Structural Design of a Movable Modular Shelter for Extreme Wind Conditions: A Study in Collins Bay, Antarctica.

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Abstract: This paper describes structural aspects of a movable modular shelter, designed to withstand wind gusts of 200km/h in extreme cold conditions. The shelter was conceived by a mixed team of Architects and Engineers and will be used as accommodation by researchers carrying out field work in the Antarctic Peninsula. Preliminary results confirm its viability and ease of use. Considerations are made on contextual factors, such as local wind characteristics, ease of use, and structural design issues.

Keywords: Structural Design, Extreme Wind Conditions, Modular Shelter.

Introduction

The objective of the Polar Lodge Project was to design and build a sustainable, low-impact, optimized, modular lodge, to facilitate scientific studies in the Antarctic. The Design of the shelter was developed throughout 2018 by the Polar Lodge project team - a mixed team of Architects and Engineers from the Higher Technical Institute (University of Lisbon), Heriot-Watt University (UK) and the University of Bahrain (Kingdom of Bahrain).

Figure 1. The Structure of the Polar Lodge shelter, February 2019, Collins Bay, Antarctica.

An yurt-like tent was produced by July 2018, using an innovative timber and bio-composite structure and an experimental triple-skinned, lightweight envelope which combined with the structure is designed to withstand extreme high winds, and extreme cold.

This new Module, called Polar Lodge 2 (PL2), follows on from a 2016 experimental prototype, being in fact a traditional Mongolian yurt, that collapsed in 200km/h winds in the Antarctic (Guedes, 2016). In 2018 the yurt structure, form, and building materials were overall upgraded, under the supervision of Prof. Sue Roaf (Heriot-Watt University), in response to the severe weather conditions found in Antarctica during 2016.

PL2 presents a new environmental and sustainable approach to creating resilient structures for the extreme cold, combining ancient tent design with leading edge modern technologies and materials. The major drivers for the design not only included the original specification that the structure should be modular; easy to transport and fast to assemble by a small team; resistant to high winds; have minimum impact on the ecosystem; and be comfortable but the associated performance specifications were upgraded in light of experience.

1. Local Wind Characteristics

Antarctica is the coldest continent on Earth, with minimal recorded temperatures ranging from −93.2 °C to −98 °C (Vizcarra, 2018). This Continent also holds the record of the strongest winds: winds can easily reach gale force, between 100 and 200 km/h, and in places where the wind flows through narrow valleys, it can attain a speed of 90 m/s (325 km/h). There are on average 11.6 days per month when the wind exceeds 100 km/h (Bromwich, 1989).

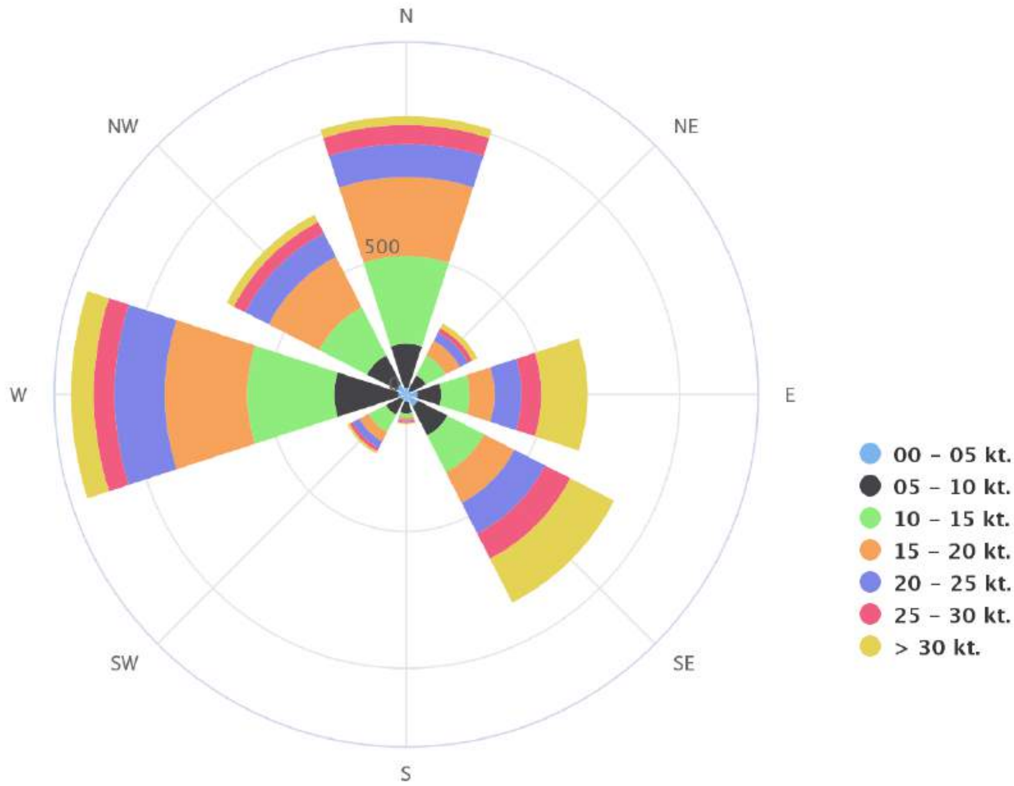

Figure 2. Wind Rose for Bellinghausen, showing the Monthly Mean values for predominant wind directions and intensity (source: Chilean Air Force Airport at King George Island) .

The continent has an EF Köppen classification of ice-cap climate, with very cold, and generally extremely dry weather (it is technically a desert, averaging 166 mm of precipitation per year). Temperatures in inland Antarctica rarely rise to 0°C even in summer.

With the exception of a few seaside areas, snow rarely melts, and, after being compressed, forms the glaciers. The continent is rarely penetrated by weather fronts, due to the effect of the katabatic winds caused by cold air sweeping down from the central plateau toward the ocean, particularly in spring and autumn.

Figures 2 and 3 show the mean values for wind speeds in different stations in the Antarctic. Figure 4 shows the results of a study measuring the frequency of storm force winds, over 180Km/h (Turner et al, 2009).

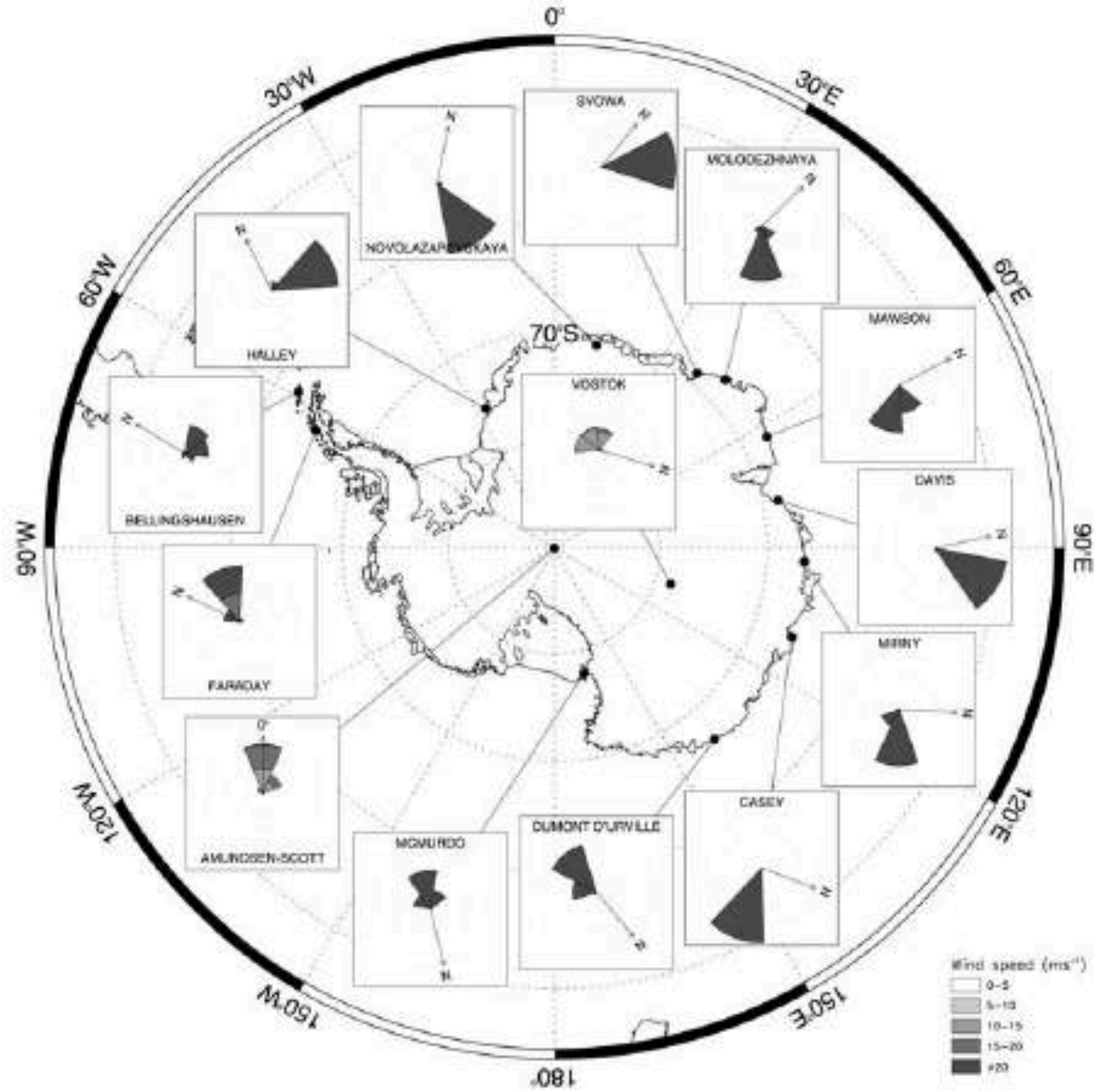

Figure 3. Wind Roses for the last 100 strongest winter wind events recorded in different Antarctic stations (source: Turner et al, 2009).

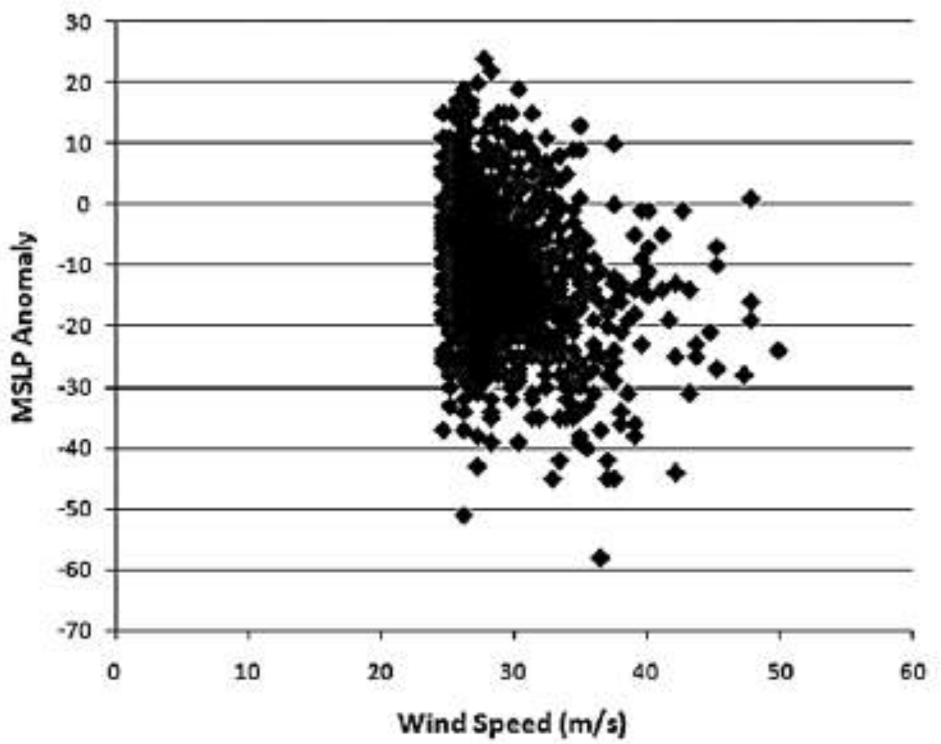

Figure 4. Scatter diagram of winter season wind speeds (m/s) of storm force or above measured at Mawson station in 2008 (source: Turner et al, 2009).

The Lodge was placed in Collins Bay, below the Bellinghausen Dome. Although Bellinhausen is not amongst the stations with the highest frequency of storm force winds (cf. figure 3), storm force winds of over 200km/h occur during winter in this location, making it adequate for this study.

2. Design Considerations

PL2 iteratively developed from the traditional yurt form erected in 2016 and was subject to a number of studies before the field trip to erect it, and considerable modification as it was being raised. Modifications included:

2.1. Structural Resistance

The structure of the Yurt-like lodge was optimised using appropriate software. Through a series of iterations, several components were redesigned in order to increase the overall robustness of the model, namely:

a) The timber ceiling ring, which was made smaller in diameter and thicker, letting the beams go across it by 3 to 5 cm. This is the most sensitive element of the structure: after an analysis of the previous model it was found that it collapsed due to the lack of resistance of the ring, which broke under extreme wind pressure, consequently bringing down the structure.
b) The overall thickness of all beams and trellises.
c) All the joints' attachments' were reinforced (ceiling ring to beams; beams to trellises), including the door's attachments.

The model comprises five parts: a circular trellis, a doorframe, a roof, a top ring and two central columns. The top of the Lodge was fixed in order to, in a simplified manner, model the steel cables that were attached at such location.

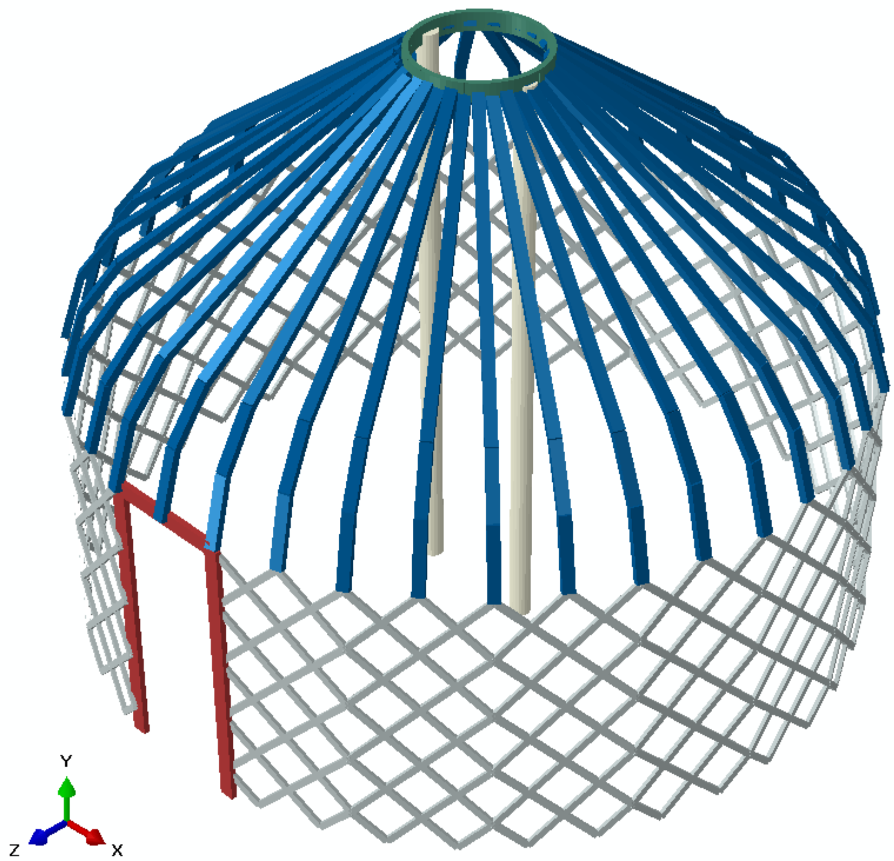

Figure 5. Overview of the numerical model

Figure 5 shows the final built result. Figures 6 to 8 show the behaviour of the final solution under different wind speeds. As the Lodge location is in a particularly wind spot, as the dominant wind is funnelled through a valley of rocks, for safety's sake simulations using a 1.5mx1.5m rock wall facing the dominant wind were also carried out. Bags to fill with rocks were brought to the site, and this wall was put up during one morning (figure 9).

The wind load was applied as equivalent forces, calculated according to EN 1991-1-4 distributed along the negative axis Z direction on the beams of the exposed side. Three wind speed values were considered: 100, 140 and 200 km/h. For these, two situations were modelled, without and with the rock wall serving as a wind breaker. The latter was considered by modeling only the forces due to suctions that arise on the faces that are not exposed to wind, but assumed redistributed by the canvas to the beams of the exposed faces.

In Figure 6 the longitudinal stresses on the Lodge beams respectively, with and without the rock wall, are shown for a wind speed of 100 km/h. The tensile and compressive maximum stresses were limited to 12 (tensile) and 20 MPa (compressive), respectively, in the color mapping. These are typical values for a good construction wood. If the stresses surpass these values, red (tensile) and blue (compressive) colors are shown in the model.

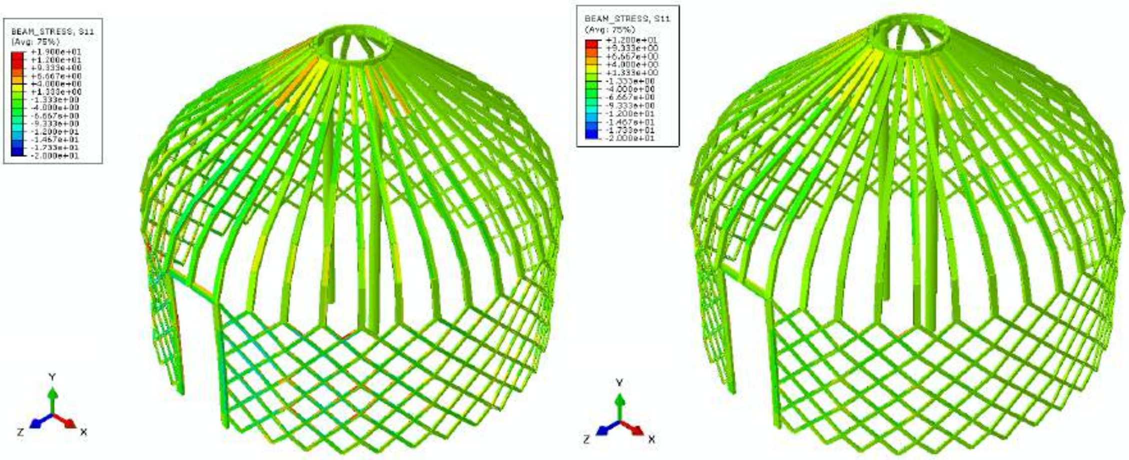

Figure 6. Longitudinal stresses on the Lodge beams - wind speed of 100 km/h. Left: without rock wall; right: with rock wall.

In Figure 7 the longitudinal stresses on the Lodge beams for a wind speed of 140 km/h, which was actually measured on site on the 24th February, and respectively, not considering and considering the rock wall are shown.

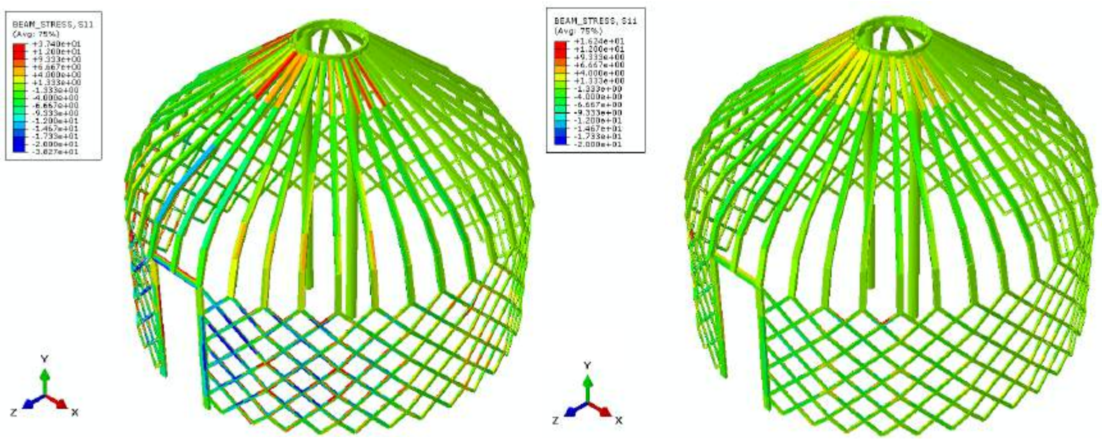

Figure 7. Longitudinal stresses on the Lodge beams - wind speed of 140 km/h, measured on site on the 24th February. Left: without rock wall; right: with rock wall.

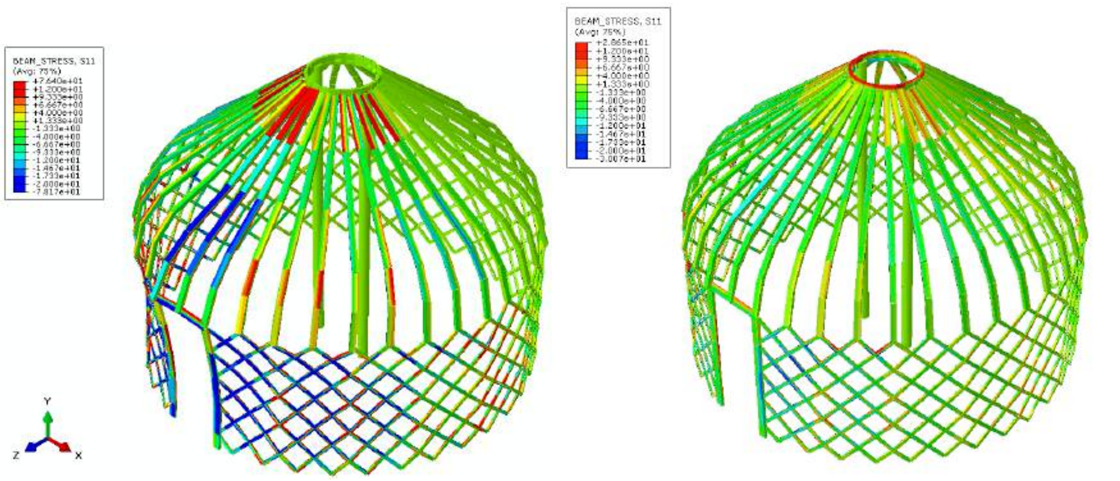

Figure 8. Longitudinal stresses on the Lodge beams - wind speed of 200 km/h. Left: without rock wall; right: with rock wall.

In Figure 8 the longitudinal stress field on the beams for a wind speed of 200 km/h and respectively, considering and not considering the rock wall are shown.

In all the scenarios considered, the main stress concentrations are, as expected, in the exposed faces of the trellis and of the roof. Regarding the former, an increase in the cross section area will increase the resistance of the Lodge trellis and the maximum values of stresses can be reduced bellow the allowable limits. Considering the latter, the placement of intermediate beams/supports connecting the mid-span of the roof beams and the vertical central columns are deemed to be able to reduce the magnitude of the stresses to about 25% of the actual value.

From the previous figures it can be concluded that the Lodge can resist wind speeds of up to circa 140 km/h, as it did in the field. However, for winds up to 200km/h this may only be achieved due to the wind breaker materialized as a rock wall in the exposed face. Bags to fill with rocks were brought to the site, and this wall was put up during one morning. Figure 9 shows the adjacent rock wall.

Figure 9. The adjacent rock wall (covered in black canvas)

Figure 10. The final result, including the 10+10 ties to the ground.

To ensure further stability, 10 ties were also placed vertically from the roof to the ground, and another 10 ties were placed over these, forming a 45º angle with the ground. Figure 10 shows the final result.

2.2. Building Materials

In order to establish future performance comparisons with the previous prototype, wood (Ash wood) was chosen as the material for the structure. Budget considerations also weighed in this decision. The optimised timber structure was made by *Yurtmaker* in Telford.

A survey was also carried out in the UK in early 2018 by Prof. Sue Roaf, in order to identify the best suitable envelope materials, in terms of durability, weather endurance, and thermal insulation capabilities.

The final decision felt upon two innovative materials for the skins: 1) a space blanket type multi-layer double skin from ORVEC of Hull, and 2) re-used Dyneema racing yacht sails for the outer coat from *Northsails* in Palma de Mallorca, Spain. The tent cloths were manufactured by the master tent makers at *Sheerspeed* in Honiton.

2.3. Ease of use

The portability and ease of assembly' objectives were accomplished: The whole Lodge fitted in a single Zodiac boat, and was transported from Escudero to a remote location in Collins Bay, within Collins glacier. It was then mounted in approximately 2 hours. The stone wall took approximately further two hours to be put up and wrapped.

3. Further Work

The lodge will be used until the end of Summer (late March) and again from November 2019 till March 2020. Feedback from users, including questionnaires, will be collected during these periods, and posted online (at extremelodge.com). This will allow a more thorough assessment of the Lodge, leading to its optimisation.

Further issues concerning the performance of the materials, structure and overall comfort will also be assessed in the next campaign.

4. **References**

5.

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