GR20_HW02 - Vernacular and Climate Sensitive Architecture (Irkutsk, Acapulco)

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Vernacular and Climate sensitive Architecture

Irkutsk, Acapulco

Introduction

The second report of this course is to collect and analyze some examples for the two cities that we have. First is one of the largest cities in Siberia. The second one is Acapulco that located in the southern part of Mexico on the seaside; it is the largest beach of the country (Fig.1) . following the Watson&Labs matrix we will minimize the energy needs for heating, cooling, ventilating and even illuminating the indoor spaces.

Figure 1: Irkutsk and Acapulco location in the world map

1. Chapter 1: Examples of Vernacular Architecture

1.1 Irkutsk

As we know from the last homework, Irkutsk is a city located in the southern part of Russia, which is one of the largest cities in Siberia. We saw that its temperature arrange between 30@C and -40@C as hourly temperature, So it had had a ***borderline subarctic climate,*** characterized by an extreme variation of temperatures between seasons. It can be very warm in the summer, and very cold in the winter. ***Precipitation*** also varies widely throughout the year, with July also being the wettest month, when precipitation averages 113 millimeters (4.4 in). The driest month is February, when precipitation averages only 7.6 millimeters (0.30 in). Almost all precipitation during the Siberian winter falls as flurry, dry snow.

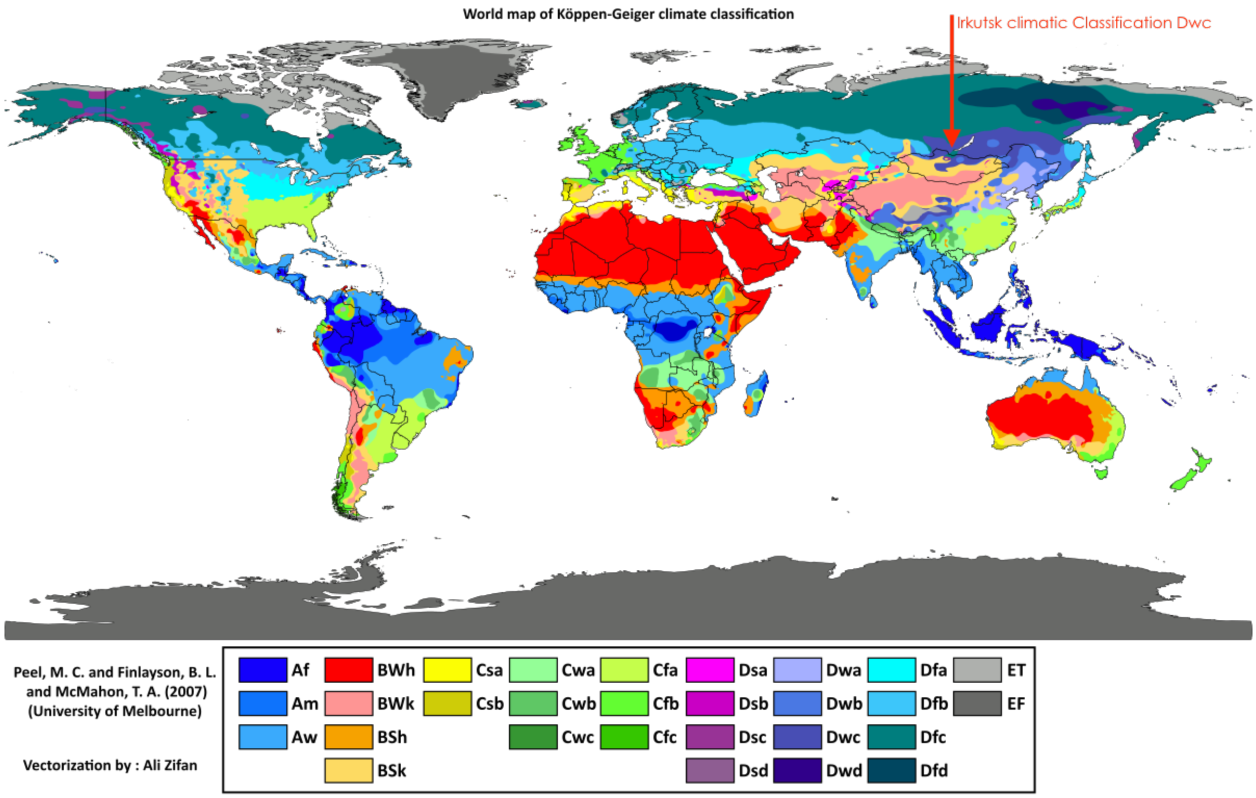

Figure 2: Irkutsk climatic Classification Dwc

As Wladimir Koppen climate classification, Irkutsk has **Dwc** classification which mean Monsoon-influenced subarctic climate; coldest month averaging below 0 °C (and 1–3 months averaging above 10 °C . At least ten times as much rain in the wettest month of summer as in the driest month of winter (alternative definition is 70% or more of average annual precipitation is received in the warmest six months).

For that we can start to see how the people in the past lived there adapt there life with the location by some strategies they follow like there houses, clothes and cultures.

1.1.1 Vernacular Architecture of Irkutsk

Starting from there traditional buildings as locally architecture made from local materials resist the climate and responsive to it.

Irkutsk is famous for its ***wooden architecture***. It has preserved many of monuments including ancient log structures. Some of the log structures have presently been restored. Almost all of the wooden houses are privately owned. Siberian wooden houses of course differ from the log structures of the European Russia.

The art of constructing wooden houses in this part of Russia passed through 3 well marked stages:

1-The 1st stage was the shortest. **Those constructed from specially published pattens during the end of 18th through the beginning of 19th century.:**The houses of the first settlers of the city represented it. Unfortunately, none of these houses remain. Obviously, they were very simple structures -

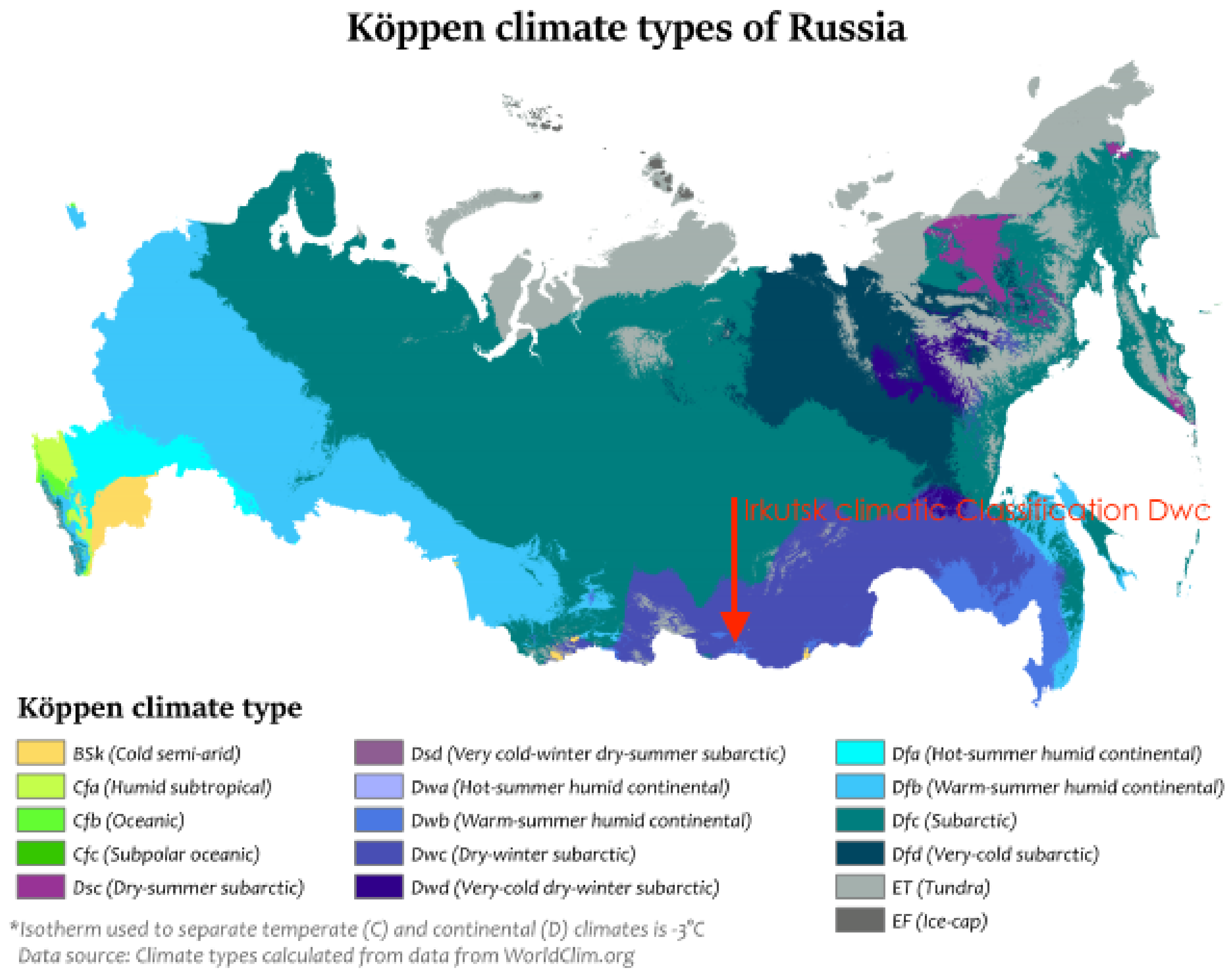

Figure 3: Irkutsk climatic Classification Dwc

huts. Siberian huts were huge brown structures. They all had basements which were used to store provisions. The basement is the most characteristic feature of Siberian houses.

2-The 2nd stage came in the middle of the 18th century. **Houses of individual projects made up by the local masters.** During this time the house was modified. The basement was turned into a kitchen of living space, a front porch and balcony appeared and the windows were widened.

3- The 3rd stage began in the first half of the 19th century. **The most common type in Irkutsk with a basement, a high porch and a balcony on the back side of the house.** Simple structures gave way to more complicated and interesting construction. These houses had different porches and attics. The facades were decorated with carvings and thread work. Special emphases were placed on adorning windows, with rich carvings and scrolls. The sign of the sun could be outlined with jagged star shapes

Wooden architecture of Siberia of XVI-XVIII centuries is characterized by great simplicity and severity. Houses and huts of both village and city residents were constructed from large logs, at least 35-40 cm thick.

- **The windows:** Usually, five or six windows face the street (Fig.7). The windows are rather big. The house is richly decorated with serous mostly of the Baroque style which was popular at that

Figure 4: 1st stage houses

Figure 5: 3rd stage houses

time. Sculpturesque shutters are painted in blue and green. Blue and green are 2 favorite colors in Siberia. In the houses were often larger than those of typical Russian houses.It often exceeded a meter. The window frame was usually made of wood, sometimes of iron. Local casings are also unique, they are distinguished by their large size, complicated headings and stunning carving samples (Fig.6). **Window-to-wall ratio** is rather big, bigger than in the rest of Russia, it spans from 1/3 to 1/6.

Figure 6: Windows of Irkutsk Houses

- **The roofing** were mostly high, gable. The ends of boards were overlapped with a thick log hollowed out from below – an "apex" ("gable") - at the very top, at the junction of batters. This log pressed the entire structure of the roof with its weight, giving it the necessary strength. The end of the "apex" usually protruded forwards and was sometimes decorated.

Figure 7: Windows on the facade

1.1.2 Materials properties:

Wooden houses are built in pine and cedar. Sometimes the foundation is of larch because it is firm and when put under water becomes as strong as iron. The upper part is constructed our of pine, because it helps to retain heat inside the house. Until the end of the last century, the interior of wooden houses was made out of clean logs.

For the long term durability of historical wooden buildings, constructors and users who deal with this subject have to know wood properties exactly. Wood is an organic, hygroscopic and anisotropic material. Its thermal, acoustic, electrical, mechanical, aesthetic, working, etc. properties are very suitable to use it is possible to build a comfortable house using only wooden products. With other materials, it is almost impossible.

- **Thermal Properties**

· Low coefficient of thermal conductivity

· Low thermal expansion

· High Specific heat

Those properties lead to the internal temperature of the houses insulated in a simple way from the extremely low external temperature.

- **Acoustic Properties**

· Sound absorption

· Prevents echo and noise

- **Electrical Properties**

· High resistance to electrical current (Dry wood)

· No static electricity

- **Mechanical Properties**

· Strength is quite high

- **Aesthetic Properties**

· Decorative material

- **Oxidation Properties**

· Metals get rust, wood doesn't. It's very suitable to the humid zones like Irkutsk.

- **Workability**

· Easy to repair and maintain

· Easy to execute, for that the old people of that place use it as main material of built

Also the wood has some problems with the durability, it must be treated to be protected from the deteriorations and diagnoses.

1.1.3 Pictures from Taltsey Museum (wooden architectural) 17-19 century) :

Figure 8: The Old Building Designs

1.1.4 Vernacular Architecture in Subarctic climates

Considering other zones with similar climates we can find out how they dealt with the severe cold of the region. North America and some parts of China share with Irkutsk the same climate.

Native american living in far north regions developed ways to keep the cold, rain and wind at bay. Techniques for warming were part of the secret engineering of a dwelling. The smaller and the more **subterranean** the building is, the easier is to keep it warm. Indians designed their houses and tents using partitions of hanging mats and other wind breaks to stop the wind coming inside from the doorway. Indian dwellings were generally heated from centrally located hearths. Lot of insulation methods were used, starting

Figure 9: Facade Of Houses

Figure 10: Order Of Houses In The City

from earth that surrounded the house that provided thermal mass and efficient **wind-blocking**. (*Native American Architecture* - Peter Nabokov, Robert Easton 1989)

Meanwhile, from the other side of the Gobi desert, China is facing Subarctic climate as well. Chinese people had more stable cities thus their dwelling are more complicated and better optimized. Over time, they constructed quadrangular brick courtyards and used special techniques in order to combat the cold climate: their usual method of construction was to build south facing low-rise houses, with spacious courtyards to obtain sufficient **solar access** throughout the structure; and the houses were commonly insulated by using 500 mm thick mud walls and two layer of windows. They used rice strach to seal window frame edges and

Figure 11: Order Of Houses In The City

Figure 12: Wind shielding structures (*Native American Architecture* - Peter Nabokov, Robert Easton 1989)

other joints in order to make the building **air-tight**. Another unique feature is the "Kang" arrangement, which has been used for heating homes in Northern China for more than 2500 years. A kang system consists of a stove, a kang (bed), channels and a chimney. It utilizes the residual heat of smoke from an adjacent cooking stove, which burns **biomass** and uses the bed to release heat to the bedroom and finally the smoke is exhaled via the chimney. It allows four different home functions of cooking, sleeping, domestic heating and ventilation. The ventilation is integrated into one system and moreover, it harnesses biomass burning for both cooking and space heating and thus reduces the use of commercial energy. (Sun, 2013)

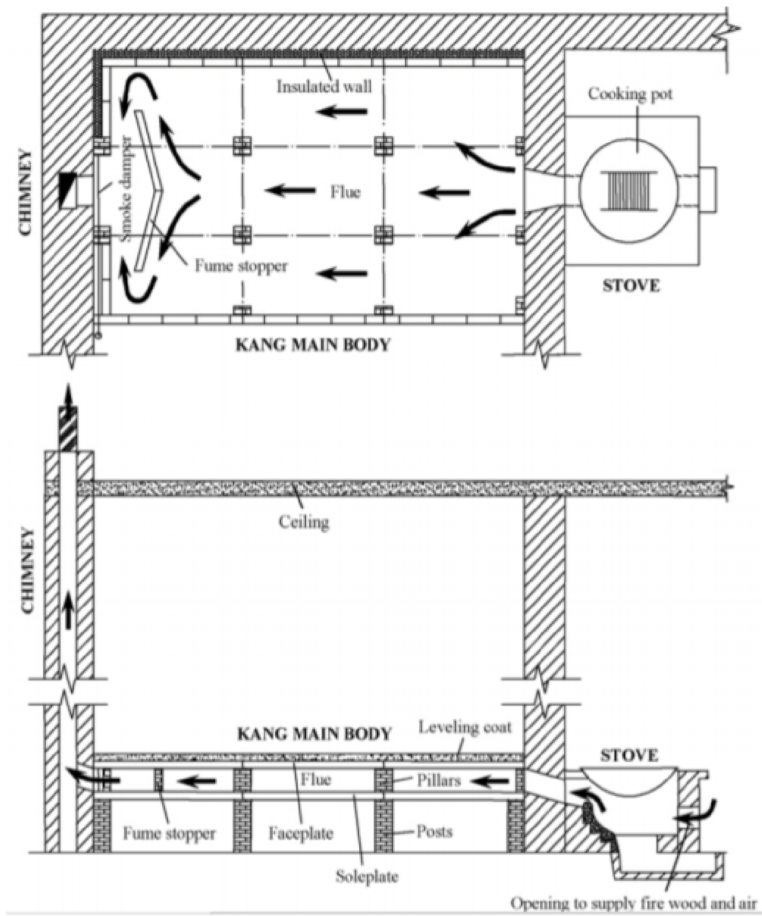

Figure 13: Keng Section and elevation (Sun, 2013)

As native american did also in cold regions of china people excavated deep **cave dwelling** . Because of the capacity of the heavy mass, the cave is cooler during the summer and warmer in the winter, which is an ideal solution for achieving thermal comfort. Moreover, it was cheap, available and balances the local environment with local inhabitants. (Sun, 2013)

1.2 Acapulco

Acapulco is a city that located in the southern part of Mexico on the seaside; it is the largest beach of the country. The external temperature ranging between 19 C and 29 C as we saw last homework. Acapulco

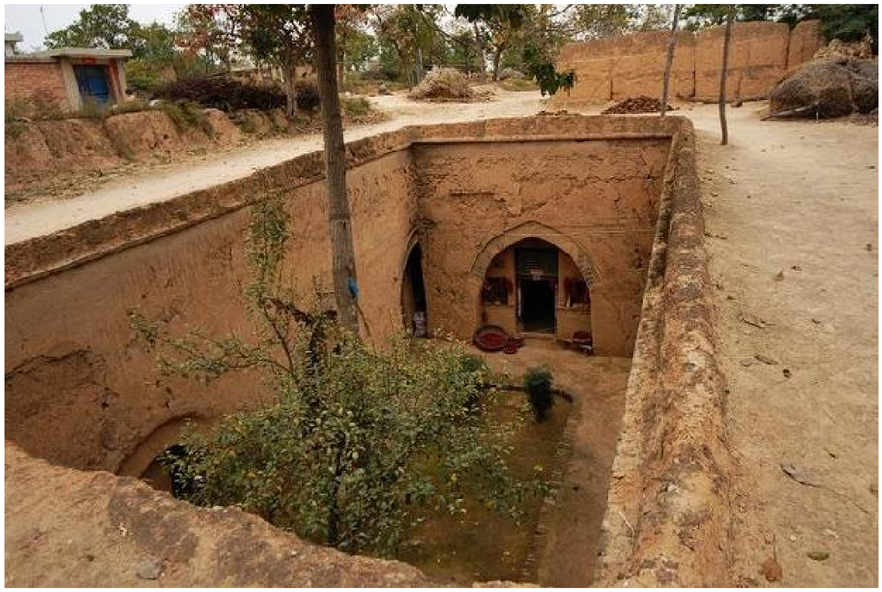

Figure 14: Cave dwelling (www.easytourchina.com)

features **a tropical wet and dry climate** (Köppen: Aw): hot with distinct wet and dry seasons, with more even temperatures between seasons than resorts farther north in Mexico, but this varies depending on altitude. The warmest areas are next to the sea where the city is. Tropical storms and hurricanes are threats from May through November. The forested area tends to lose leaves during the winter dry season, with evergreen pines in the highest elevations.

Tropical savanna climate or tropical wet and dry climate is a type of climate that corresponds to the Köppen climate classification categories "Aw" and "As". Tropical savanna climates have monthly mean temperatures above 18 °C (64 °F) in every month of the year and typically a pronounced dry season, the driest month having precipitation less than 60 mm and also less than 100 − [total annual precipitation {mm}/25] of precipitation.[1]:200–1 This latter fact is in direct contrast to a tropical monsoon climate, whose driest month sees less than 60 mm of precipitation but has more than 100 − [total annual precipitation {mm}/25] of precipitation. In essence, a tropical savanna climate tends to either see less rainfall than a tropical monsoon climate or have more pronounced dry seasons.

For that we can start to see how the people in the past lived there adapt there life with the location by some strategies they follow like there houses, clothes and cultures.

1.2.1 Vernacular Architectural

Acapulco, site of legend and history, In its spontaneous trajectory, in its different historical moments, a unique architecture was generated and, firstly, referring to the viceregal era, is that example of the military architecture of protection that is Fort San Diego, the first fortress, completed in 1617.

It had the form of a very irregular pentagon, with curtains unequal in length and with protrusions of protrusions and angles very different from each other. The present fort or castle began to be constructed in 1778 and finished the 7 of July of 1783. The architect Ramón Panón and the engineer Miguel de Constanzó gave to the project the form of a regular pentagon, with five bastions entirely equal and of great salient. This building is part of your identity of the city.

After we explained the main landmark so we can start to explain the main houses.

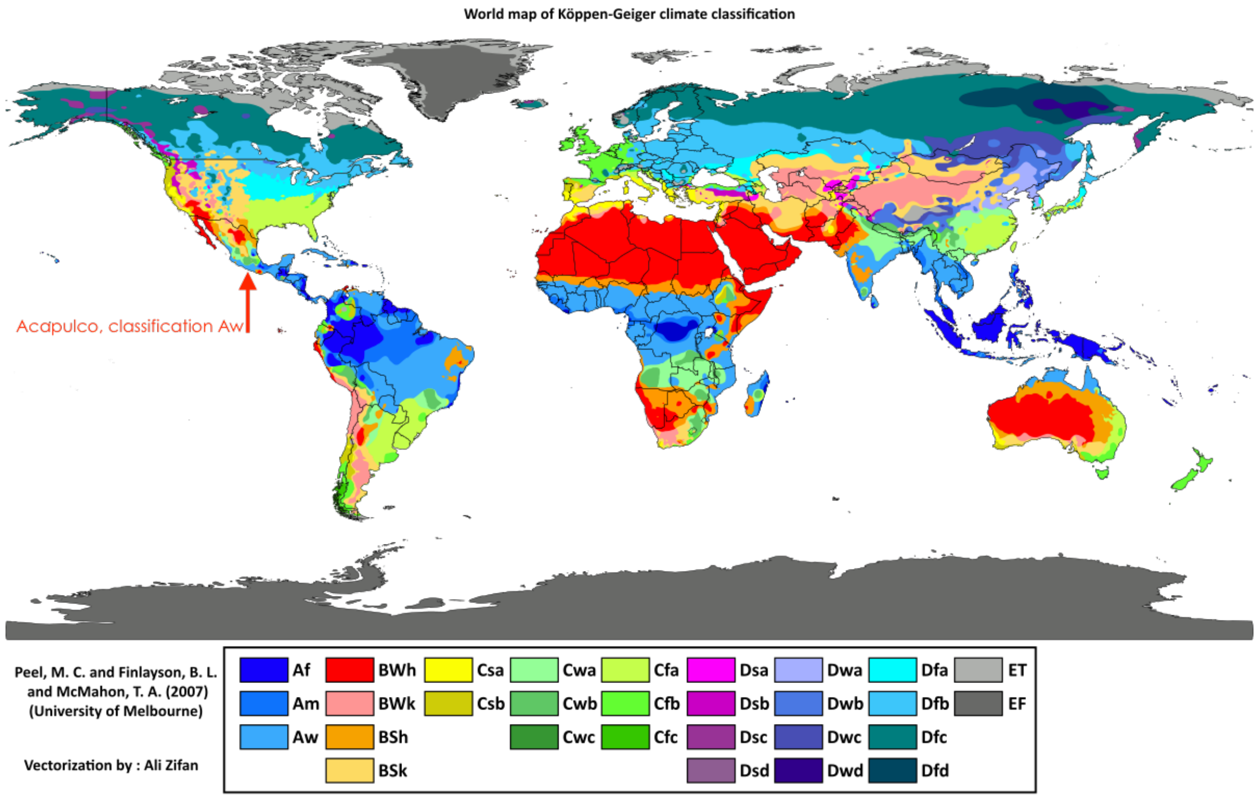

Figure 15: Köppen climate classification categories "Aw"

1- Palm house: The houses are of a plant, this one is generally rectangular the roofing is to two waters and is covered with palm or grass. The floors are of earth, the walls of bajareque, with portico to the front. The houses are small.

2- Clay house: The houses are of a plant and this one is rectangular, the walls are of adobe and also of bajareque, the outer zones are covered by the portal, the roof is of tile and its cover to two waters. They have portico at the front (sometimes also in the back).

These houses consist of a single floor built of masonry of granite stone, walls of bajareque or adobe and the roof of clay tile; there is another variant, where the walls are thicker and the material used is brick, the roof is also tile and has a greater foundation, so also, a variant of these typologies is that they have a portal or corridor in front of the house, which in the case of adobe walls, the material used is wooden posts, and in the case of brick walls, the columns are of the same material with an ornamental order. In this second variant the walls are revoked with plaster and painted with lime in vivid colors (blue, pink, yellow).

- **The most used materials** in construction are burnt clay, lime, mud, sludge, palms leaves and green straw. Those types of the materials are use usually for the warm climate because they are balancing the internal zone temperature by humidity of the material pores.
- **Opening and windows** used for ventilation and changing the internal air, while the used the shelters as shading system to protect the internal zone from the solar radiation.
- **The roofing** Big inclination in order to drain the rain

A **palapa** is an open-sided dwelling with a thatched roof made of dried palm leaves. It is very useful in hot weather and, therefore, very common on Mexican beaches, such as in Acapulco. It is perhaps one of the

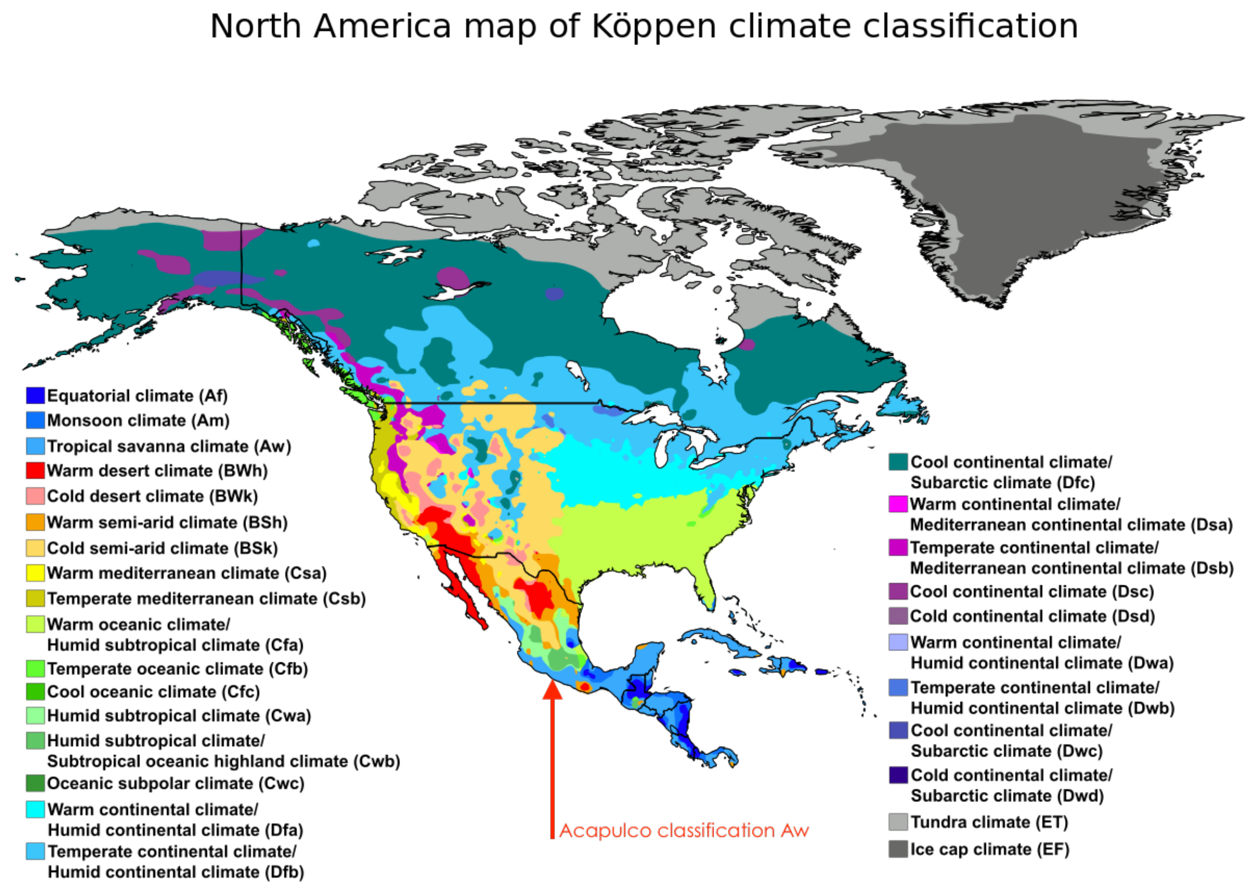

Figure 16: Aw classification

most important architectural contributions of West Mexican culture.

1.2.2 Materials properties:

As we saw that the main built material is the clay breaks reinforced by green straw bonded with lime, so we will discover some specific properties of this material.

- **Thermal Properties**

· Moderate to high thermal mass

· not good insulators, but in the past popular belief

- **Acoustic Properties**

· very good sound insulation

· Noise control

- **Mechanical Properties**

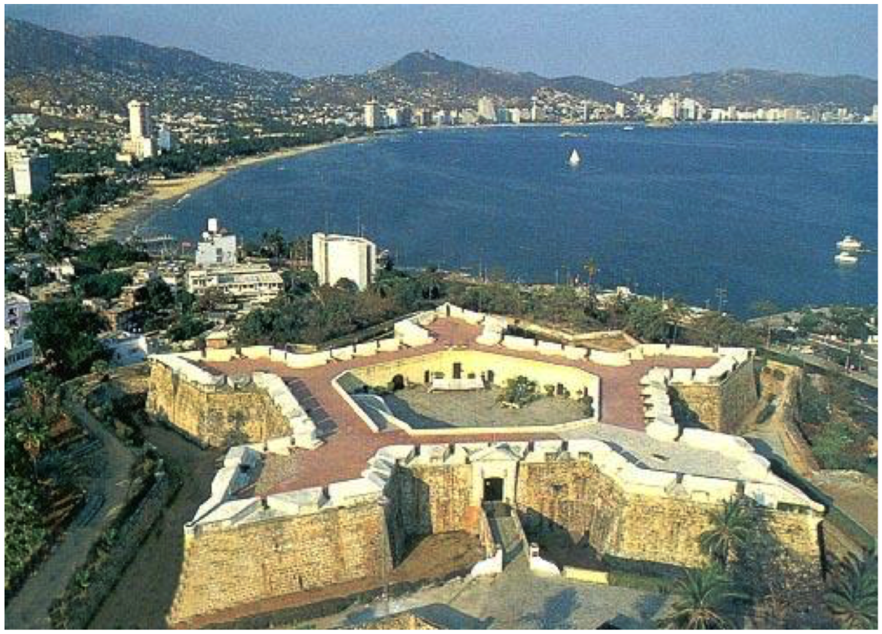

Figure 17: Fort San Diego

Figure 18: Clay House - “Architectura vernacula en zonas costieras, aplication en vivienda” p.g 65 - Stephany Chavez NavaC

· Its walls are capable of providing structural support for centuries but they need protection from extreme weather

- **Breathability and toxicity**
- **Buildability, availability and cost**

1.2.3

Figure 19: The Entrance Approach (p.g.66)

Figure 20: The Walls Of The Houses (p.g.66)

1.3 Comparison

Figure 21: The Roofs (p.g.66)

Figure 22: Palapa - Wikipedia

2. Chapter 2: Climate design strategies

In this chapter it is going to be discussed and analyzed the different passive strategies that can help to reduce the energy use, as well as increase the comfort level of the buildings. It will be analyzed the strategies for the two assigned climates, Irkutsk and Acapulco. Which are completely different climates.

For the analysis is going to be used the Watson and Labs matrix. In this matrix are define in a general way the strategies to follow in order to achieve the objectives. These objectives vary depending on the period of

Location	Irkutsk Russia	Acapulco Mexico
Climatic zone	Temperate zone	Torrid zone
Classification	Subarctic climate	Tropical savanna climate
Code	Dwc.	Aw.
Tdp average	30@C and -40@C	19 C and 29 C
Humidity	High	High
Precipitation	High	High
Vernacular Architecture	Wooden architectural	Straw clay architectural
Most types	3 types	2 types
Materials	Wood, stone	Clay, green straw, lime, palm leaves ,wood
Openings	6 windows each facade	Openings to the sea sides close to the southern side
Shading	No shading	Shelters
Roofing	With inclination	With inclination

Table 1:

the year.

2.1 Irkutsk

Irkutsk, as it has been explained, is a borderline subarctic climate, with an extreme variation of climates, but the cold temperatures are predominant during the year. For this reason, the strategies to apply in this region are the ones for the winter period.

As can be seen in the matrix, the objectives in winter are to increase heat gain and reduce heat loss. And are also described some general ideas about how to achieve them.

2.1.1Conduction

- **Heat Storage:**

The main idea of improving the **heat storage** is the use of the **thermal mass**. The idea is to have a material which is able to delay the heat transfer some hours. How it has been analyzed in the previous

(*) in theory ... you could

		HEAT SOURCES			
	Main strategies	Conduction	Ventilation	Radiation	Moisture transf.
WINTER (cold season)	*Increase heat gain*	*Improve heat storage when available*	Improve indirect gains from warm soil or sun	Improve solar gains	-
	Reduce heat loss	Reduce heat transfer from inside	Reduce air exchanges and infiltrations	(*)	-

Figure 23: Winter Watson and Labs Matrix

homework the daily variations in Irkutsk can reach more than 20 degrees. This are the better conditions for the thermal mass to work. During the day, the building stores the heat in the warmer hours. And then at night the heat is released, lowering the heating needs and discharging excessive heat.

This kind of technique is useful when it is applied in permanent residences, while for example in weekend residences, can happen that it is not possible to reach a certain comfort level without a proper amount of time. This can result in reaching the desired comfort level when no one is in the house. For this reason, it is necessary to be careful in applying this technique.

About the materials to use, the thermal inertia depends mainly in 3 properties: thermal conductivity, density and specific heat. Is important to consider the thermal mass which in this case is necessary to consider the volume as well.

In the previous chapter it has been explained that the most used material in Irkutsk is wood. Its properties do not look like the most suitable for the application of the technique. Nevertheless, with a good combination of materials, like for example adding an insulator with a high thermal mass, very good results can be reached. Is important as well to take special care of thermal bridges that can spoil the strategy.

The selection of a good insulator as well as the control of thermal bridges also are the suitable strategies for reducing the global coefficient of thermal exchange (H'_T).

About the indirect gains from the warm soil as can be seen in the next graph, in Irkutsk due to the soil temperature is difficult to design an effective passive strategy: in colder months the contact with the soil may be positive since temperatures are in any case higher than the outdoor temperature, while in summer ground will drain heat from the building, witch will worsen the already weak non-heating season. The design will exploit ground contact only in colder months as vernacular architecture suggests, but the thermal exchange will be blocked somehow during summer. Probably exploiting ground ventilation will ensure this effect.

2.1.2Ventilation

Other than the previously mentioned **ground ventilation** we can reduce heat losses. In a region as cold as Irkutsk is very important to reduce air changes and infiltrations. As we saw in chinese architecture one measure to avoid them, is improving the air tightness of the building. The wood is not the best material for this requirement, however there are some solutions that can improve considerably its efficiency. One of them consist in the use of wood fibers.

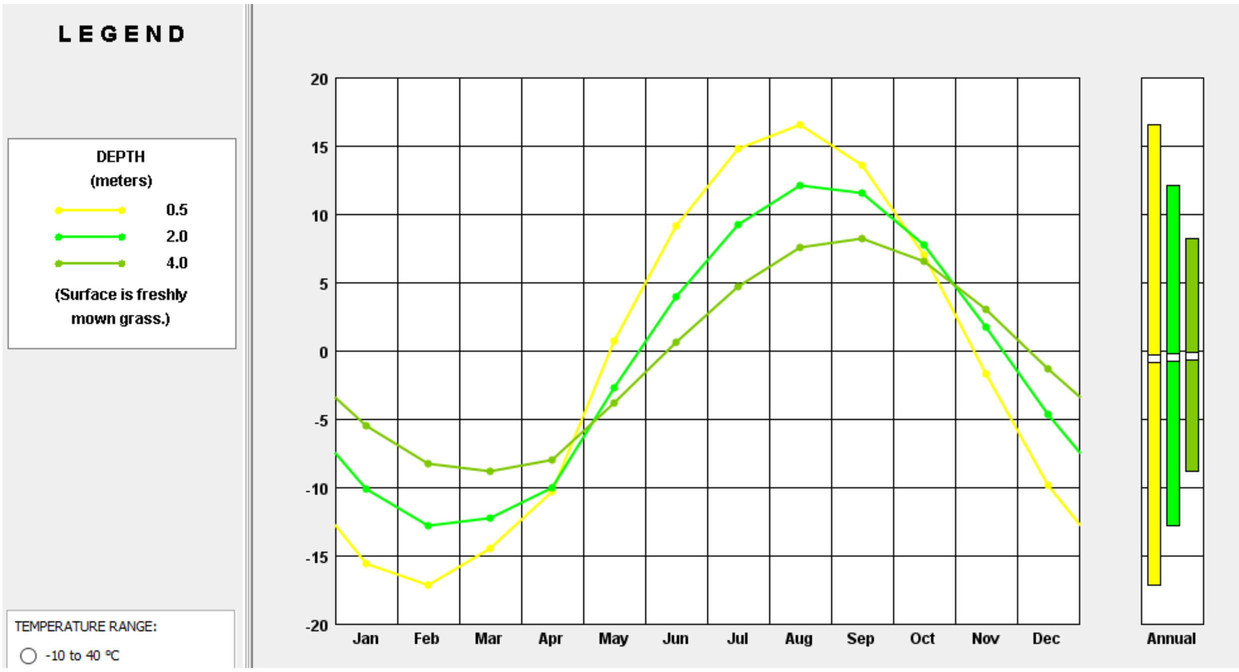

Figure 24: Irkutsk ground temperature

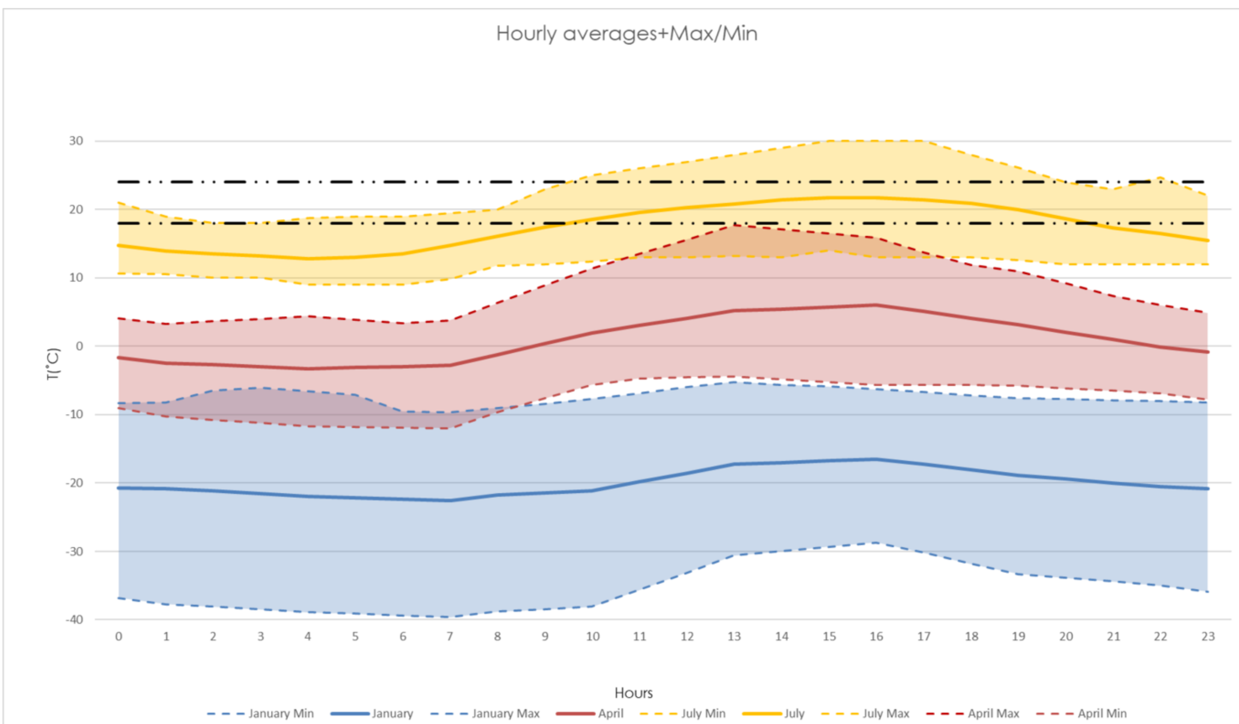

Figure 25: Daily cycle of significative months

2.1.3 Radiation

- **Daily Solar Radiation and Natural Lighting**

As it has been said in the Irkutsk architecture is very characteristic to have a high number of windows, and also bigger than in the rest of Russia. The idea is to take advantage of the **sun light**. But if the proper windows are not use, the result can be to have great heat losses. To avoid losses double or triple glazed windows must be chosen, also with a special coating in the right pane that allows the heat to enter but no to abandon the building. Apart of air other gases can be used to increase the performance such as argon. Of course a correct orientation in order to maximize the solar heat gains. As being in the North Hemisphere this means avoid the north orientations, especially for rooms oriented to spend a lot of time living in them (bedrooms, living rooms). And finally and looking a bit deeper in the thermal bridges aforementioned it is important to choose the correct material for the window frames. Big window-to-wall ratio can also reduce the illuminating electrical load of the building, allowing the use of more **natural lighting**.

Historically, the usual materials for them have been wood or iron, for security reasons. Those are not exactly the best thermal performance materials. Reason why aluminum frames with thermal breaks such as polyamide are more suitable.

2.1.4 ASHRAE guidelines

ASHRAE "Cold-Climate Buildings Design Guide" provides information on how to design durable and comfortable buildings in this climate:

- The colder the climate, the more important it is for critical equipment to be sheltered – you can't expect service personnel to properly repair HVAC equipment in a winter blizzard.
- In extreme climates, windblown snow takes on a consistency similar to sand and requires special design techniques to keep it from getting into HVAC intakes.
- A building envelope must address all modes of heat loss to be truly efficient; ignoring any mode of loss may lead to excessive thermal transfer.
- Design out cold bridges in both building fabric and engineering penetrations.
- Avoid or minimize any external service pipe runs.
- Provide safe access to roof mechanical plants in all weathers – frozen roof surfaces can be a hazard.
- Locate air inlets and exhausts in locations that avoid snow drift and blockage.

2.2 Acapulco

In the case of Acapulco, the climate conditions are radically opposed to those in Irkutsk. Reason why the strategies will be different.

As it is a tropical wet and dry climate and the temperature varies from 19ºC to 29ºC the strategies applied will be the ones for the summer period.

SUMMER (hot season)	*Reduce heat gain*	Reduce heat transf. from out to inside Reduce heat storage.	Reduce air exchanges and infiltrations of hotter external air	Reduce solar gains	-
	Increase heat loss	Increase heat transf. from in. to outside	Improve air exchanges and infiltrations of colder external air	Increase radiant losses (cooling)	Use evaporative cooling

Figure 26: Winter Watson and Labs Matrix

2.2.1Conduction

In this case the strategies are focused in favor the flux of heat from inside to outside, keeping cool the interior of the building.

In the contrary as in Irkutsk due to the low variations in temperature the thermal inertia is not really helpful in this type of climate.

2.2.2 Ventilation

In this region the ventilation is very important, it is one of the most important factors that allows to have a better comfort sensation, not only because of the need of **heat dissipation** but also because of the **humidity reduction**, and also the improve of the air quality.

For this reason, Acapulco architecture is **full of openings** that allow the pass of air and creates a flow, mainly by having openings in opposite facades. Frequently blinds and lattices are used as constructive elements because they provide protection of the radiation and allow the free circulation of the air. So in general the Acapulco architecture is considered a **lightweight architecture**.

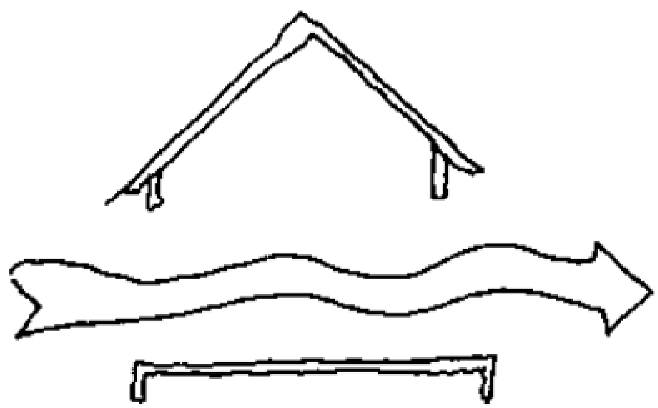

Figure 27: Lightweight architecture full of openings

It is important as wellto increase the velocity of the air inciding on the occupant, not only for its direct coolant effect but also for the cooling derived from a fastest sweat evaporation. To achieve it **long and narrow buidings** with a high area/volume relation and with big openings were built.

Considering the daily cycle we will consider night ventilation when external air is cold enough. This will improve comfort inside allowing to discharge the heat stored during the day.

2.2.3 Radiation

In tropical climates the solar radiation is never welcome. In these latitudes the main concern respecting the sun is how to **avoid both direct and diffuse radiation.**

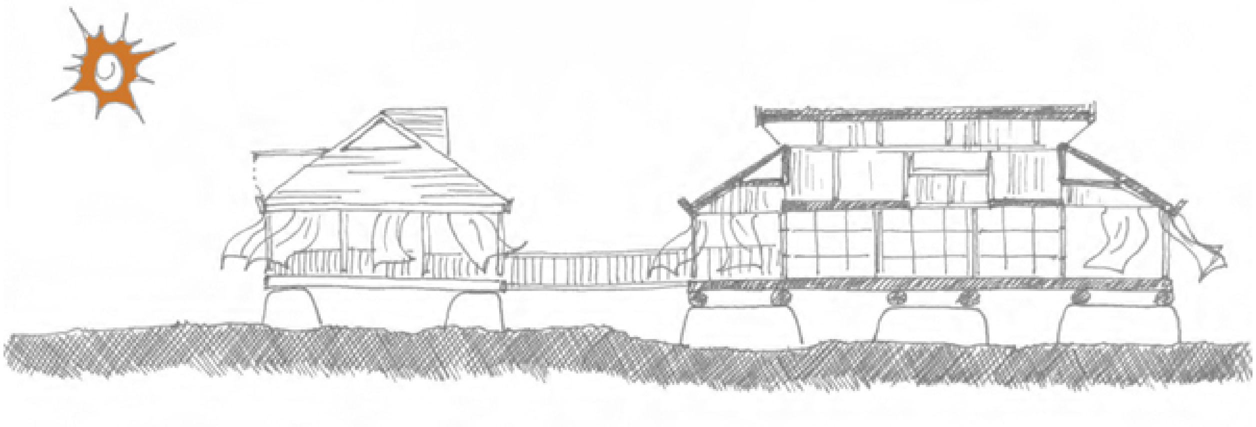

Figure 28: Long narrow building

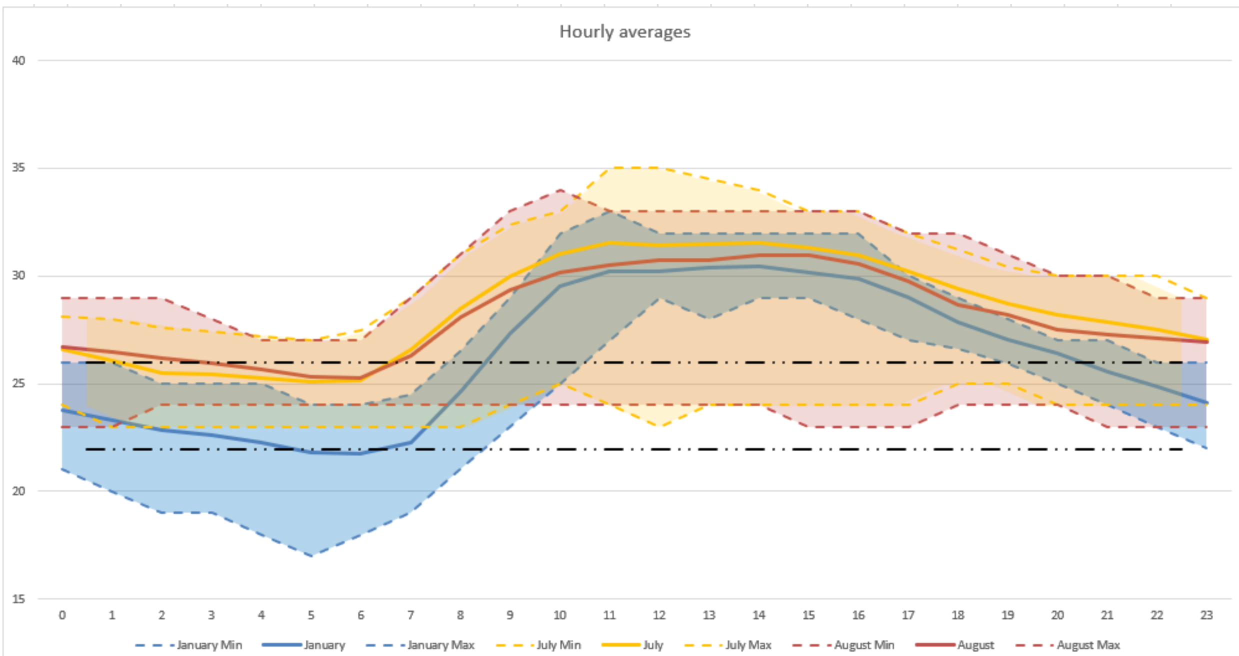

Figure 29: Daily cyle

The first step to avoid as much radiation as possible is the oriention. Contrary to other regions where the sun is important for heating purposes mainly in winter, in Acapulco the radiation must be avoided during all the year. In order to do so, the **best orientation is North-East**.

Once oriented, other different ways to provide shadow are used, mainly in the openings which are the most critical spot. But as it has been explained the ventilation is important and the openings are necessary. So, the shading devices have to be able to permit the ventilation and to avoid the sun radiation. The **overhangs** acquire a great importance in the architecture of the region, becoming in cases in porches, because they provide both, ventilation and shadow.

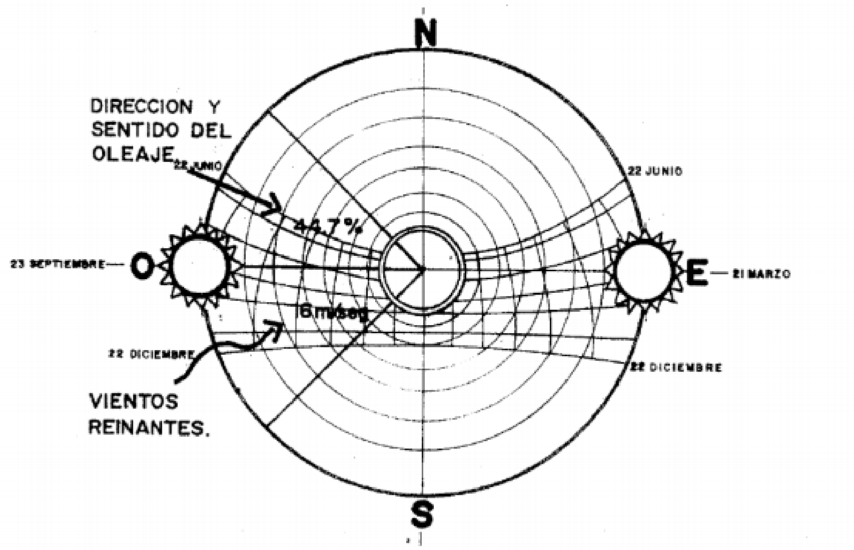

Figure 30: Sun, wind and swell in Acapulco

Other strategy concerning the radiation is the **use of light colors, especially white**, that reflects as much radiation as possible. Are used for both walls and roofs. Avoiding the radiation absorbtion it is also reduced the increase of the temperature due to the sun.

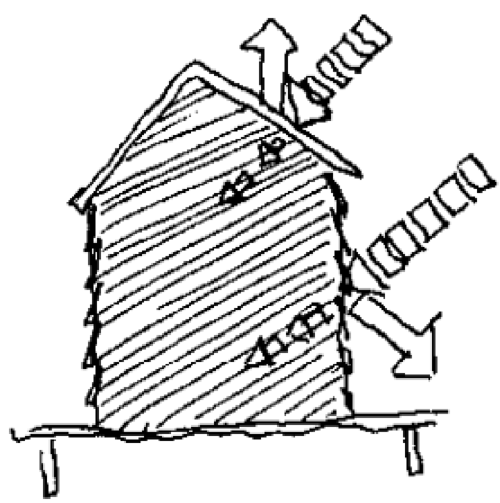

Figure 31: Sun reflexion

3. Chapter 3: Examples of climate responsive architecture

As there is no any type of responsive architectural in the two cities or countries that considered in this report, so the only thing we can compare is the need of the responsive architecture. The two cases we studied is al bahr tower in Abudhabi which it has similar condition of solar radiation and warm climate. While the second case related to the wind, temperature and light.

3.1 Al Bahar towers in Abu dhabi, UEA.

It is the world's Largest Sun-Responsive Façade Shades , Located in the financial centre of Abu Dhabi, Al Bahar Towers represent one of the most impressive examples of adaptive architecture and integrated design completed in recent contemporary architecture. The idea was simple. To control the solar gains introducing an external shading system rather than just relying on the glass to filter the solar radiation. The inspiration came from the **Mashrabiya**, the traditional Arabic lattice shade used to protect from the sun and re-interpreted and applied to two 150m high towers. The Mashrabiya panels are currently covering **3 predefined positions** – folded, intermediate, unfolded -, but could be re- programmed to stop in any required configuration. They are grouped in sectors and operated by a **sun tracking software** controlling the opening and closing sequence according to the sun's position. The control system is linked to an anemometer and a solar radiation sensor, to **adjust the position** in case of extreme wind speed or prolonged overcast conditions.

- **Advantages:** reduced glare, improved daylight penetration, less reliance on artificial lighting, react differently according to the sun's orientation and to adapt to varying external conditions, reduced solar gain (need for air conditioning).
- **Dis-advantages:** susceptible to external factors (high temperatures, wind, sand, salt water), fatigue, maintenance (in particular referred to a high number of mechanical parts), achievement of same life time.

3.1.1 Mechanism

The triangular panels are made of a **PTFE-coated glass fibre mesh**, which is a material capable of **withstanding high temperatures** and it is a "**self-cleaning**" fabric. The final fabric presents an open area of 15% and a light transmission of 25%. The panels are very **lightweight** (due to the PTFE membrane structure) and therefor not much power is needed to change their geometry. The panels are constructed in a way that one can easily be replaced when damaged, so **recycling** the façade will be reasonably **easy.**

3.1.2 Details

1- Strut sleeves: penetrates the curtain wall and connects to the main structure

2- Fabric mesh frame and sub-frame: supporting the fabric mesh

3- Fabric mesh

4- Slider: allows the mobile tripod to travel along the arms

5- Actuator + Power & Control: cable connection back to the tower

6- Structure arms: supports the whole mechanism

7- Mobile tripod: drives and supports the fabric mesh frames

Figure 32: Al Bahar towers

In detail, also, are reported the horizontal section detail of **joints** between the Mashrabiya panels, in particular the first referred to a simple contact connection between modules, while the second is the real mechanical joint for each triangular panel.

3.2 Thematic Pavilion at the Expo 2012 in Yeosu, South-Korea designed by SOMA Architecture, Vienna.

The façade covers a total length of about 140 m, and is between 3 m and 13 m high. It consists of 108 kinetic and operable louvers of **glass fiber reinforced polymers (GFRP)** that fulfil a climatic function and allow different modes of operation depending on the user's needs. Within the operation mode the louvers are

Figure 33: Al Bahar towers

individually actuated and create animated patterns along the façade. The potential **choreography** ranges from local motion to overall waves affecting the whole length of the façade.

During the day, the lamellas contribute to the shading of the sunlight entering in the building, favoring **comfortable lightning and temperature conditions** for the visitors and decreasing the consumption of energy of the structure. They operated by energy gained through solar panels on the roof.

After sunset the visual effect of the moving louvers is intensified by linear LED bars, which are located at the inner side of the front edge of the louver.The dimension of the laminas constituting the façade, directly influence the lightning conditions within the pavilion: the longer the single lamellas, the wider the degree of their aperture and, consequently, the area affected by direct lightning.

The different appearances of the building – open towards the Expo site and compact towards the sea- is

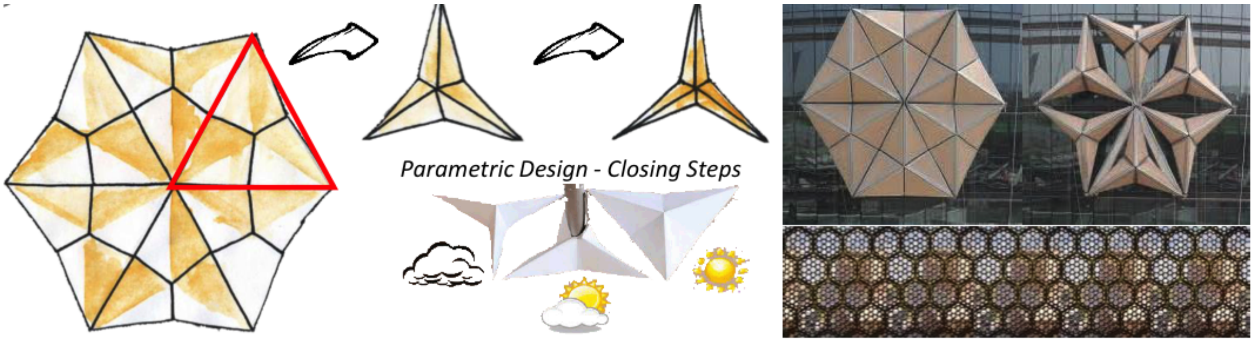

Figure 34: Mechanism of one module

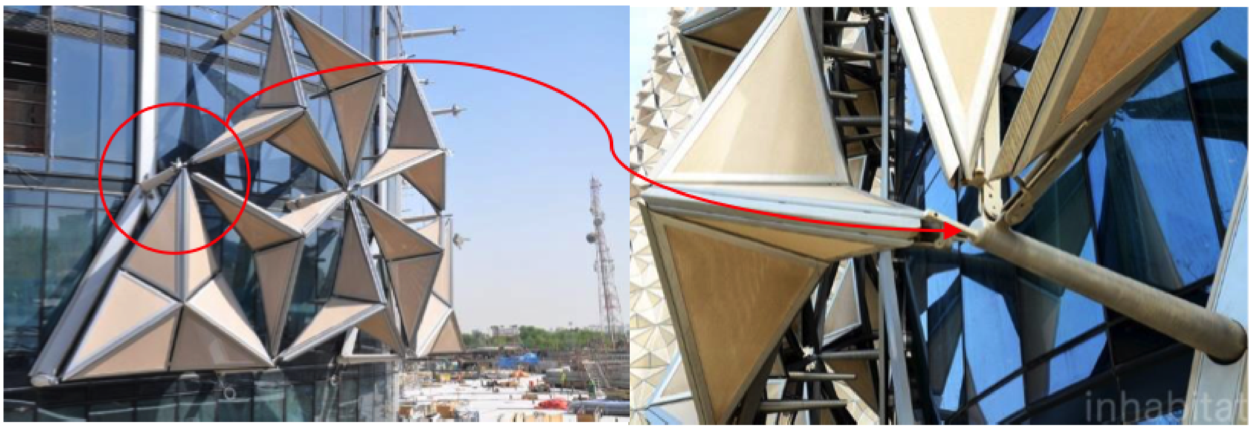

Figure 35: The Structural System

Figure 36: The structural concept

also routed in the constraints of the site. Facing the open sea the reinforced concrete cones prevent the pavilion from damage through typhoons and high waves. The roof and the kinetic façade will have a steel sub-structure. The kinetic façade will be produced out of GFRP and uses the material characteristics and flexibility for its mode of operation

- **Advantages**:

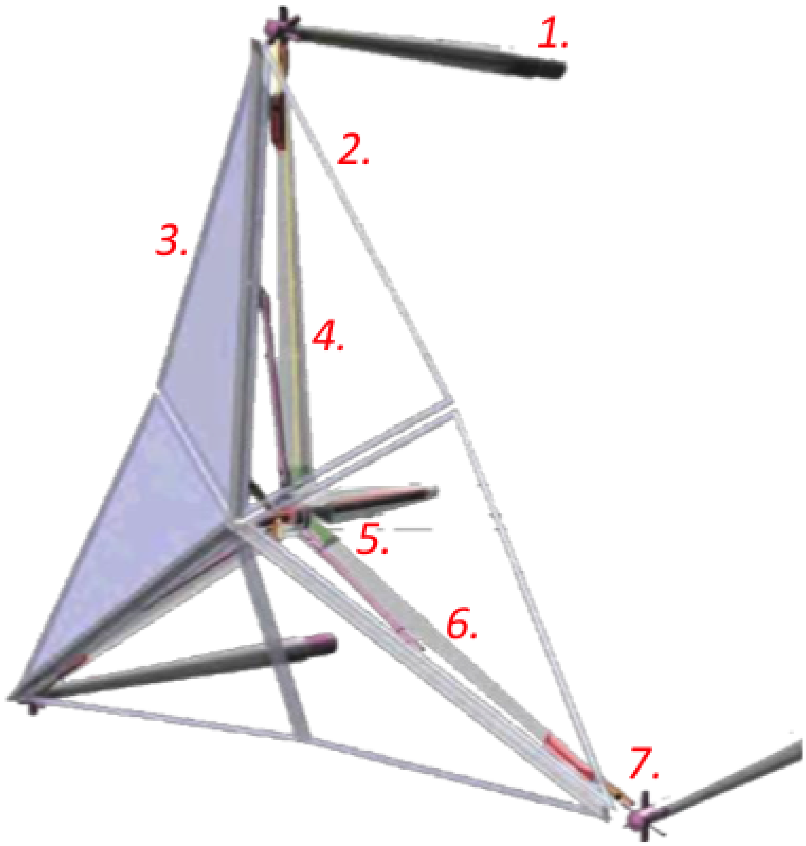

Figure 37: 3D details drawing for one part

· The mechanism is a hingeless flapping avoid easy deployability provided by the use of technical hinges. Due to the high number of load cycles that act on gliding and rotating elements, however, hinges tend to gall over time which causes expensive maintenance or even periodical replacement.

· The mechanics and the louvers are scalable at different dimensions and are adaptable to free form double curved surfaces.

- **Dis-advantages:**

· Considerable view restriction

· Impossibility to exploit light and thermal control in case of strong wind.

3.2.1 Mechanism

The façade is made of slightly curved GFRP plates which **combine high tensile strength with low bending stiffness**, allowing for large reversible elastic deformations. The lamellas are supported by two hinged corners at the upper and lower edge of the GFRP blade, while, in the other two corners, a small compressive force is applied in the plane of the fin, creating complex elastic deformation triggered by a failure mode, here shell **buckling**. Actuators reduce the distance between the two bearings and in this way induce a bending which results in a side rotation of the lamella.

Each actuator, a **servomotor driving a ball screw spindle**, is synchronized, whereupon sensors continuously check the lamella's status and report appropriate data back to the server via a BUS- system. The façade

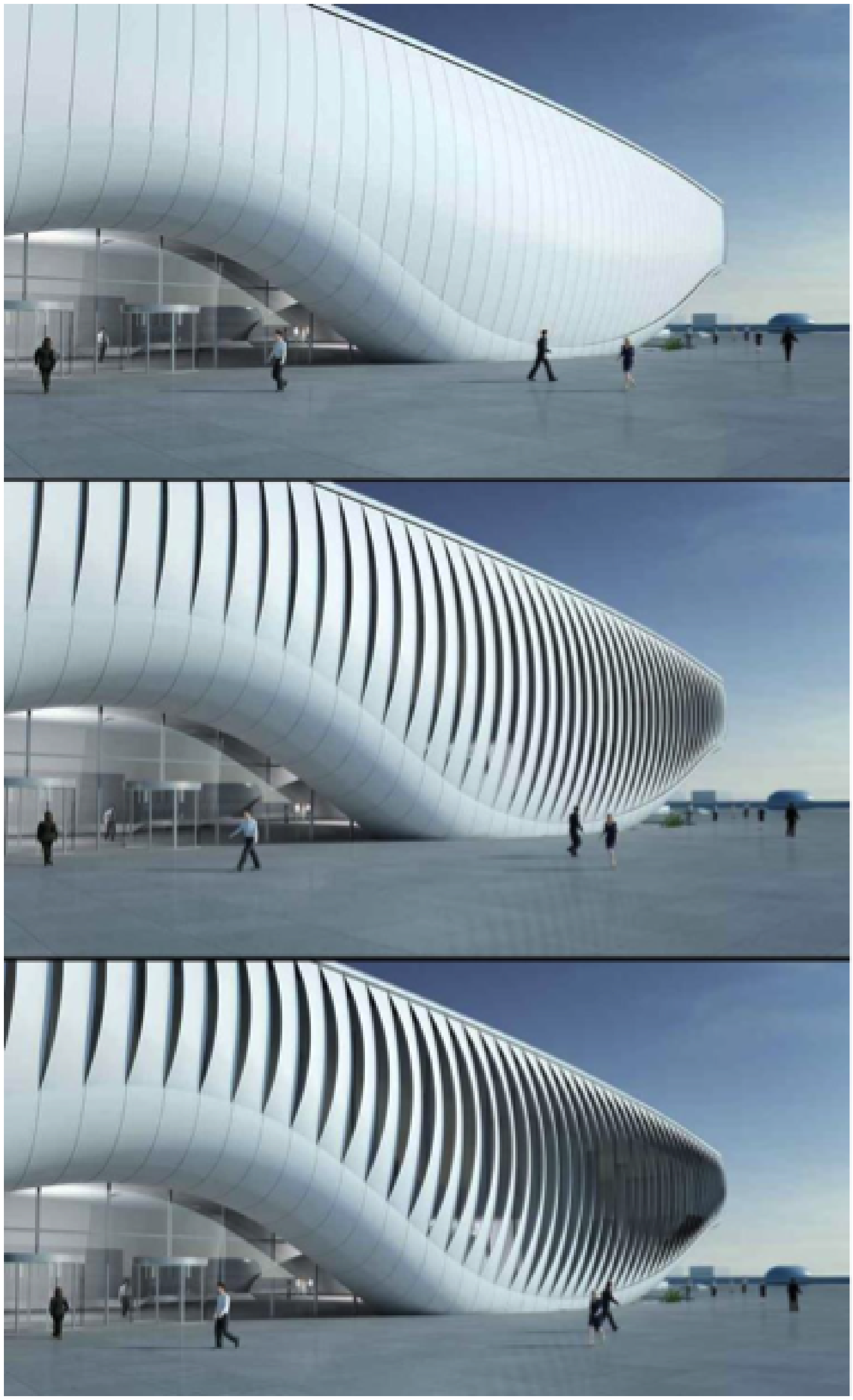

Figure 38: Thematic Pavilion shelters movement

is adaptable both to necessary light conditions as well as to structural-physical conditions. Furthermore, by operating a special pre-programmed choreography, the kinematic facade acts as a moving focal-point for visitors to the Expo.

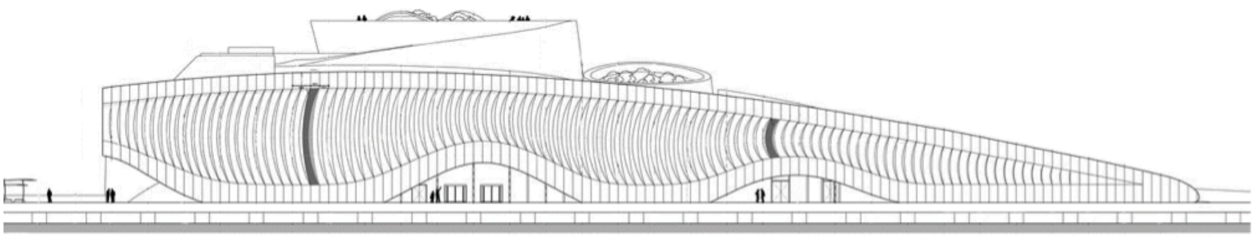

Figure 39: Elevation of the building

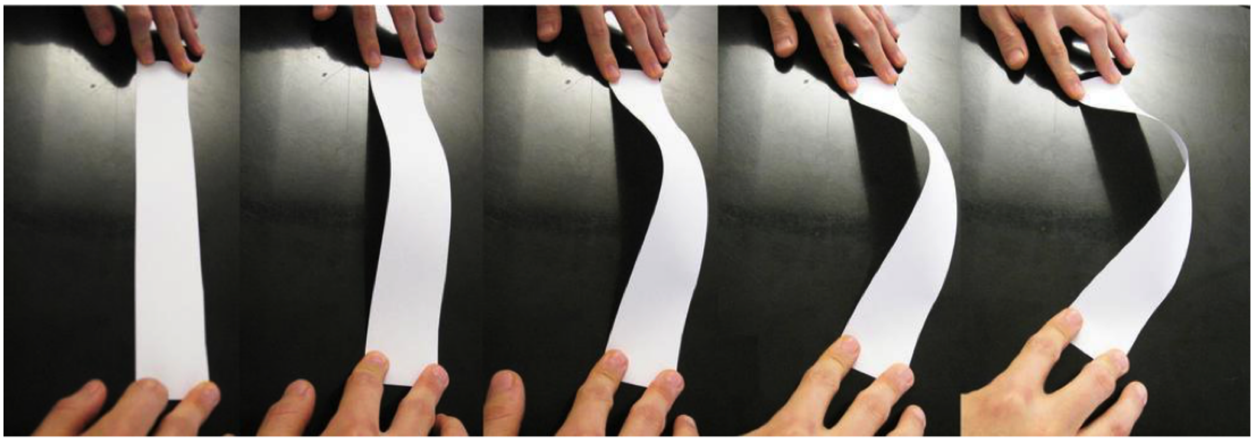

Figure 40: Mechanism

Each louver can be addressed individually within a specific logic of movement to show different choreographies and operation modes. Upper and lower motors often work with opposite power requirements (**driving – braking**). Therefore generated energy can be fed back into the local system to save energy.

The opening procedure of a 13 m louver requires a movement of 450 mm for an opening angle of 60°. The maximum movement speed of one actuator is about 3,80 m/minute. Shorter louvres open less.The façade had to be designed for very high wind speeds of up to 35 m/s occurring on the South Korean coast under Typhoon conditions. The **aerodynamic stability** has been determined, since slender or large spanned structures with a low stiffness tend to wind induced instabilities: if wind is less than 12 m/s the façade can operate; if the wind is stronger than 12 m/s the façade will automatically close and pretension will be applied by pre-stressing the weak edge accordingly to increasing wind loads.

3.2.2 Details

The 13-metre-long louvers consist of an **isotropic laminate** with a thickness of about 9mm (*type 1*), they are stiffened at both longitudinal edges with a 200mm rib and a 30mm rib (*type 2*) respectively.A hard rubber buffer bar protects the GFRP laminate, when the façade is closed and one louver rests on the other.

The connection detail between GFRP louver and actuator is realized by means of an **inlay**, fabricated out of steel sheets and steel sleeves, laminated in tapered parts of the louver.

Figure 41: Vertical Section

References

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