend the location of research in various data sources.

1. Introduction
The climate adaptation existed in the vernacular house in Aceh, namely Rumoh Aceh. This climate adaptation is shown in the design of Rumoh Aceh. This design includes the material, construction, space organization, orientation, opening, ventilation, and infiltration [1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]. As the climate in Aceh is a tropical climate with hot temperatures and a high amount of rainfall, the Rumoh Aceh building has been sustained for a very long time, as evidence of adaptation to the climate. The use of local material in this building is proper to the local climate [1]. Thus, sufficient air circulation in this building is resulted [2]-[4]-[10]. Moreover, this building also gains sufficient natural lighting [2]. Meanwhile, those configurations applied in Rumoh Aceh can be considered as climate adaptation strategies. Since the climate tends to change over centuries, it is assumed that Rumoh Aceh also adapts to climate change. In the meantime, climate change adaptation is important for the ongoing response to global warming [11].

The study of climate change adaptation so far has been concerned with two things. First, the study of climate change adaptation which emphasized the architect or designer involvement in designing adaptive building [12–14]. Second, the study of climate change is concerned with the government policy for creating a more sustainable environment in urban areas [13]-[14]-[15]. Those two trends of consideration of the study showed that climate change adaptation can be seen from a top-down perspective. Society as social capital was not considered as a significant factor as the society always
treated as the object of design. Only a few studies investigated this topic. One of them examined historic dwellings to test the building’s capability in adaptation to climate change [11]. The second study examined the construction and environment element of a traditional residential building to get the idea of sustainability [16]. The other study discussed the role of tacit knowledge [17]. Some case studies of the other area showed significant information of their vernacular residential building adaptation as a pearl of local wisdom [11]-[17]. Although some studies of Rumoh Aceh described and examined the local wisdom of the building [1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10], none of the studies related it to the sustainability concept in the climate change framework. Some studies related to sustainability in the framework of Islamic architecture [7]-[8]. Some others associated it with environmental quality [2] and particular aspects, such as energy and thermal comfort [4]. Some others focus on the study aims for conservation [5] and building resiliency on earthquake and tsunami as local wisdom [6].

Hence, by focusing on vernacular building, this study aims to complete the previous studies which did not too much notice the dimension of society as a significant factor. At the same time, this study gives more examples of tacit knowledge that was owned by vernacular buildings created by the society, in this case, a residential building. Specifically, this study aims to explore the sustainability concept acquired by Rumoh Aceh in an attempt to adapt to climate change. In line with that, this study answered the question of the form of climate change adaptation in Rumoh Aceh. The answer to this question makes it possible to understand the basics of thought and understanding of the society in their attempt of climate adaptation, along with the changes.

This study of climate change adaptation in Rumoh Aceh is based on the argument that every society carried its specific way in response to climate change. Some agents acted using formal knowledge of science, such as architects, designers, and governments, while the society uses their knowledge of culture and tradition which is called tacit knowledge or local wisdom to respond to climate change.

2. Vernacular architecture and local wisdom
The term vernacular architecture was introduced by Rudofsky in 1964. The term comes from the word verna (from Latin) which means domestic, indigenous, native slave, or home-born slave [18]. Rudofsky used this term to classify architecture (generally residential) that is tied to its location employing locally sourced materials and knowledge. It also can be interpreted as an architectural design that adapts to the local climate, uses local techniques and materials, influenced by the social, cultural, and economic aspects of the local community [19]. Thus, vernacular architecture is born from the society to the next generation of the society and has passed through a natural selection process of climate, social, cultural, and economic factors in the community. As a result, vernacular architecture produces a form and configuration of space that is considered most appropriate according to the local society which is also called ‘local wisdom’ or ‘genius loci’.

Conceptually, local wisdom and local excellence are people's wisdom that relies on the philosophy of traditional institutionalized values, ethics, ways, and behaviors [20]. Local wisdom is a value that is considered good and right, therefore it can survive for a long time and even be institutionalized. There is a concept of sustainability in the local wisdom of vernacular architecture. This concept existed because the vernacular architecture itself has passed through a natural selection process of climate.

Vernacular architecture is known as architecture originating from the society or also called the architecture without an architect. However, the presence of vernacular architecture provides an understanding that humans have the sense and taste to create the most appropriate forms of occupancy and under the conditions of nature, environment, and culture of the people. Because vernacular architecture discussed the relation between buildings and people [19]. The vernacular architecture itself does not appear in an instant, a day or two. But through a long process experienced by the community in adapting to nature, and also touched by the cultural values embraced by the community. Thus, vernacular architecture has complex elements in its formation.

If simplified, there are at least three aspects that have a strong influence on the formation of vernacular architecture, namely the technical, cultural, and environmental aspects [18]. In detail, the
technical aspects include structure, construction, building materials, and the method of construction. While those included in cultural aspects are the prevailing rules and patterns that have become traditions in the community. This includes space patterns, mass patterns, shapes, structures, and ornaments. The environmental aspects intended here are the natural environment, namely climate, location, natural disasters, and settlement patterns that adjust to the natural environment [18].

3. Sustainable architecture and climate change
Ever since the Industrial Revolution, human activity has exploited nature in ways that have changed the composition of the atmosphere. This activity is also leading to climate change. Temperatures increase at different speeds in different regions. Even in many regions, warming has already exceeded 1.5 degrees Celsius above pre-industrial levels. More than twenty percent of inhabitants live in regions that have already experienced warming higher than 1.5 degrees Celsius in at least one season [21]. As a result, global warming has become a major issue. The lack of sustainability policies has led to problems such as air pollution, acid rain, ozone puncture, flood, extinction of several species, and destruction of rainforests [22]-[23]. All of these problems are the result of human activity. If there is no action taken to reverse these trends, the results will be even worse.

Some efforts have been made to restore nature to its original state or to find ways of living in harmony with nature. In 1898, environmental pioneer Ebenezer Howard proposed a strategy to overcome the problem of industrial cities with a concept known as the Garden City. In his book, The Culture of the Cities, Lewis Mumford tried to build environmental awareness by explaining his optimistic view of cities as cultural centers capable of implementing biotechnical restoration [24]. In the 1970s, the first international conference on the subject was held at the United Nations, entitled the Conference on the Human Environment. An agenda emerged regarding sustainable development, but it was not until the Brundtland Commission Report of 1987 that the concept of sustainable development entered into public awareness. The Brundtland Commission's Report defines sustainable development as development that can meet the needs of the present without reducing the ability of the future generation to meet their needs [25].

The main issues of sustainability are related to energy, water, natural resources, ecology, habitat, and natural species. Since the buildings and activities in the buildings consume almost half of the energy produced, architecture contributes to almost half of carbon dioxide emissions. Recognition of this problem led to new energy-efficient, environmentally friendly architectural approaches, including what is today called green architecture, or sustainable architecture. These new approaches focus on the environmental impact of the building process and finally the building itself. Yet these approaches to sustainability are not only ecological but also economic and socio-cultural because the environmental focus cannot be separated from these other aspects. Hopwood et al. examined different approaches in sustainability discussion. They classified and mapped the different trends of thought on sustainable development, their political and policy framework, and their attitudes towards change and means of change [26].

Since the sustainability concept was raised after the global warming issue which caused damage to the environment, the study of climate change also increased. Snow and Prasad examined potential climate change effects on buildings. They highlighted the potential for capacity building through education and presented examples of adaptive strategies for building design [12]. The potential effects on a building are increasing temperature, storm and inundation, flooding, and extreme weather events [12]. The proposed adaptive building strategies by Snow and Prasad are discussed in the next section. In line with them, Altomonte examined the interactions between the human system and dynamic environmental forces, trying to underline the causes and consequences of the evident alteration in the climatic equilibrium of the planet and exploring how built environments can contribute to mitigate and adapt to these changing conditions [14]. The two key strategies suggested by Altomonte were: reduce energy consumption and learn from nature [14] Another study identified several significant pieces of literature on the relationship between climate change and buildings [15]. They found that the majority
of identified literature concerns climate change impacts on buildings in a warm climate, with overheating being seen as the greatest challenge. Additionally, few empirical studies are found; most identified research is based on computer simulations or literature reviews. The volume of research on the consequences of climate change on buildings in cold regions is surprisingly small, considering the pecuniary stakes involved. The predictions of climate scenarios suggest regulatory/policy measures on climate adaptation should be taken as quickly as possible to avoid greater costs in the future [15]. Meanwhile, Shaw et al. proposed a framework for delivering adaptation action at the regional and local level plus guided on creating local adaptation strategies. They also provided further details on some of the key technologies available to help manage climate risks [13]. On the other hand, Roaf et al believed that there is much to learn from the buildings and technologies of the past, and the lifestyles and adaptive behavior and opportunities created by their occupants [27].

4. Methods
The study about climate change adaptation in Rumoh Aceh is a qualitative study based on observation and literature analysis. The focus of observation was directed to some aspects which were acknowledged before through desk review. Those aspects are material and construction, form, orientation, spatial configuration, ventilation, and infiltration. Therefore the scope of observation includes technical, cultural, and environmental as vernacular aspects [18].

The data used in this study were from the literature study in desk review and the observation. The data from the literature study was selected from the source concerned about the topic of sustainability of Rumoh Aceh and the topic of sustainability in the climate change framework. The data from this phase that were taken to the study were images, diagrams, maps, and texts. Some pictures are also taken from the observation phase, besides notes taken. Some diagrams drawing are performed to display the intentional information. The observation was taken place at Lambunot Village, Aceh Besar, Peurada Village and Tibang Village, Banda Aceh.

The data that was obtained was classified on the same theme by the key concept of coding. The data were analyzed by using the triangulation analysis method. The data obtained in the observation were compared to the data from the literature review. In the end, the data were interpreted in the sustainability context which became the basis of the climate change adaptation concept. All the phases informed above became the base for the inference process.

5. Results and discussion
To simplify, the study is divided into three sections: (1) construction and material, (2) form, orientation, and spatial configuration, and (3) opening, ventilation, and infiltration. This classification was based on vernacular aspects [13].

5.1. Construction and material
Rumoh Aceh applied local material nearby [1]-[8]. Therefore, there is no single same material that has been used in a different location. When the location of the house was near the forest, the material used would be wood. In other places, when the location was near to other resources, such as bamboo, the house will use it as building material [1]-[9]. The material used in Rumoh Aceh range from wood, timber, sago palm, bamboo, palm fiber to stone [1]-[4]-[5]-[8]-[9]. Since the material used in Rumoh Aceh can be obtained easily related to the location, it can be considered economically efficient. The quality of this material, not only it is considered green material because it is from natural resources nearby, but also because of the ability of this material to adapt to the tropical climate, since the material itself living in the same climate [4]-[8].

The construction of Rumoh Aceh is commonly undertaken by society [8]-[9]. This activity to build a house with the helping hand of the society was part of the culture of the traditional society. In the
perspective of construction cost, it also can be considered efficient. The cost of the man resource was reduced, at the same time, it enhanced the relationship between members of the society.

The construction of Rumoh Aceh is a knock-down construction system [3]-[9]. It allows the construction materials available to reuse if the building is demolished or removed to other places. By this way, it keeps the value of the building stable. It also gives the building's ability to sustain from the earthquake and flood, as it follows the movement of the wave [3]-[4]-[5]-[6]-[8]. These strategies were environmentally safe and economically efficient. The house also used lightweight construction which contributed to keeping the room thermally comfortable [4].

This expression suits what Altomonte has mentioned that before the modern age, society tend to use local material to readjust to the local climate when they first migrate to a new location [14]. He suggested imitating this procedure since this was supreme responsiveness to the climate. The adaptation strategies from the tacit knowledge owned by Rumoh Aceh in their construction and material are shown in Table 1.

| Construction and material | Tacit knowledge strategies | Key aspect of sustainable concept |
|---------------------------|----------------------------|-----------------------------------|
| Using local material      | Nearby material            | Economic                          |
|                           | Type of material based on location | Environment/ climate adaptation Socio-cultural |
|                           | Green material             | Environment                        |
| Construction              | Process of construction involved society | Socio-cultural                     |
|                           | Local knowledge of construction system (knock-down system) | Socio-cultural Economic Environment |
|                           | Adaptation to earthquake and flood | Environment Economic Socio-cultural |

As shown in Table 1, the strategies that belong to the tacit knowledge of the society can be distinguished to the sustainability concept.

5.2. Form, orientation, and spatial configuration
The form of the Rumoh Aceh plan is a rectangle span from East to West [4]-[5]-[7]-[8]. The orientation of the house limited the building skin surface face the Sun directly. This arrangement reduced the heat of the building as the heat absorb surface was arranged minimal wide [4]-[8]. The form of the roof also supports this arrangement by letting the wind getting through under the roof. It makes the air under the roof cooler than outside the building [8].

Figure 2. Form of Rumoh Aceh owned by Mrs. Hindun binti Abdul Qodir (left), owned by Mrs. Mahyuni (middle) and owned by Mr. Sulaiman Abda (right).

Figure 3. Orientation of Rumoh Aceh owned by Mrs. Hindun binti Abdul Qodir (left), owned by Mrs. Mahyuni (middle) and owned by Mr. Sulaiman Abda (right).

The space configuration of Rumoh Aceh was influenced by the combination of user activity, culture, and climate. How society perceived the concept of gender and the concept of public-private resulted in the spatial configuration of Rumoh Aceh [5]-[7]-[28]. The house generally was divided into three-part, as shown in Figure 4.

Figure 4. Space configuration in Rumoh Aceh owned by Mrs. Hindun binti Abdul Qodir (left), Mrs Mahyuni (middle), and Mr. Sulaiman Abda (right).
Although the orientation and the spatial configuration was the result of society language of the culture in an attempt to implement the concept of their belief \([7]-[28]\), it is also the dialog of the culture and climate adaptation\([4]-[7]-[8]\). The climate adaptation of this arrangement shows by providing space under the house to allow water flow during the flood meanwhile it is also used as social space during the normal season \([4]-[7]-[8]\). This configuration can be seen in Figure 5.

![Figure 5. Cross section in Rumoh Aceh owned by Mrs. Hindun binti Abdul Qodir (left), Mrs. Mahyuni (middle), and Mr. Sulaiman Abda (right).](image)

Thus, the adaptation strategies in form, orientation, and configuration that belongs to Rumoh Aceh are listed in Table 2.

| Form, orientation, and space configuration | Tacit knowledge strategies | Key aspect of sustainable concept |
|-------------------------------------------|----------------------------|----------------------------------|
| Form                                      | Rectangular shape          | Socio-cultural                   |
|                                            | Roof shape                 | Environment/ climate adaptation   |
| Orientation                                | The largest surface avoid facing the sun track | Environment Economic |
| Space Configuration                        | Dividing based on public-private | Socio-cultural |
|                                            | Space under the house      | Environment                     |

5.3. *Opening, ventilation, and infiltration*

The door functioned as the circulation of people as a membrane that connects the outdoor environment to inside the house. At the same time, the door also functioned as ventilation for air circulation since the door is always open during the day. On one hand, it allows cross ventilation to circulate. On the other hand, it also expresses the open culture.

The window functioned as the source of natural light to get inside the house, at the same time allowing air circulation through the house. However, to manage the heat get into the house, the size of the window is considered small comparing to the size of the house \([4]-[7]-[8]-[28]\). These strategies are performed to limit the heat without losing the opportunity to get air circulation.

The maintaining condition of thermal comfort in Rumoh Aceh, not only limited to the opening like windows and doors but also ventilation and infiltration. The ventilation in Rumoh Aceh may be applied in other traditional houses in the tropical climate, is not only in the upper position of the window and the door. But also at the below roof, to let the hot air flows to outside \([5]-[7]-[8]-[10]\).
Figure 6. From left to right: window, door, kerawang- the ventilation under roof, and infiltration- ventilation from the floor in Rumoh Aceh.

Meanwhile, the infiltration which allows the air from outside to enter the room (cross ventilation) was also applied to the walls and floor. The material used on the walls and floors allows the infiltration to be performed. The construction makes the spacing between the materials became air infiltration to keep the thermal comfort in the room [4]-[7]-[8]. The strategies for this thermal comfort and air circulation were considered environmentally friendly since they did not consume fossil energy. It also applied for the lighting of the house which uses natural lighting during the day. The adaptation strategies in opening, ventilation, and infiltration owned in Rumoh Aceh were shown in Table 3.

Table 3. Adaptation strategies of Rumoh Aceh from the opening, ventilation, and infiltration.

| Opening, ventilation, and infiltration | Tacit knowledge strategies       | Key aspect of sustainable concept |
|----------------------------------------|----------------------------------|-----------------------------------|
| Opening                                | Door                             | Socio-cultural                    |
|                                        | Small windows                    | Environment/ climate adaptation    |
|                                        |                                  | Economic                          |
| Ventilation                            | Ventilation under roof           | Environment                        |
|                                        |                                  | Economic                          |
| Infiltration                           | Allowing air circulation         | Environment                        |
|                                        | through floor and wall           | Economic                          |

Construction, material, form, orientation, space configuration, ventilation, and infiltration in Rumoh Aceh covered all aspects in vernacular [18]. All of that application in Rumoh Aceh showed conformity with Altomonte's statement about the genius loci belongs to traditional society [14]. The genius loci addressed to solve the climate risk as well as to express the belief and culture. Since the vernacular residential stood for a very long time and has sustained over the years, it is also has adapted to the changes of climate. The sustainability of the house is explored in each section of the sustainability concept.

The concept of sustainability is based on three pillars: economic, social, and environmental. Even though the searching of these three pillars' origins did not come to an end [29], however, this concept has already spread out and is popular in the discussion of sustainability. Though some believed it is hard to set a framework based on unclear concepts, the attempt of explanation of the three pillars in the context of sustainable architecture is still needed. Exploring these three pillars of sustainable development and relate them to sustainable architecture is translated in Table 4.
Table 4. From sustainability concept to sustainable architecture.

| Sustainable aspect | Sustainable development | Sustainable architecture |
|--------------------|-------------------------|--------------------------|
| Economic           | The limitation that a sustainable society must place on economic growth | The ability of architecture to maintain the value of the building and to keep the construction cost-efficient |
| Social             | Continued satisfaction of basic human needs | The functionality of architecture accommodate the human need |
| Environment        | Continued productivity and functioning ecosystems | The use of limited resources effectively without harming the environment |
|                    | Protection of genetic resources and the conservation of biological diversity | |

source: Author, with adaptation from Brown in Purvis, et. al, 2019 [(29)].

Furthermore, in the effort of the vernacular houses to adapt to climate change, they provided sustainability concepts which is the local wisdom of the society. Exploring these concepts which have been sustained for a very long time will benefit the nowadays contemporary house design. The sustainability concepts in vernacular residential in Aceh can be seen in Table 5.

Table 5. The sustainability concept in solving climate risk in Rumoh Aceh.

| Sustainable concept | Sustainable architecture | Rumoh Aceh strategies | Solving climate risk |
|---------------------|--------------------------|-----------------------|---------------------|
| Economic            | The ability of architecture to maintain the value of the building and to keep the construction cost-efficient | Using local materials | Managing heat transfers |
|                     | Using a “knock-down” construction system | Managing earthquake and flood risks |
| Social              | The functionality of architecture accommodate the human need | The spatial configuration provides public and private function | Managing flood risks |
|                     | Form, orientation, and specific ventilation and infiltration to provide thermal comfort | Reducing energy consumption |
|                     | Provide natural lighting | Reducing energy consumption |
| Environment         | The use of limited resources effectively without harming the environment | Using local materials | Preserving resource natural |
Related to climate change, some studies have proposed strategies from urban scale to building scale. The strategies proposed by experts are compared to the strategies that belong to the genius loci of Aceh society in the vernacular residential building called Rumoh Aceh. Since some of the strategies proposed by the experts are related to a particular climate, only a few strategies suits to the local climate in Aceh are compared here. The comparison can be seen in Table 6.

**Table 6.** Rumoh Aceh adaptive strategies compare to strategies proposed by experts.

| Potential effects/hazards | Rumoh Aceh adaptive strategies | Snow and Prasad (2011) | Altomonte (2008) | Shaw (2007) |
|---------------------------|--------------------------------|------------------------|------------------|-------------|
| Increasing temperature    | Using local materials          | Insulation             | Innovative Heating, Ventilation & Air Conditioning | Planting, shading, and advanced glazing systems |
|                           | Cross ventilation              | External shading       |                   | Materials to prevent penetration of heat |
|                           | Infiltration                   | Cross ventilation      |                   | Innovative use of water for cooling |
|                           | Manage orientation of the building |                         | Renewable & environmental building materials | Mechanical cooling |
|                           |                                |                        | Building envelope systems | |
| Flooding                  |                                |                        | Flexible & adaptive structural systems & Raising floor levels | |
| Coastal Storm Surges and Inundation | Constructing sea walls | Flexible & adaptive structural systems | | |
|                           | Elevating building             | Elevating building     |                   | Raising floor levels |
|                           | Located in the mountain area   | Retreat from the coastal area under threat | | |
| Flood strangling          | Raise the building             | Raise or move the building | Flexible & Adaptive structural systems & Green roofs | |
|                           | Building movable by the knock-down construction system | Build a second or multiple stories and use the lower story as non-living or ‘non-productive space | | |
|                           | The lower story is used as social space (non-living productive space) | | Renewable and environmental | |
|                           |                                |                        |                   | One way valves permanently fitted in drains |
Using local material which adapts to wet climate and water

Replace cladding, flooring, and linings with water-resistant materials

Move services (hot water, meter board) above flood levels

Build a levee or floodwall around the building

Raise flood awareness and preparedness with building occupants

Replace cladding, flooring, and linings with water-resistant materials

Modular building systems

and sewage pipes to prevent backflow and, widening drains

Flood resilient measures, including raising floor levels, electrical fittings, and equipment; rain-proofing and overhangs to prevent infiltration of heavy rain around doors and windows; temporary free-standing barriers which hold back floodwater from properties.

Flood resilient materials

The comparison from Table 6. shows that the strategies considered by the experts for climate change adaptation were already implemented in Rumoh Aceh. Meanwhile, extreme weather events as a potential hazard were not discussed in the experts' topics, as well as were not found in the Rumoh Aceh. All other potential hazards discussed in the study and proposal of the experts were found in Rumoh Aceh as local wisdom. These facts are in line with the statement of some studies that suggested imitating the genius loci of responsiveness from traditional buildings [14]-[27].

This study shows that Rumoh Aceh, as a vernacular house, has adapted to climate as an effort for sustainability. The strategies of adaptation were also aligned with the strategies for climate change adaptive buildings. There are some forms of adaptation which are in construction, material, form, orientation, spatial configuration, opening, ventilation, and infiltration. As a vernacular house, this house's form, structure, and organization are influenced by technical, cultural, and environmental aspects [18]. All of the vernacular aspects were part of the sustainability concept, in terms of sustainable architecture.

6. Conclusions
This study found that adaptation to the climate of Rumoh Aceh as a vernacular house produced by the local knowledge (genius loci) of the society. This local knowledge was earned by society from generation to generation for hundred years. In other words, the concept of sustainability which was discussed by experts in decades has been implemented by traditional society.
Analysis of sustainability concept as an adaptation for a climate has made it possible to find two important things. First, the indigenous knowledge that belongs to the society can not be neglected. Second, the study also gives a new perspective in viewing the relation of sustainability to society, which recently only viewed as the concern of experts and government. The indigenous knowledge and new perspective in viewing the relation sustainability to society have made it possible to find a new way of sustainability research. This knowledge can also be used as a base for designing contemporary houses.

This study is limited to analysis of the house concept at the methods which is not allowed to get perspective from the user. This analysis is not allowed the result of the study to become a reference to only rebuild the vernacular house, even though it is possible. However, the local wisdom that its owned should be applied to a future residential design. Further research should be taken by comparison to other areas and the variation of the data resource. The focus on extreme weather events also needs to be raised to find adequate strategies. In this way, the proper policy can be produced on the climate change issue.

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