Ski Yurt: Upcycle of Downhill Skis for a Shelter in Cacine—Guinea-Bissau

Graziano Salvalai, Marco Imperadori, Marta M. Sesana and Gianluca Crippa

Abstract Downhill skis are composite materials with very high performances. Very often after few years of use, they are changed due to new fashions or ski techniques. This means a lot of waste which still has the potential for very high structural performances. Thus, the idea to upcycle these materials thanks to a cooperation with the University of Grenoble in the joint activities of their laboratory and Velux Lab. Several tests and dome structures were realized in order to show the potential of these materials. Then a yurt was designed, tested, and pre-built at the Politecnico di Milano before shipping it to Africa, through the equatorial forest in Guinea-Bissau, as a first shelter-base camp in a desolated land where a mission was later founded. The purpose is also to make a structure with very high performances and that is resistant to the aggression of termites (only hard wood is suitable there but it requires deforestation) without using steel since it is too expensive. So the final goal is not to send waste to Africa but to show how waste can also become a very solid structure and a valued asset.

Keywords Shelter architecture · Skis · Upcycling · Recycling

1 Introduction

Skiing is one of the most popular sports in the world. According to recent estimates, about one hundred million people ski regularly or occasionally. Out of the European countries, Germany has the most people skiing by far with roughly 14.6 million participating in the sport, followed by France with approximately 8.5 million and the United Kingdom with 6.3 million (www.statista.com). The main equipment consists

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on skis which, after a number of seasons tend to be disposed of because of delamination, splinters, cracks, etc., or simply because they have become obsolescent. The skis are in general constructed from high-tech materials made up by a sequence of several layers: steel plates, plastics, and resins that gives high resistance and good ductility. The material composition of the skis is particularly complex and they cannot be recycled easily by deconstruction: the making-up materials of a typical alpine ski are assembled with a sandwich structure, perfectly bonded together and hard to disassemble. An alpine ski weighs about 1.8 kg, 35% of which is represented by the angular steel blades, 20% by the wood core, 10% by the surface foil, and the remaining part (about 35%) is mostly represented by adhesives, foams, and rubber elements (Wimmer and Ostad-Ahmad-Ghoradi 2007). Regarding its disposal, the only recycled component is represented by the metal layer, while the remains are shredded and burned in incinerators contributing to the CO_2 emission. Considering the cradle to grave approach (manufacturing, distribution, use, and disposal) and the approximately 1.500 tons of skis fallen into disuse every year, ski manufacturing absorbs a substantial amount of energy. The number of most ski areas in Europe can be found in Germany, with a total of 498. There are 349 ski locations in Italy, 325 in France, and 321 in Russia. The statistics shows a large number of skis sold every year: the number of alpine ski units sold in the USA from the 2015/2016 was close to 750,000. A survey carried out in five large ski areas in northern Italy, between March and April 2014, shows the amount of ski disposals (Table 1).

The interviews involved 23 ski shops with the aims to analyze the local ski's market trend, the technical life of the skis, and the amount of the equipment disposed of. From the data collected, about 2100 skis, approximately three tons of high-tech material have been disposed of only during the winter season of 2014. In this scenario, supported also by the environmental impact analysis, reuse at the end of their life span represents an interesting opportunity. Furthermore, considering the high-performance characteristic concerning both the geometrical and the structural resistance, skis can be efficiently used as structural components in emergency shelter design. Several scientific studies concerning emergency post disaster shelters are available in literature dealing with the technological design, the adaptability, and

Table 1 Analysis of ski disposal in Lombardy (Italy)

Place (Province)	Number of ski's shop interview	Skis disposed per year
Livigno (SO)	2	900
Bormio (SO)	1	300
Ponte di Legno (BS)	3	200
Madesimo (SO)	2	200
Valle Seriana (BG)	15	500
Total	–	2100

Source Surveys carried out by the authors between March and April 2014 versatility of different solutions (Alegria Mira et al. 2014; Crawford et al. 2005; Battilana 2001; Meinhold 2014). Only few publications have focused on the reuse of recycled materials for shelter construction (Imperadori et al. 2014; Salvalai et al. 2017). The purpose of this work is to investigate the reuse of high-tech recycled materials for emergency and temporary architecture exploiting the characteristic of high technology (Daudon 2015; Jalesse et al. 2015). A temporary emergency shelter called "Ski Shelter" composed of recycled skis and covered in a lightweight envelope composed of thermal-reflective-multilayer insulation and polyvinyl chloride (PVC) sheet, has been studied, and built in real scale. The joint between skis has been tested, from the structural point of view, with experimental tests. The first tent prototype has been donated to the Missionaries Oblates of Mary Immaculate and is now operating in the Republic of Guinea-Bissau.

2 The Ski Shelter: Concept and Technology

The Ski Shelter project aims to develop a shelter prototype characterized by an easy assembly method, lightweight, and reused materials, with the capacity to maintain acceptable internal thermal comfort conditions for the user in hot and cold temperatures.

The basic design began from the archetype of the Mongolian yurt, represented by a portable, round tent covered with skins or felt and used as a dwelling by several distinct nomadic groups in the steppes of Central Asia (Fig. 1). The ski yurt prototype has been designed as a composition of a regular grid made up of: 24 concentric axes, representing the beams, and 24 pillars, which together divide the circular base. At the center of the room, a pillar composed of reused standard steel elements for building scaffolding supports the openable 80.0 × 80.0 cm skylight. Linear assembly of several skis constitutes the beams and pillars, the tips of each ski have been previously modified, according to the structural design. The skis have been assembled together to create composite beams and pillars, increasing the inertia and stability, locally and globally. The joints between skis were reinforced with wooden spacer elements (Fig. 2).

The designed geometry has a diameter of 6.0 m, which covers an area of approximately 30.0 m^2 (Fig. 3). The internal height is equal to 1.70 m at the lowest point and 3.80 m in the center of the building area. The shelter is modular and the number of units is potentially implementable according to the emergency situation requirements: the coupling of multiple Ski Yurts allows for a variation of the spaces reaching variable housing dimensions. The building envelope has been created from a textile material coupled with different resistive layers: a double PVC layer, both outside and inside, with a thermo-reflective insulation system interposed in between (Fig. 4).

The high of the pitched roof has been increased in order to maximize the "chimney effect" and improve consequently thermal comfort during summer (Fig. 5). The Ski Yurt prototype can be used as a single shelter or can be assembled into a more complex architecture by means of a modular connection space.

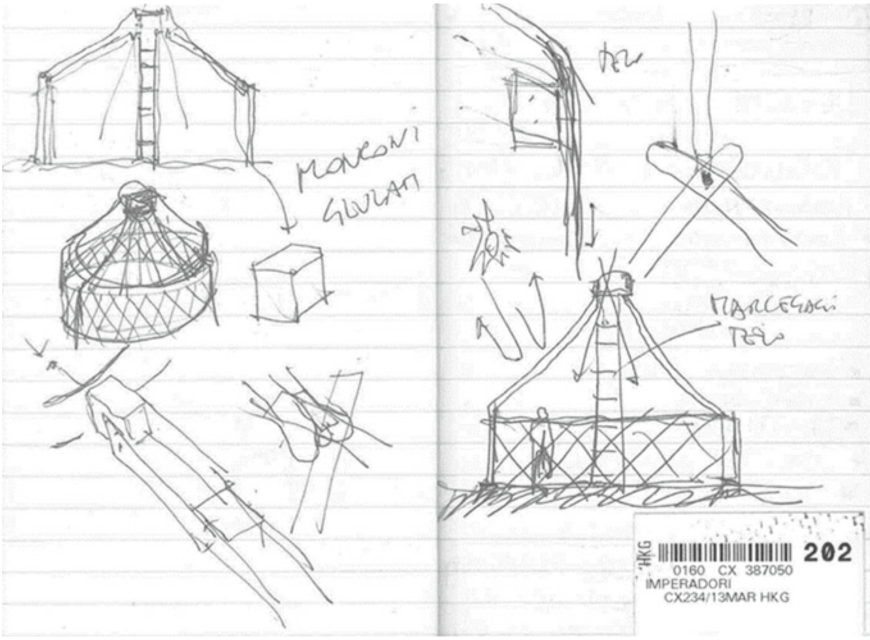

Fig. 1 Schematic concept of the ski yurt. *Source* Marco Imperadori

Fig. 2 Photorealistic view of a structure module

2.1 Technological Design

In order to make shelters easy to erect and dismantle, they need to be light weight and have few and easy assembled pieces. Certain types of shelters, such as plastic sheets and tents, are simply erected for a short time span and then dismantled. If the design of a shelter is complex, it will require more training and resources to build it, leading to potential delays (Bashawri et al. 2014). The solutions adopted for the

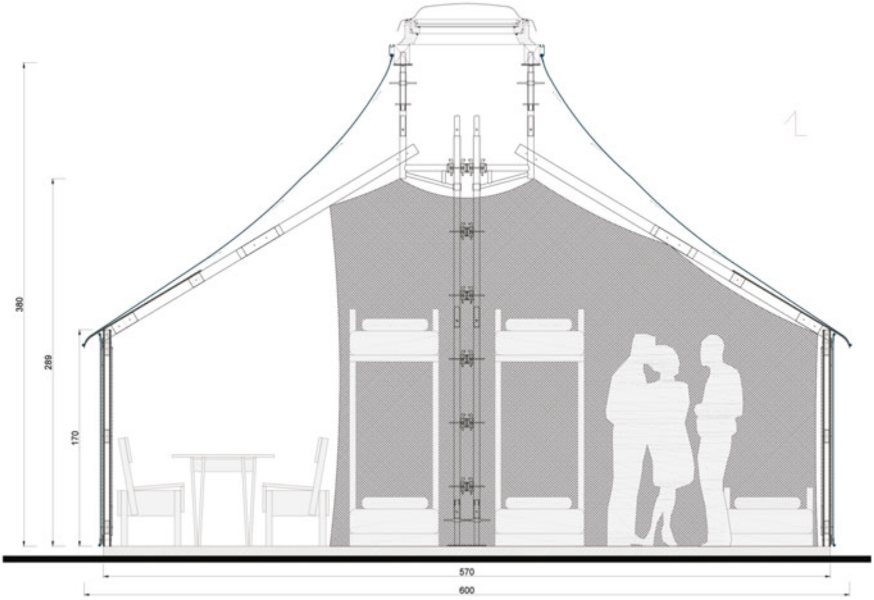

Fig. 3 Vertical section of a standard Ski Shelter

Fig. 4 Photorealistic view of the Ski Shelter

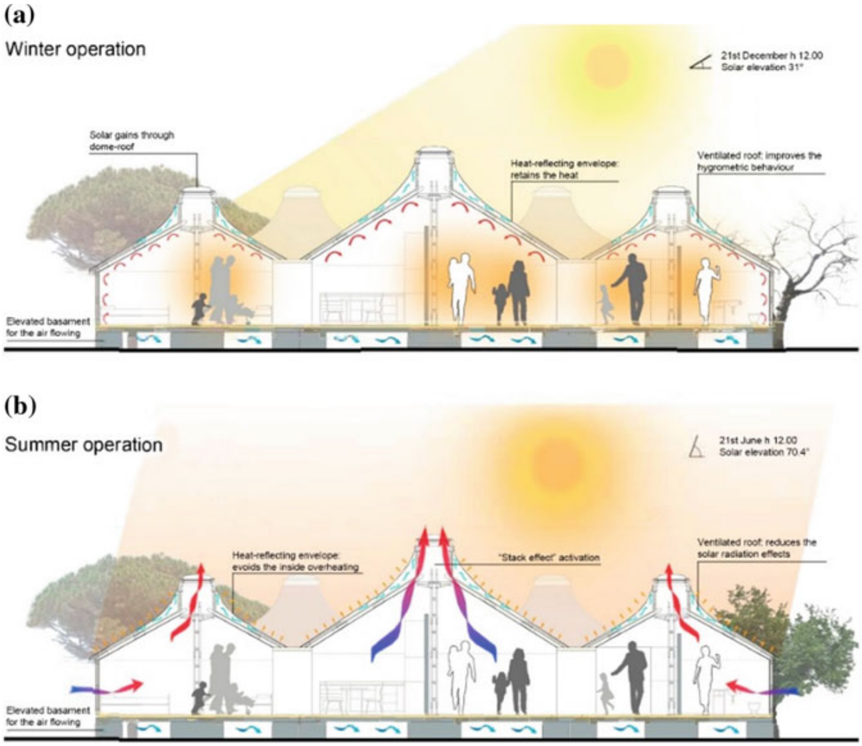

Fig. 5 **a** Winter and **b** summer schematic design of the Ski Shelter

Ski Shelter assembly do not require special skills or in situ operations, and respect the requirements typical of the emergency structure, such as flexibility, portability, lightness, quick installation process, and durability. Considering that the external layer has been made up from a polyester/PVC material, which is characterized by a translucency range of about 0.8–4.0% and with high resistance (Fig. 6). This material presents effective fire resistance and a low specific weight (1450.0 g/m^2). Currently, polyester/PVC is the material most commonly used in architecture since it provides a good balance between cost, performance, and durability (the average life span is between 7 and 15 years), strength and elasticity (Campioli and Zanelli 2009). The thermal resistance to heat transfer is given by the presence of the reflective multilayer insulation (MLI), material already tested by different research studies (Imperadori et al. 2013; Ward and Doran 2005; Salvalai et al. 2015).

This material is a thermal insulation composed of multiple layers of thin sheets developed mainly for spacecrafts. It is commonly used on satellites and other applications in a vacuum where conduction and convection are much less significant, and radiation dominates. In general, the material consists of a series of reflective films covered in a material with low emissivity such as aluminum films and reflective plastic films. For about 30 years, these materials have been used in building, where they

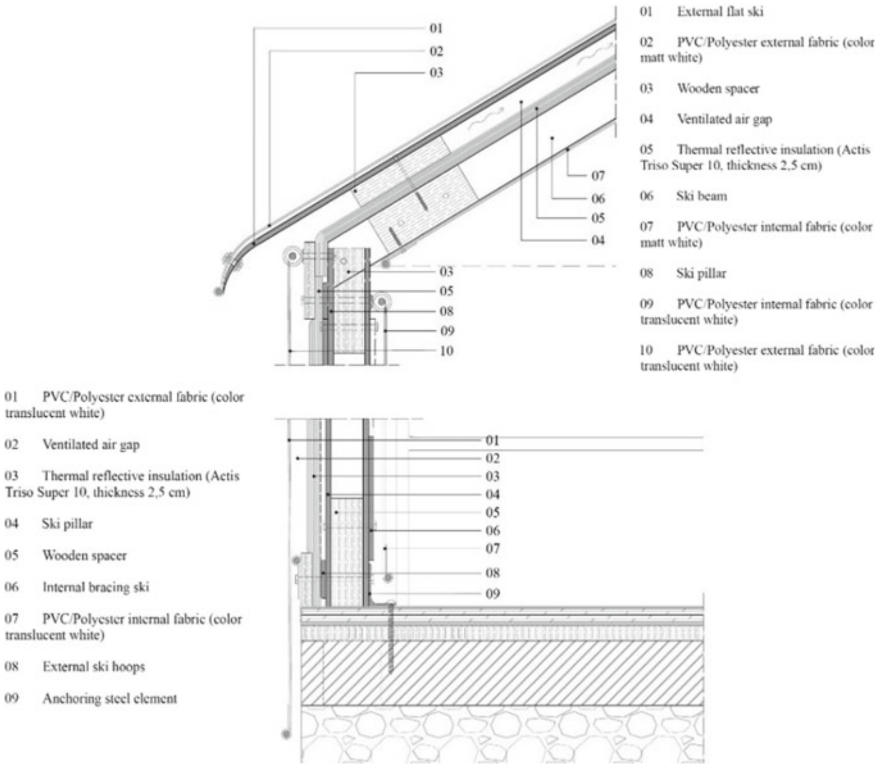

Fig. 6 Constructive detail of the connection Ski Shelter

are able to effectively solve, and in an innovative manner, the problem of thermal insulation, acting in all heat transfer directions. The MLI used in the present study is the ACTIS TRISO Super 10 multilayer (http://www.actis-isolation.com). It is composed of synthetic materials such as wadding sheets or plastic material; and natural fibers, such as sheep's wool. The combination of these thin materials, arranged in succession to one another, gives excellent results in terms of thermal performances: in winter months, it prevents the heat flow from the inside to the outside, while in summer months, when the radiative component of the external thermal load is bigger than the conductive and convective one, it reduces the heat flow from the outside. Figure 6 shows the technological details of the Ski Shelter: the connection between the ground and the skis and between the vertical wall and the roof structure.

2.2 Concept Design and Testing Procedure

The Ski Yurt geometry offers exceptional mechanical resistance being composed of several structural elements close to each other. As mentioned before, the Yurt is built on the basis of 24 concentric triangles with a rotation of 15°. In the center of the Yurt a steel pillar sustains the "crown" which acts as a support for the roof window and the other structural elements that converge on it. To each axis corresponds a composite "ski beam" tilted 30° on the horizontal plane, which is anchored to the "crown" at the top and to the "ski pillar edge" at the bottom (Fig. 7). At both points, the joint does not neither transfer shearing actions nor bending moment (hinge behavior). Different diagonal skis contribute to withstanding the horizontal forces. In the end, the horizontal stress coming from the beams is absorbed by two orders of "ski hoops" placed one on the top and one on at the base of the pillars' edge. Again, these joints are discretized as three-dimensional hinges. All the nodes of the structure have been connected by threaded steel bolts.

In 2015, together with the Politecnico di Milano and ESPE Lecco (a technical professional school for construction workers in Lecco), the Ski Yurt was tested verifying the construction phases. The main goal was to derive specification and suggestion for further design and construction optimization. During the test, all the technical elements have been numerically named to help and speed up the assembly phase (Fig. 8).

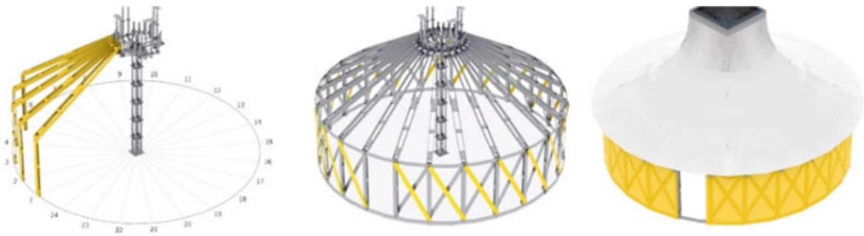

Fig. 7 Technical drawing of the different construction phases

Fig. 8 Pictures of the pre-assembly phase

The whole construction process took four working days to assemble the skis for the individual structural elements, such as beams and pillars. Then, it took an additional five days to assemble the whole yurt structure. The working team was composed of an average of four people, two of them skilled workers and two of them students. The shelter was then taken apart in half a day, packed and loaded into a container ready for shipping to Guinea-Bissau.

3 Performance Verification: Simulation Study

Several studies are available in literature analyzing the shelter performances through experimental and simulation studies in different geographic areas that verify the internal conditions (Cornaro et al. 2015; Ajam 1998; Manfield 1999, 2000). The tent prototype was also analyzed by dynamic thermal analyses performed with Trnsys v.17 Environment (https://sel.me.wisc.edu/trnsys/). The geometrical model (Fig. 9) was modeled in Trnsys3d (http://www.trnsys.de/), a plug-in for Google SketchUp.

The geometry was modeled as a homogenous thermal zone with a total volume of 83.15 m^3. The vertical surface (33.84 m^2) and pitched roof (43.15 m^2) have been implemented in type 56 considering a solar absorbance coefficient of 0.4 (clear color) and the convective heat transfer coefficients were set equal to 3.0 W/(m^2°C) for internal surfaces and 17.8 W/(m^2°C) for the external ones. The ground floor was modeled considering the direct contact between the ground and the internal zone. The model allows for predicting the internal temperature considering in one side the free-running operation and in the other side the ideal heating/cooling demand with an internal set point control of 18 °C in winter and 26 °C in summer. The simulation was performed considering the climate of Palermo (Italy), characterized by high ambient air temperature in the summer with high solar heat gains. The thermal performance of the tent is summarized in the Table 2.

Different ventilation strategies have been tested: night-time ventilation (8:00 p.m. to 8:00 a.m.) and day-time ventilation (10:00 a.m. 14:00 p.m.) both with an air change of 3 volumes per hour (ach). Changing from day ventilation to night ventilation there is no significant reduction of the temperature level due to the low thermal inertia of the yurt envelope. In general, intensive ventilation strategies allow for an increase in the

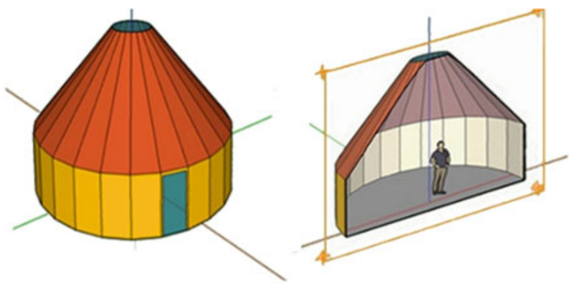

Fig. 9 Three-dimensional single thermal zone simulation model

Table 2 Features of the elements that make up the multilayer technology

	Thickness (mm)	R (m^2K/W)
Wall/roof ($R_{tot} = 5.538$ m^2K/W)		
R_{si}		0.131
Internal envelope in Polyester/Pvc	1.20	0.006
Air gap	60	0.182
Insulation ACTIS TRISO SUPER 10	25	5
External envelope in Polyester/Pvc	30	0.176
R_{se}		0.038
Basement ($R_{tot} = 3.768$ m^2K/W)		
R_{si}		0.171
Internal envelope in Polyester/Pvc	1.20	0.006
Background slab	25	0.834
Insulation ACTIS TRISO SOLS	7	2.5
OSB panel	28	0.215
R_{se}		0.038

interior comfort conditions. The thermal comfort level has been analyzed according to the EN UNI 15251:2008 standard. Figure 10 shows the correlation between the operative room temperature (ORT) and the running mean ambient air temperature.

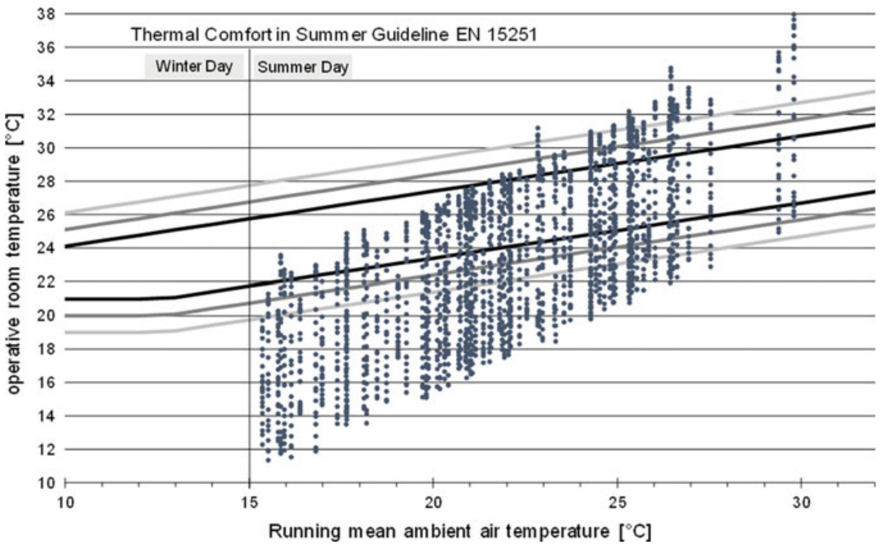

Fig. 10 Summer thermal comfort evaluation according to the EN 15251 standard

Fig. 11 Construction phases in Cacine, Guinea-Bissau

The annual energy balance (useful energy) shows that the cooling consumption exceeds that for heating at about twice the amount: the energy for cooling is equal to 1003 kWh and those for heating equal to 559 kWh. The total energy related to the floor area is equal, respectively, to 33.3 kWh/m^{2}y and 18.6 kWh/m^{2}y, reflecting the predominant summer climate conditions of southern Italy. The low energy-consumption level would lead to different benefits such as energy procurement and fuel transportation.

4 Conclusion and Development

The presented work demonstrates the high potential of upcycle materials like disposed of skis, in order to use them for building temporary and emergency architectures, due to their features of lightness, quick installation, and flexibility.

The Ski Yurt shows an innovative concept of potential living, a secure, comfortable, and healthy space easily assembled and disassembled. Modularity and simple connections between different components guarantee easy transport, assembly, and maintenance by locals without specific tools and skills. The experimental Ski Yurt, after the assembly test in Italy, has been donated and transported to the Cacine community to become the base camp for the new mission center coordinated by the Oblate Fathers of Mary Immaculate (Fig. 11). Local people rebuilt the Ski Yurt easily, and since then it has become an important reference point for the population as a useful, comfortable, and safe space.

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