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Extreme Cold Conditions Architecture

An Antarctica's shelter prototype

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Abstract. Nowadays, when performing expeditions to the most remote places in Antarctica, scientists typically use tents as shelters. These tents, albeit being very portable and easy to assemble, lack the structural stability to withstand the harsh conditions of the Antarctic environment. Therefore, this paper pursues to conceive a novel shelter prototype that, more adequately, protects and lodges the researchers in their scientific missions in this icy continent, all the while maintaining a focus on portability and sustainability. In a first stage, some facts about the Antarctic continent are presented, likewise its significance to Science and our species. Secondly, a mobile base, inspired by a yurt, conceived within the framework of POLAR LODGE (a subproject of the Portuguese Polar Program), is analysed. The paper then focuses on a brief review on aerodynamics, seeking to comprehend the interaction of shapes and air flow, so that the design performance requirements related to strong winds are better understood. Finally, in a second stage, based on the previous researches, two different paradigms of a portable base are exposed and the final prototype is conceived and presented alongside a brief discussion of its constitution, assembly methods, materials and techniques.

Keywords. *Aerodynamic; Antarctica; Detachable-Structure; Module; Sustainability.*

Introduction

Nowadays, when performing expeditions to the most remote places in Antarctica, scientists typically use tents as shelters. These tents, albeit being very portable and easy to assemble, lack the structural stability to withstand the harsh conditions of the Antarctic environment, namely very strong and unpredictable winds.

This paper seeks to contribute to find solutions for the lodging of researchers in their cold environment expeditions, particularly in the Antarctica continent, by developing a sustainable, wind-resistant and detachable module. This novel module finds inspirations in the project POLAR LODGE [4] and in a brief review of the basic principles of aerodynamics. The work was accomplished by means of 3D modelling.

The work is divided in five main topics. The first topic presents a brief summary about the main characteristics and importance of Antarctica continent. Secondly, the POLAR LODGE project is introduced; this project produced and installed in Antarctica a lodging module inspired in the Mongol nomad lodge - the yurt. The third topic is a brief review on the basics principles of aerodynamics; this was motivated by the POLAR LODGE project reported experience on the difficulties to withstand the very hard Antarctica's wind conditions and the need to search for a streamlined shape. The fourth topic presents two different paradigms for a novel model. Finally the fifth topic introduces the final novel module, detailing its morphology, materials and structure.

Antarctica

The name Antarctica originates from the opposition to the Artic [6].

Antarctica is the southernmost continent on our planet and almost its entire surface is covered by ice. Due to its location, this region is one of the most extreme places on Earth. The average temperature in the inner region of the continent varies between -40 °C to -70 °C in Winter and -20 °C to -35 °C in Summer. In regards to the Antarctica's costal edge the temperature varies between -20 °C to -30 °C and 0 °C respectively. Wind is a constant in the icy continent and wind conditions are often. The wind is harsh and unpredictable [6].

The continent has an extreme importance for Science, albeit the harsh conditions. In this icy place, the researchers can study the past changes in Earth's climate by extracting ice cores from the ice sheets [7]. Antarctica has also a great significance in an astronomic level. This region, especially the lakes beneath the glaciers, emulates the Jupiter and Saturn's moons features. Similarly, the dry and cold atmosphere creates some of the best conditions in our planet for observing the space [8].

In what regards our planet, Antarctica has also an important feature of regulating the Earth's climate, namely the temperature, humidity, atmospheric pressure and wind patterns due to the Antarctic Circumpolar Current [9].

The Antarctica continent incorporates a vast spectrum of minerals and resources, such as coal, gold, iron, lead, uranium and zinc [6]. Nevertheless, in what concerns human interests in near future, water might be the main resource incorporated in Antarctica. 75 % of the planet's fresh water is stored in glaciers ice [10]. Antarctica continent embodies 90 % of the total glacier ice [6], representing approximately 70 % of all the fresh water in our planet.

Even though being a pristine region, this continent suffers as well from the human impact especially from the global warming. This impact is expressed by the ice shelf collapsing and defrosting [11].

Yurt Project, POLAR LODGE

This project, within the framework of POLAR LODGE (a subproject of the Portuguese Polar Program) developed a mobile, resistant and comfortable module to lodge scientists in their expeditions to the most remote places in Antarctica. The motivation for such a module lies on the fact that, nowadays, researchers use tents for lodging [12]. These tents albeit being very portable and easy to assemble, lack the structural stability to withstand the harsh conditions of the Antarctic environment.

The prototype was inspired by the design and features of the Mongol tent - the yurt. A significant part of the module's materials is biodegradable. It consists of a base and a frame structure made with wood (chestnut), covered by wool layers, and protected by a PVC fabric, due to its impermeable features [12].

In what concerns thermal comfort conditions, the measured temperature difference between the external environment and the interior of the module was 6 °C and 8 °C when installed in Collins Glassier. These were considered as excellent conditions within the scope of a portable structure [12].

The module was capable to withstand winds of 100 to 120 km/h, which was considered average wind speeds for that region. However, due to the climate change conditions, extreme wind phenomena are now more frequent. By the end of the summer 2016, 200 km/h winds were registered. The prototype's resistance to wind load was not enough and the module was dismantled. On the other hand, the use of tents will be more and more impossible due to these winds [12].

Consequently, there is a need to develop a novel prototype with the ability to resist to high wind loads. Considering that these types of portable modules may not depend on high-strength foundations nor concrete heavy structures; the module's geometry must consider the basic principles of aerodynamics together with the prevailing wind direction.

Basic principles of aerodynamics

The objective of minimizing the consequences of high wind loads in the new architectural module requires the comprehension of how shapes interact with air flow. Therefore, a brief review on aerodynamics was carried out.

In this contest, the main feature in aerodynamics is the drag force which has an opposite direction from that of the movement of the object [13]. Aerodynamics engineering uses the drag coefficient to represent how different shapes interact with the air flow and to design streamlined geometries. The lower the drag coefficient, the more streamlined is the form. The drag coefficient is usually determined experimentally and is related to the drag equation:

$$D = Cd \cdot \frac{\rho \cdot V^2}{2} \cdot A \qquad \text{(eq. 1)}$$

where,
D: Drag [N];
Cd: Drag coefficient [-];
ρ: Air density [kg/m3];
V: Wind speed [m/s];
A: frontal area [m2].

The least drag coefficient is obtained with an airfoil section geometry (fig 1), which means that this is the shape that assures the minimum wind drag.

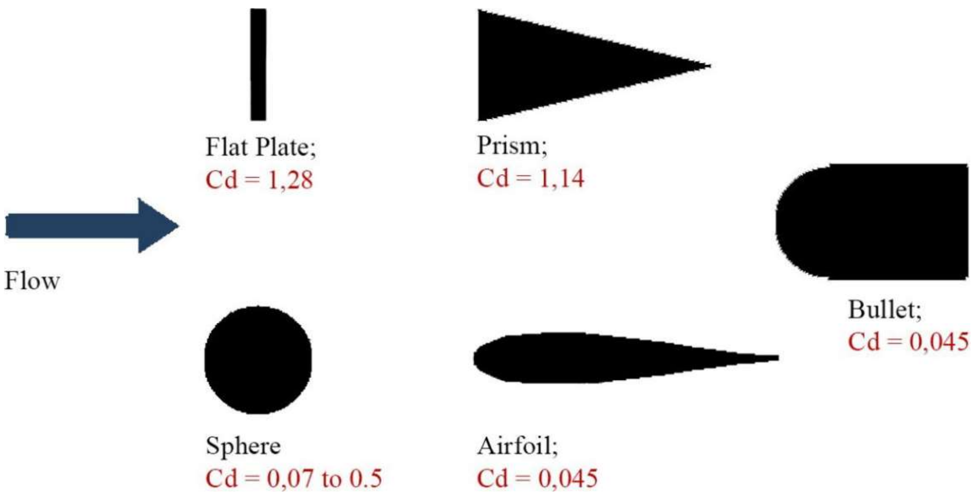

Figure 1. Drag coefficient values according to different shapes. All objects have the same frontal area. Based on: [8].

In this kind of shape (airfoil section or streamlined body or even a teardrop form) the drag force is caused by the skin friction and flow pressure. This geometry provides a gradual pressure gradient over the body [1]. This geometry also offers a delay in the separation flow (that comes from the interaction of the object and the flow) resulting in a minimum pressure drag [14]. This also decreases the turbulence in the trailing edge [3].

Different paradigms

During the development of the novel model two different paradigms of prototypes were envisaged.

The first exemplar was inspired by the Sogn Benedetg chapel's geometry, designed by the Swiss architect Peter Zumthor, inaugurated in 1988 [5]. The yurt's wooden grid structure is also added to the prototype. This geometry has similarities with the airfoil design (fig. 2).

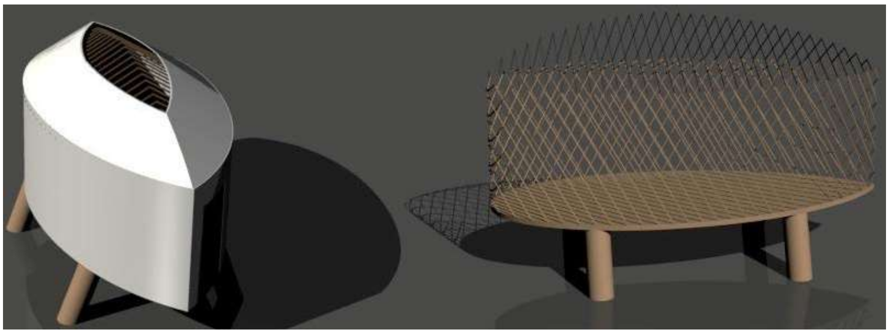

Figure 2. 3D modulation: Prototype and its grid structure similar to the yurt.

The second prototype was inspired by the musical instrument accordion. As well as the musical instrument, this prototype is capable to reduce its dimension by overlapping its parts (fig. 3). This feature is appropriate for an easy transportation. The module's structure consists in nine arches made with recycled material branded *CORETECH*. The structure is involved by mineral wool layers for thermal insulation, and it is cladded by biodegradable PVC fabric for waterproofing (fig. 4).

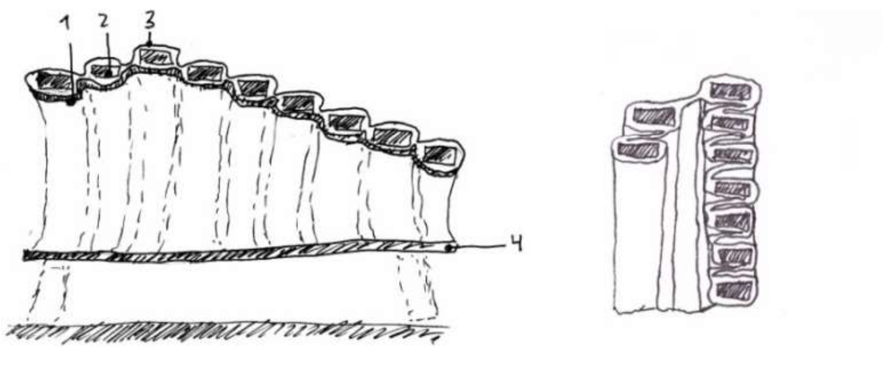

Figure 3. Right draw: Transversal section. 1- Wool layer. 2- Structure. 3- Biodegradable PVC fabric. 4- Base; Left draw: The structure's overlapping mode as the musical instrument.

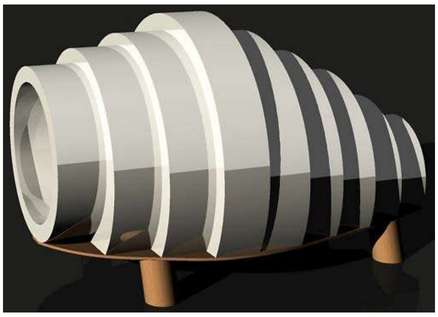

Figure 4. 3D modulation: Accordion inspired prototype.

The novel module

Constitution and materials

Four main premises formed the basis for material selection: Transportation, extreme cold, environmental impact and wind load. The difficulties in transportation arise from the fact that the final stage of the trip to Antarctica is assured by a small semi-rigid boat with a maximum load capacity of 2000 kg.

The selected materials are mineral wool, biodegradable PVC fabric, aluminum and a recycled material branded *CORETECH*. The mineral wool is the inner most material, assuring thermal insulation and complying with the need of flexibility and low weight. The biodegradable PVC fabric, used for the middle layer, is flexible, light and waterproof [15]. These materials, namely the wool and the PVC fabric were already tested in the POLAR LODGE project [4].

The aluminum is used as the outer layer protective shell. It is a light (only about a third of iron and steel's weigh), ductile and easy to mold material that ensures the appropriate superficial strength to wind loads and does not become fragile nor it corrodes due to its permanent protective layer. Furthermore, the recyclability of aluminum and its abundancy (the third most common element in Earth) [2] makes it an appropriate choice from the sustainability standpoint.

Finally, *CORETECH* was chosen as structural material. This is a recycled material, composed by grinded automobile sub products. It is waterproof, has high durability and good compressive and tensile strength within the scope of this application [16].

Design and Structure

The design process for the definition of the novel module's geometry considered the brief aerodynamic study, described above. To minimize the high wind loads, the form's design has been inspired by the airfoil section or the teardrop shape, to become a streamlined body. Besides shape, the module's final geometry also considered the minimum dimensions suitable for four researches.

To comply with the needs for easy disassemble, low weight and strength, a "waffle-like" structure was envisaged. It is defined by four longitudinal and seven transversal arches. Each type of arch is assembled concurrently to the other. Both types of arches have a maximum height (*h*) of 3 m. The larger axis has a dimension of 3.26 m and 6.32 m respectively in the transversal and longitudinal directions (fig. 5; line segments, *aa*' and *bb*'). The prototype's base is also made with the same material as the structure. The entire module will be elevated preventing the permafrost humidity.

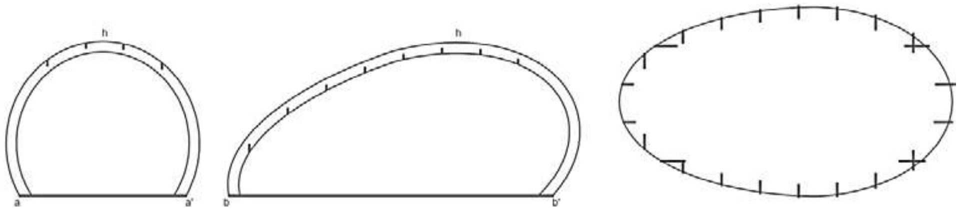

Figure 5. Structural plan: Transversal arch (left); longitudinal arch (centre); floorplan (right).

Figure 6 shows the assembled structural elements. Figure 7 illustrates the set of filling and cladding materials. The structure is involved by mineral wool layers for thermal insulation, the biodegradable PVC fabric for waterproofing and the aluminum "shell" for resistance to wandering and wind loads. The aluminum shell is divided in four sheets.

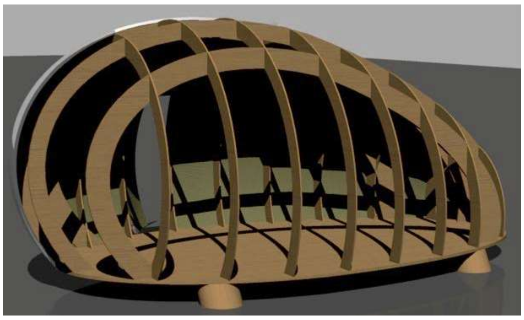

Figure 6. Final module's 3D modulation: Structural set

Figure 7. Final module's 3D modulation: Extruded aluminium plaques

The total weight of the module was estimated with the quantity of material used and the respective density. Unit and calculated values are showed in table 1

Total structural volume	m^3	0,7746
Material density	Kg/m^3	650
Total structural weight	Kg	503,09

Table 1. Unit values of the structural elements

Considering a *CORETECH* material density of 650 km/m³ the structural elements and the horizontal base have a total weight of 503,09 kg.

The drag (*D*) value of the prototype was also calculated according to equation 1 with the geometry's drag coefficient (*Cd*) [13], the air density (*ρ*) at -2 °C (average temperature in Bellingshausen), the wind speed (*V*) (maximum speed registered by the end of Summer 2016) and the module's frontal area (*A*). Units and calculated value are showed in table 2.

Drag coefficient (*Cd*)	-	0.09
Air density (□)	kg/m3	1,302
Wind seed (*V*)	m/s	55,6
Frontal area (*A*)	m2	20,7
Total drag (*D*)	N	3749,2

Table 2. Unit values to calculate the module's drag with eq. 1.

The module has a total drag of 3,7 kN or 0,18 kN/m². For comparison, in what regards a common building wind loads, the Portuguese safety value is 1,2 kN/m² or less.

Interior

Due to the streamlined body design, the internal volume has two different areas: a wider space between the wind-facing side and the middle of the floorplan and a narrowed space in the opposite side. The first is intended as a working space, while the latter as a resting and sleeping area. Total floor area is 16 m². A skylight, inspired by the Mongol's yurt, illuminates the module's interior (fig. 8 and fig 9), protected by a transparent biodegradable PVC fabric. The wool can be seen through the interior to conceive a cozy environment (fig. 9).

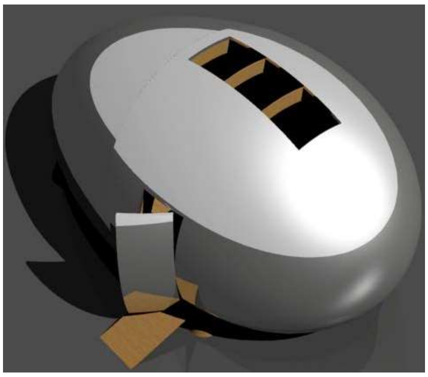

Figure 8. Final module's 3D modulation: Skylight from the exterior.

Figure 9. Final module's 3D modulation: The wool walls, the structure and the light from the skylight.

Orientation

The geometry that was defined is based on the need to minimize wind load on the surface of the module. However, this geometry is flow direction-sensitive; to minimize the wind drag, facing the module against the prevailing wind flow is crucial. Therefore, the prevailing wind direction must be ascertained. This task was carried out by analyzing local climatic data with the use of Autodesk Ecotect Analysis 2011. The climate file for Bellingshausen (-62,5; -58,9º) was used. It may be noted that there is a prevailing West-East direction (fig. 10).

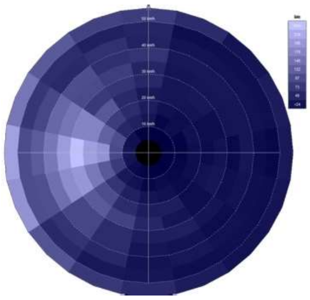

Figure 10. Dominant winds in Bellingshausen, (-62,5; -58,9º). Wind frequency (Hrs) 1st January – 31st December. 00:00-24:00h.

Territorial insertion

The aluminum moreover gives a reflective surface. The novel module can be comfortable and resistant all the while maintaining less physical impact upon this fragile territory, shown in the figure 11. The withdrawal's prototype could be prevented too, due to the detachable module's feature.

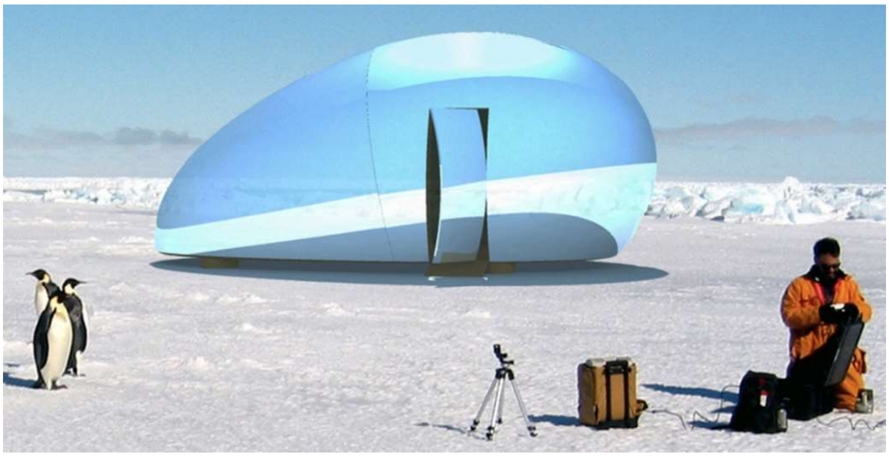

Figure 11. Final module's 3D modulation: Prototype's territorial insertion. Background photography: Ted Scambos, NSIDC.

"The future depends on what you do today" (Mahatma Gandhi, 1869-1948)

Conclusions

Among all the unique challenges involved in the development of a novel mobile module for researchers to explore and unravel the features of Antarctica, four have been identified as being crucial to the success of the project: sustainability, transportation, geometry, and structural integrity.

During the development of the module described in this paper, the PROPOLAR project proved to be a valuable case study as it had conducted on-site testing of materials, structures and inner spatiality. This led to several vital insights such as the recognition that simpler and more sustainable materials often prove to be as good as more engineered ones (as is the case with wool in relation to thermal comfort). Furthermore, it alerted us to the importance of aerodynamics in the design of a module's geometry to ensure structural integrity even in the presence of very strong winds.

Due to the icy continent's harsh and inhospitable conditions, it has remained relatively untouched by direct human contact. Therefore, any project of this kind must attempt to limit as much as possible its impact on the surrounding environment. So, in regards to the materials used in the module, an attempt was made to focus on simpler and less environmentally-impacting materials. As such, wool was chosen for the inner layer of the module due to its excellent thermal comfort, comparable to that provided by more engineered and less sustainable materials. Moreover, waterproof capabilities were achieved with biodegradable PVC fabric and aluminum was used for the outer layer protective shell due to its lightness, durability, ductility and abundancy. To comply with the needs of easy disassemble, low-weight and structural strength, a "waffle-like" structure made with a recycle material branded *CORETECH*, was envisaged with a total weight of 466 kg. This recycle and waterproof material has high durability, good compressive and tensile strength.

The structure and the modules were developed by means of 3D modelling.

As future work, firstly, a 1:5 prototype of the module described in this paper will be constructed and subject to tests in a wind tunnel to tune the geometry. Secondly, a real-scale prototype will be built to analyse and improve assembly logic. Finally, a third improved prototype will be sent to Antarctica to be tested under real conditions.

"(…) it has the right meaning which respects the ecological values of Antarctica, the shearing and an environmental respect." [12]

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