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Fog Collection and Sustainable Architecture in Atacama Coast

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Abstract

It seems imperative to integrate renewable energy and climatic design in zero-carbon buildings in arid lands by employing natural and social science-based innovation applied in natural or built environs. The aim of this initial study is twofold: On one hand, to establish general climatic design codes for potential fog collection in different scales and, on another hand, augment rate and yield of fog collection used for drinking and irrigation in natural and urban areas.

The purpose is to integrate zero-carbon design in sustainable landscape and architecture and thus envision potential inhabitation through autonomous space-frame configurations along the coast of Tarapacá Region in Chile. In a sequential way, this study distinguishes three scales of interventions: territorial, local and domestic.

This research integrates climatic, structural and constructional factors by employing agile space-frame fogtraps; implementing appropriate low-passive energy technologies and combining hydrophobic and shading fabrics. Design is upgrading the following aspects:
1. Increasing rate and yield of advection fog by taking into account harvesting rate and climatic parameters
2. Structural reinforcement of fog collectors through lightweight, modular and deployable polygonal space-frames
3. Reducing installation and maintenance of fog collection (material research)
4. Purification of drinking water due to concentrations of pollutants
5. Lowering frame impacts on ground and surrounding mainly in *lomas*
The survey methods consist of literature review; fieldwork; comparative analysis of existing fog collection's techniques and climatic design simulations.

1. The cost of Atacama desert: a hyro-eolic lab

It is well-know that the phenomenon of desertification is caused by both climate change and the manned actions (United Nations Environment Programme). In the case of Chile, the land degradation of arid, semi-arid and dry sub-humid areas is the result of two main variables: El Niño's climatic performance and massive mining activities along the Andes Range, which require large amount of surface and subterranean water resources by extracting, processing and transporting minerals.

Parts of Atacama Desert have not reported a drop of rain since recordkeeping began. Somehow, more than a million people squeeze life from this parched land.

Stretching 1000 kilometres from Peru's southern border into northern Chile, the Atacama Desert rises from a thin coastal shelf to the *'pampas'*[1]. There are sterile, intimidating stretches where rain has never been measured. Without moisture, nothing rots. Everything turns into perpetual. Settlements are established into coastal cities, mining complexes, fishing villages, and oasis towns. Along much of the coast of northern Chile, rainfall is so scarce that remote communities long had to import water by trucks, a quite expensive and inefficient supply process, in order to survive. In the Atacama's coastline, a dense fog known as *'Camanchaca'* is abundant. Despite its aridity, the Atacama Desert hosts an impressive variety of plant life. The fog feeds flora called *'lomas'*, isolated islands of vegetation that can contain a wide variety of species, from cactuses to ferns.

[1] Lifeless plains that dip down to river gorges layered with mineral sediments from the Andes.

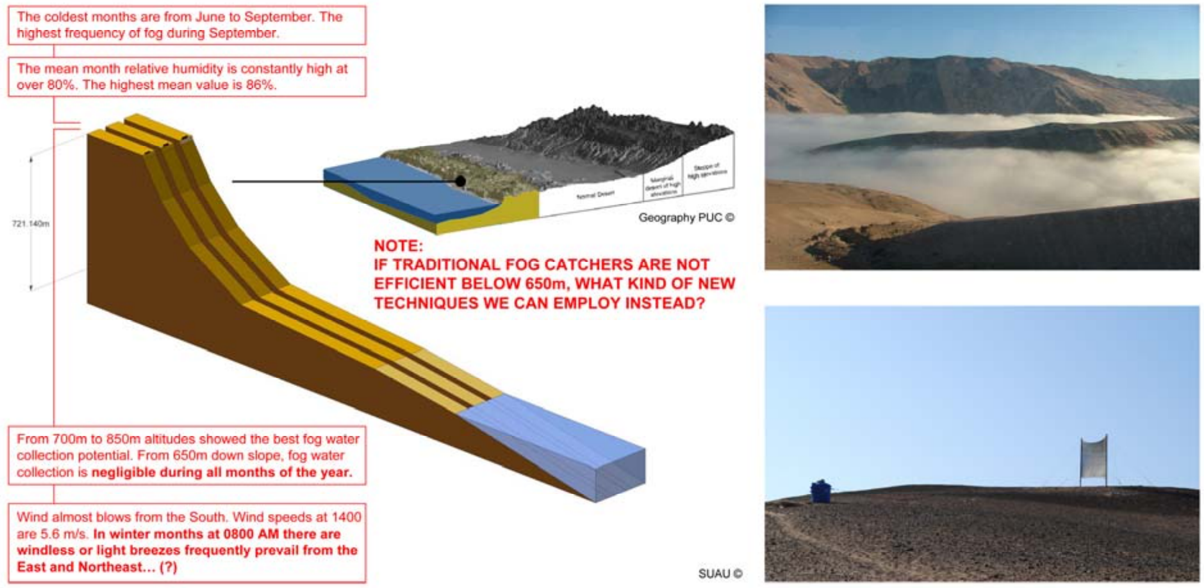

Figure 1. Atacama Desert and its 'Camanchaca' phenomenon: Section and views of the cliff facing S-SW winds in the fog oasis of Alto Patache. Source: Suau.

According to environmentalist and activist groups about 34% of the Atacama's total land surface is affected by this dehydration process. With no rainfall, the depletion and pollution of freshwater sources, and the existing pressures of urban population densities in the port cities, the current administration seems bland in the attempt to mitigate and trim down the precious water exploitation caused by the mining sector.

Demographic data shows how rural settlements are shrinking or simply depopulating and emigrating to port cities such as Antofagasta or Iquique. So it is urgent to map an atlas that shows how this territory is at risk by exposing current water resources; the shrinkage of rural settlements and degradation of fertile hectares used for agriculture.

Water scarcity intrudes just as harmfully on communities less accustomed to managing with freshwater shortages: from the high valleys of the mountains to coastal hillside of slums. As result this fragile ecological linkage is experiencing the loss of regional biodiversity. Demographic data shows how rural settlements are shrinking or simply depopulating and emigrating to port cities such as Antofagasta or Iquique.

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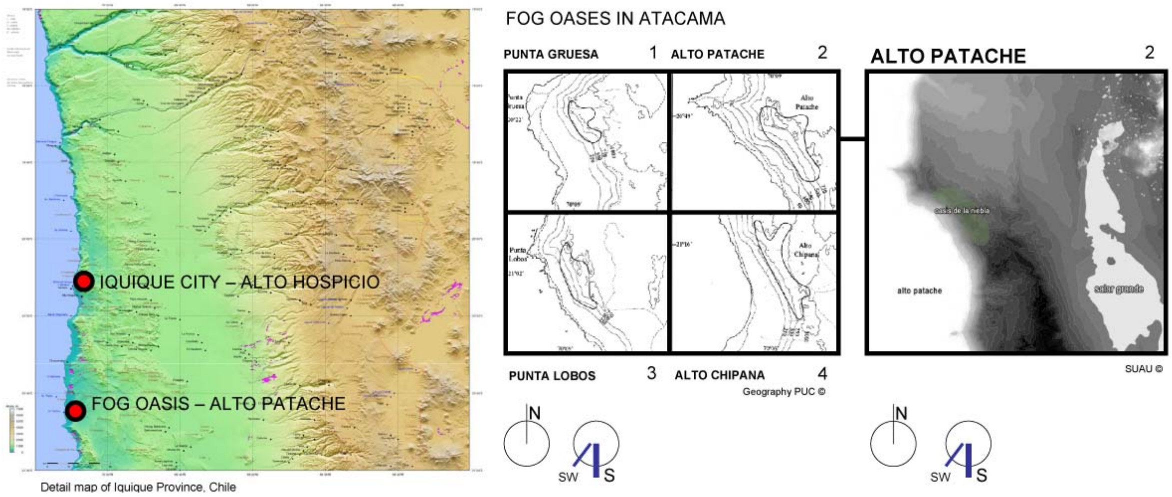

Figure 2. Map of coastal fog oases in the Region of Tarapaca, Chile: Alto Patache and Cerro Guanaco (nearby Alto Hospicio, Iquique). Source: Suau, 2010.

2. Research by design

It is imperative to integrate energy and climate into architecture by providing a more effective and holistic management of renewable energy like solar, wind and water supplies, particularly when it is reinforced by science-based innovation in the landscape, urban and domestic scale. This study is determined as much by climatic, geographic and biological factors as by any alternative for appropriate technologies. The main aim is stopping desertification by repairing endangered fog oases ecosystems; harvesting water for drinking and irrigation and fostering potential inhabitation in self-sufficient polyhedral configurations along the coast of the Tarapacá Region, Chile. Due to existing winds we also can obtain regular wind-based electricity.

Decades of pioneer applied research developed by *University del Norte* (1957) and recently continued by the *Centro del Desierto de Atacama* (CDA) have demonstrated that some of the most influential responses to these scarcities have been mounted at the level of fog oasis, farming fields, local villages and impoverished neighbourhoods.

The initial research stage (2010) has critically revised the studies made by the hydrologist Christiaan Gischler[2] and three-dimensional fogtrap prototypes (so called macro-diamonds) developed by Carlos Espinosa and Ricardo Zuleta in Camanchaca laboratory. Based on these precedents, this survey updated and collected climatic and geographic data provided by CDA combining meeting with experts and fieldwork in two fog oases: Alto Patache and Cerro Guanaco. Both are unique natural environments, nevertheless the latter is close by an urban settlement and it is more vulnerable.

The final stage was to elaborate standard design codes for 3D fog catchers and integrate the principles of polyvalence in each design. To achieve fog collectors' shape, frame and components I took into account three main climatic factors: Wind (direction and speed), humidity and temperature. Parametric design was used to test various solutions of water collection in different scales, from landscape to domestic ones.

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[2] Gischler, C. *The Missing Link in a Production Chain*. 1991, UNESCO/ROSTLAC, Montevideo

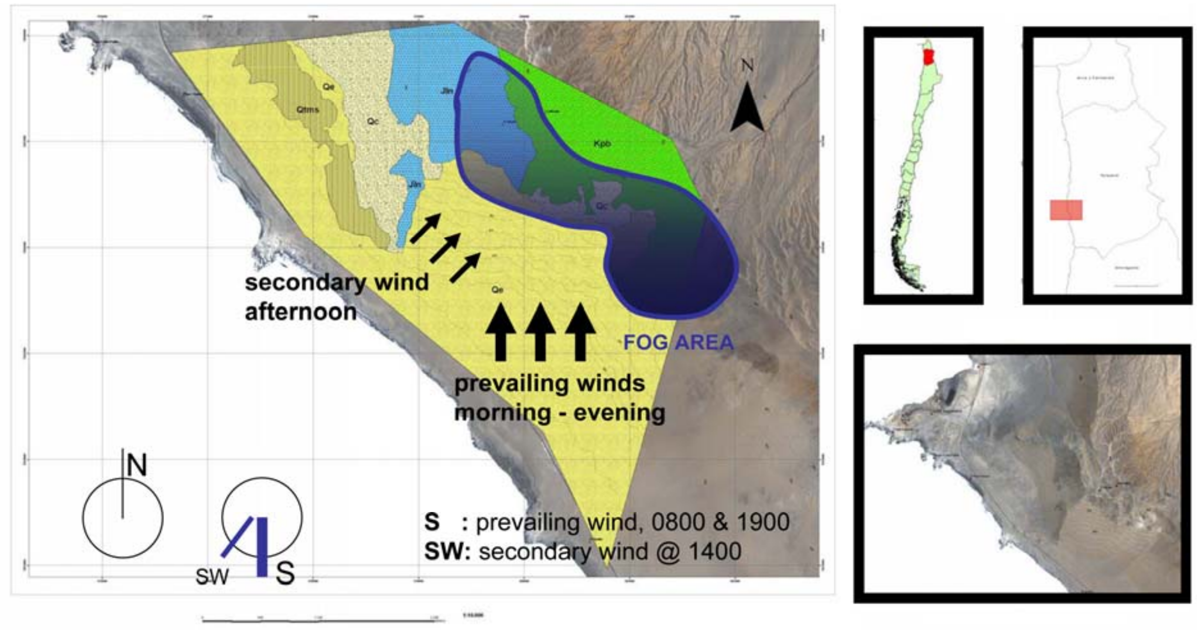

Figure 3. Geological map of Alto Patache overlapped by the fog area along the ridge. Source: Suau.

3. A glance about two-dimensional fogtraps

The more fog, the more wind. Fog catchers are structurally fragile devices. Nets tear, pipes leak, and wind can blow the whole structure over. Metal frames and tensors normally corrode and birds attack nets in joining areas ruining the process of fog trapping.

The conventional fog collectors[3] utilised in Chile are two-dimensional tensile devices waving delicately on the tops of coastal arid cliffs. These structures are long and light nets mostly made with polypropylene, glistening with moisture, transforming fog into precious water for reforestation, cultivation fields or small communities on the slopes below. Fog collection deals with horizontal precipitation. It actually imitates the missing link of trees. Once trees grow, they serve as natural fog catchers. A forest in a waterless area can trap and drip as much water into the dry soil as any idyllic rainfall.

These nets stand perpendicular to the prevailing wind, which blows fog into the woven plastic mesh. From there, droplets group and then fall into gutters that carry the water to collection tanks. The collector itself is completely passive, and the water is conveyed to the storage system by gravity. If topographic conditions are favourable, the stored water can also be conveyed by gravity to the point of use. The storage and distribution system usually consists of a plastic channel or PVC pipe approximately 110 mm in diameter which can be connected water hose for conveyance to the storage site/point of use. Storage is usually in a closed cistern. Chlorination of storage tanks may be necessary if the water is used for drinking purposes.

Nevertheless there are some technical aspects that need to be upgraded:

- The current technology represents a significant risk investment unless a pilot project is first carried out to quantify the potential rate and yield that can be anticipated from the fog harvesting rate and the periodicity of the fog within the area.

[3] The fog catchers are plastic (nylon or polypropylene) nets, measuring 30 M2 average. They catch the water, which condenses and is collected in tanks (with a capacity of about 18000 litres each) or earthen basin with a capacity of about 65000 litres. You require fine mesh netting facing the prevailing damp wind, so water is condensed on its filaments (1 mm wide and 0.1 mm thick, in a triangular weave); then collect in troughs and drain to where it is needed.

- Community participation in the process of developing and operating these technologies to reduce installation, operating and maintenance costs.
- If the harvesting area is not close to the points of use, the installation of the pipeline needed can be very pricey, especially in abrupt areas.
- The technology is very sensitive to changes in climatic conditions, which could affect the water content and frequency of occurrence of fogs. A backup water supply to be employed during low-harvest periods is recommended.

In Chile fog water has failed to meet drinking water quality standards because of concentrations of chlorine, nitrate, and some minerals derived from mining sector. It is mostly used for horticulture and forestry.

4. Design factors for fogtraps in Atacama desert

It is well-know that the occurrence of fogs can be assessed from reports compiled by climatic stations (i.e.: airports, research units, etc). To be successful, this technology should be located in areas where favourable climatic conditions exist such as fog oases along Atacama coast. Since fogs are carried to the harvesting site by winds, the topographic shape and orientation towards prevailing winds; solar position and wind speeds/directions will be prominent in determining the success of fog collectors. Nevertheless, in order to increase the yield and harvesting of water collection, we have to augment the size and material properties of nets (colours, patterns, filaments types and hydrophobic features). The study highlights several factors we should be considered in selecting an appropriate site for fog harvesting in Atacama coast:

Wind speed and velocity
The high-pressure area in the eastern part of the South Pacific Ocean produces onshore, southwest winds in northern Chile for most of the year. Prevailing/secondary winds (S-SW) are ideal for advent fog collection. Wind almost blows from the South. Wind speeds at 14.00pm rose 5.6 m/s. In winter months at 08.00am is windless or with light breezes below 2m/s in April.

Air temperature and fog water content
The higher is the formation the lower is the air temperature. In the coast of Tarapacá Region, the cooler months are from May to October. Hot seasons are from November to March [4]. For instance, in Alto Patache the high average temperature reaches 18C and the low temperature reaches roses 9.9C; daily temperature lap is 7.7 C. The highest frequency of fog condensation occurs during September. There is a relationship between temperature and fog collecting: The cooler is the mesh surface, the more water is collected.

Relative humidity
The higher is the formation the high is the relative humidity. The mean month relative humidity is constantly high at over 80%. The highest mean value is 86% in hot season (July).

Topography
It is necessary to have sufficient topographic relief to intercept the fogs/clouds; in terms of continental scale, it includes the coastal cliffs of Atacama Desert, and, in a local scale, isolated high obstacles or coastal lomas.

Relief in the surrounding areas
It is imperative that there be no major blockage to the wind within a few kilometres upwind of the site (i.e.: Alto Patache and Cerro Guanaco). In arid coastal regions, the presence of an inland depression or basin that heats up during the day can be advantageous, as the localized low pressure area thus created can enhance the sea breeze and increase the wind speed at which marine cloud decks flow over the collection devices.

Altitude
The breadth of the stratocumulus clouds and the height of their bases vary with location. As a rule of thumb, a desirable altitude is at two-thirds of the cloud thickness above the base. This portion of the cloud will normally have the highest liquid water content. In Atacama coast, the best fog water collection potential favourable altitudes range from 700m to 850m above sea level. From 700m to 850m altitudes showed the best fog water collection potential. From 650m down slope, fog water collection is negligible during all months of the year.

[4] Data extracted from Project FONDECYT 1971248, published by Pablo Osses et al., PUC, Chile (1998)

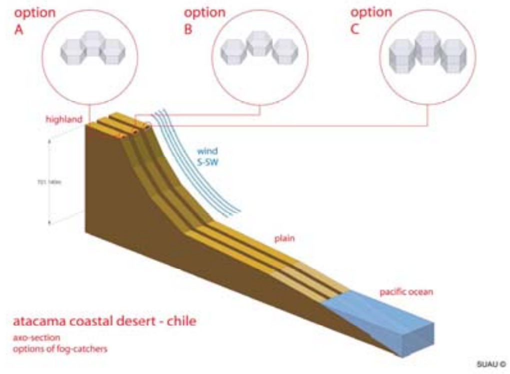

Figure 4. FogHive©, options of three-dimensional fog collector's arrays in the fog oasis of Alto Patache. Option1: Attached; option 2: detached; and option 3: stacked. Source: Suau.

Orientation of the topographic features:
It is vital that the longitudinal axis of the formations be perpendicular to the direction of the dominant winds that convey the clouds from the ocean. The advent clouds flow over the ridge lines and pass through, often dissipating onto the downwind side.

Distance from the coastline
There are many high-elevated coastal formations with frequent fog covered by transport of upwind advent or orographic clouds. In both cases, the distance to the coastline is irrelevant. However, highlands nearby the coastline are generally preferred sites for fog harvesting.

Length/height ratio and spacing between collectors
The best length/height ratio of any fog collectors is 1:1 or 1:2 (as proportional dimensions)[5]. If we do increases the length, it diminished its relative yield. Ridge lines and the upwind edges of flat-topped formations are high-quality fog harvesting zones. When long fog water collectors are installed, these should be placed at intervals of at least 5.00m to allow airflows in-between.

Crestline and upwind locations
Slightly lower-altitude upwind locations are as acceptable as constant-altitude locations on a flat terrain. But locations behind a front ridge or hill, especially where the wind is flowing down slope, should be avoided.

[5] Gischler, C. *The Missing Link in a Production Chain*. 1991, UNESCO/ROSTLAC, Montevideo. Fig 24, p28

5. Design factors for polyhedral fogtraps: FogHive©

The earth sciences taught that due to the occurrence of water in three phases: gas, liquid and solid, solar energy keeps the hydrological cycle going, shaping the earth surface while regulating the climate and thus allowing smart technologies to interfere in the natural process by rerouting water and employing its yield for natural and human environments' subsistence. This is the case of traditional fog collectors implemented along the Atacama coast through vertical tensile mesh or macro-diamonds structures.

Nevertheless, these basic prototypes require urgently to be upgraded, mainly through new shapes, fabrics and frameworks' types by following the principles of lightness, transformability, portability and polyvalence.

So it is necessary to establish new design alternatives. Not just alternative forms but also alternative sites, fabrics, and arrays. So this study questions how this varies as we vary the alternative forms and so on. These alternatives are variables under our control; there are other variables affecting deposition rate over which we have no control. These include wind speed, air temperature, and humidity. There are several routes to understanding the relationship between the variables. One is based on experience from tradition, which might be able to affirm which materials work well in which specific locations. Another one is through experiments that researchers have done and yielded empirical relationships, such as between wind speed, fog density, and deposition rates.

For instance, canvas in a conventional fog collector contains too much stressed at each joints and as result it becomes vulnerable. So this initial research has explored the relative yield in parallel flat planes with polyhedral systems with hexagonal footprint, and then few large cases with lots of smaller ones by optimizing fabric area and selecting alternative types.

In order to increase yield of collected fog water, this study has searched for suitable natural and semi-urban placements that contain high rates of fog's accumulation: Alto Patache and Cerro

Guanaco. As important as the chosen sites is also the building and structural reliability of these collectors that will be installed. Both frames and skins have to provide an optimal shape that can deal with dynamic wind directions and be resistant against high speed and rust. Its fabric necessitates increasing its hydrophobic condition, being elastic and containing lighter colours (high emittance) to ease dripping/drainage and thus avoid ultra-violet deterioration. In addition, structural supports should be well-embraced and lightweight too.

FogHive© (Suau) explores climatic design parameters combined with the agile structural principles of Tensegrity and Geodesic widely developed by Bucky Fuller and Frei Otto. The design methods mainly consisted of literature review; fieldwork; comparative analysis of existing fog collection's techniques and climatic design simulations. FogHive© is a lightweight, polyvalent and modular space-frame, fully wrapped with a light hydrophobic mesh, which can collect water fog. It also performs like a shading/cooling device and a soil humidifier for greenery and potential inhabitation. Being a transformable construction, it can easily be installed on flatten or uneven grounds. Its footprint is hexagonal.

Regarding the scale of intervention, FogHive© unit varies its dimensions. Landscape model has 12m side; local model 9m side and domestic model has 6m side.

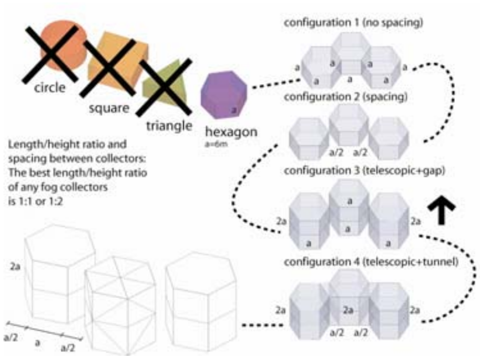

Figure 5. The hexagonal footprint seems the most efficient way to response climatically to shading and fog water capture aspects. It secures the best length/height ratio for 3D fog collectors, which is 1:1 or 1:2 (proportional dimensions). Source: Suau.

A. Territorial scale model:
It is a large polyhedral telescopic fog catchers (hexagonal footprint, side equal 12m) aligned in strategic sides of natural creeks or valleys, which will impede desertification in rural settlement or natural landscapes. Those devices bring micro-agriculture back and repair fragile ecosystems (native flora and fauna) by harvesting and distributing mainly crop water. Study area: Fog oasis in Tarapacá Region. The strategic allocation of fog collectors can not only bring local agriculture back and decrease rural emigration but also repair existing fragile ecosystems in several fog oases by harvesting and distributing mainly crop water.

B. Local scale model:
It is a mid-size polyhedral standing alone fog catcher (hexagonal footprint, side equal 9m) to supply both water and electricity to small communities (sustainable micro-agriculture and rural electrification) in natural and urban environments. Study area: Cerro Guanaco – Alto Hospicio. This space-frame fog collector can be allocated in Cerro Guanaco, a fog oasis nearby Alto Patache, a low-income sprawl. It can provide water and electricity to small communities through forestation, sustainable micro-agriculture and electrification.

C. Domestic scale model:
It is an autonomous small polyhedral space-frame (hexagonal footprint, side equal 6m) manufactured with timber, galvanised steel or carbon fibre. This inhabitable unit is modular, deployable and lightweight; with an adjustable textile system that perform as water-repellent skins when it faces South and SW winds and shading fabrics (mainly roof and North–NE-NW sides); plus blades plugged in the base frame. Water collector, filtering (purification) and irrigation network consider available materials and techniques.

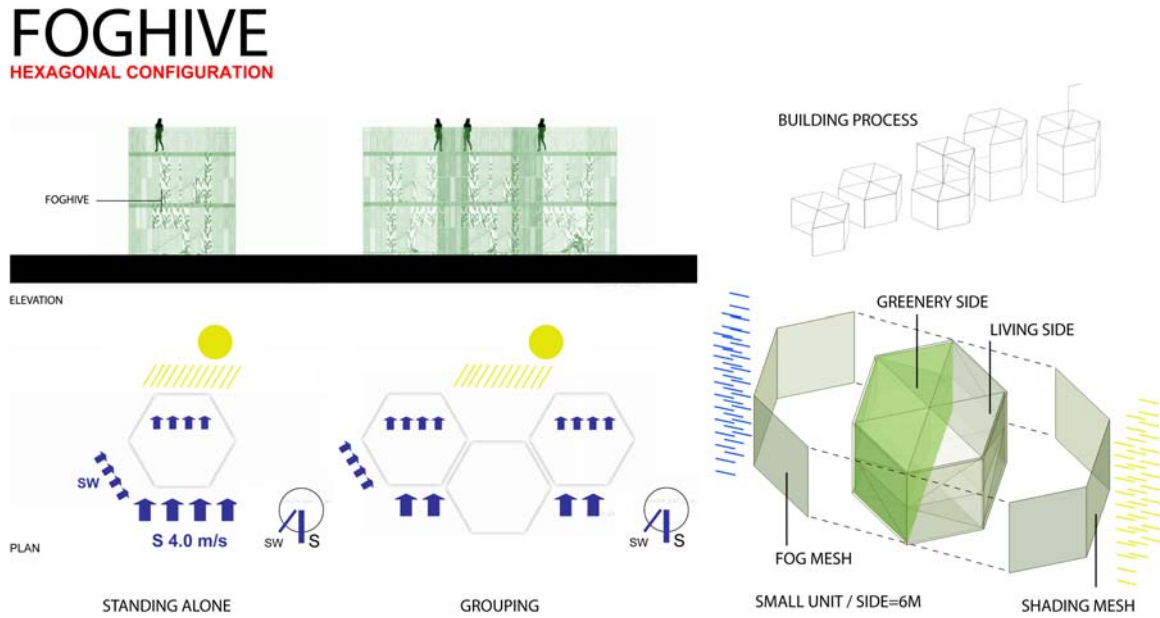

Figure 6. Plan, elevation and axonometric model of FogHive©, domestic version. Source: Suau.

Perhaps the most revealing aspect of FogHive© is that it can be also understood as a polyvalent measurement device. Prior to implementing any prototype, a pilot-scale assessment of the water fog collection; humidity and shading systems should be undertaken. It cannot replace the role of CDA neblinometers [6]. However it should be equipped with an anemometer to measure wind speed and a vane to measure wind direction. FogHive© can be connected to a data logger.

6. New questions

Despite the fact that technology meets the requirement for small volumes of water, future development work should be directed toward increasing the yield from the harvesters for small, intermediate and large applications. In particular, if this goal is to be achieved, studies need to be aimed at design levels that might increase the flows of fog towards the collection area. In addition, it is important to bear in mind that, while the technology has proved satisfactory, its successful implementation depends on the existence of the correct intersection of geographical and meteorological conditions.

Thus, a rigorous study of meteorological parameters must precede any further proposed application of polyhedral systems, not only to determine if the correct combination of geographic and climatic conditions exists but also to contribute to the understanding the complexity of these factors so that their occurrence may be predicted properly. When needed a socio-cultural development project should also be conducted at the same time to ensure that an appropriate organization exists to manage the system in an appropriate and efficient manner.

We need to be able to make some quite simple judgements of the kind that you are interested in, such as the form of the catchers. The more than we know, the more challenging are the possibilities than we can explore. What climatic factors we need to ask for, or what properties of cloth we need to study, cannot be answered confidently until we understand in-depth geographic and climatic parameters.

[6] This tool has been developed at the Catholic University of Chile (Carvajal, 1982). There are four different types of neblinometers: (a) a pluviograph with a perforated cylinder; (b) a cylinder with a nylon mesh screen; (c) multiple mesh screens made of nylon or polypropylene mesh; and (d) a single mesh screen made of nylon or polypropylene mesh. The devices capture water droplets present in the fog on nylon filaments that are mounted in a metal frame. It is a fixed device only facing prevailing winds and cannot response dynamically to daily wind changes.

Figure 7. Outer view of FogHive© array situated along the ridge. Source: Suau.

In terms of climatic issues, we would know more about the timing and nature of the fog events. There are not climatic stations in our chosen sites. The existing data is primarily averages, either aggregates of several events or averaged over a long period. If it is known that the current fog water efficiency of two dimensional fogtrap is low, then there is scope for improvement. According to the literature review we require more dynamic climatic data to understand the *Camanchaca* phenomena to exploit it. Hence the suggestion of a time lapse film ideally attached with accurate atmospheric measurement might help well. This study still have to establish the efficiency of the capture; e.g. of the total latent water in the air, how much can be extracted. That would give us an idea of how far the FogHive© concept could be pushed. One way to establish this is to measure the total water content of the air during any fog episode so-called total water content (TWC), expressed in g/m3. One simple method to do this is from a measure of visibility: The denser the fog, the greater the water. Based on the initial research of hydrophobic fabrics, we still have to explore about the size (or range of sizes) of the droplets. It could be useful in deciding on the mechanisms for fog capture, and so inform on the size of net filaments, level of porosity, etc.

The polyhedral structures' meshes not just respond to fog catching collection but also allow the potential inhabitation for endangered local flora and fauna or mini-agriculture due to they are performs like shading spaces or *umbraculos*. The modules also allow the possibility for temporary or transient accommodation at the collection sites; for instance, maintenance workers, water "harvesters", farmers or even eco-tourists.

There is a regional concern over the issue of collecting and concentrating atmospheric pollutants into the soil when untreated water is used for irrigation. There might also be concern over the impact of different net types and its durability due to birds' intrusion searching for water.

What we can play instead? There is a scientific collaborative agreement between CDA and WSA (June 2010) and we are searching for international funding to develop the advanced stage of FogHive©.

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References

Atlas del Agua by Pietro Laureano, UNESCO, LAIA editors, Barcelona, 2001

Water: Our Thirsty World, National Geographic Magazine (special issue), Voume 210, No. 4, 2010

The Missing Link in a Production Chain by C. Gischler, UNESCO/ROSTLAC, Montevideo, 1991

The Climate of the Coast and Fog Zone in the Atacama Desert of Tarapacá Region, Chile, Atmospheric Research, Volume 67, Nº 3-4, pp 301-311, 2008

The Spatial and Temporal Variability of Fog and Its Relation to Fog Oases in The Atacama Desert, Chile by P. Cereceda, Larraín H., Osses P., Farías M. and Egaña I. Atmospheric Research, 2007

Advective, Orographic and Radiation Fog in the Tarapacá Region, Chile by Cereceda, P.; Osses, P.; Larraín, H.; Lázaro, P.; Pinto, R. and Schemenauer, R.S. Atmospheric Research, Elsevier Science Volume 64, pp 261-271, 2002

Los Atrapanieblas, Tecnología Alternativa para el Desarrollo Rural by P. Cereceda. Revista Medio Ambiente y Desarrollo, CIPMA, Vol. XVI – Nº 4: 51-56. Chile. 2000

Human Occupation and Resources in a Fog-covered Site in Alto Patache (South of Iquique, Northern Chile) by Larraín, H.; Cereceda, P.; Schemenauer, R.S.; Osses, P.; Lázaro, P. and Ugarte, A. Proceedings of the First International Conference on Fog and Fog Collection, Vancouver, Canada, pp 217-220, July 1998

Camanchaca as a Potential Renewable Water Resource for Vegetation and Coastal Springs along the Pacific in South America by Gischler, C., Cairo, Egypt, UNESCO/ROSTAS, 1977.

LINKS (accessed in 05/07/2010)

http://ngm.nationalgeographic.com/ngm/0308/feature3/#know

http://www.fogquest.org/

http://www.uc.cl/geografia/cda/

http://www.oas.org/dsd/policy_series/5_eng.pdf

http://www.idrc.ca/index_en.html

http://www.fogharvesting.com/

http://www.inhabitat.com/2007/04/16/watair-turning-air-into-water/

http://www.wateraid.org/