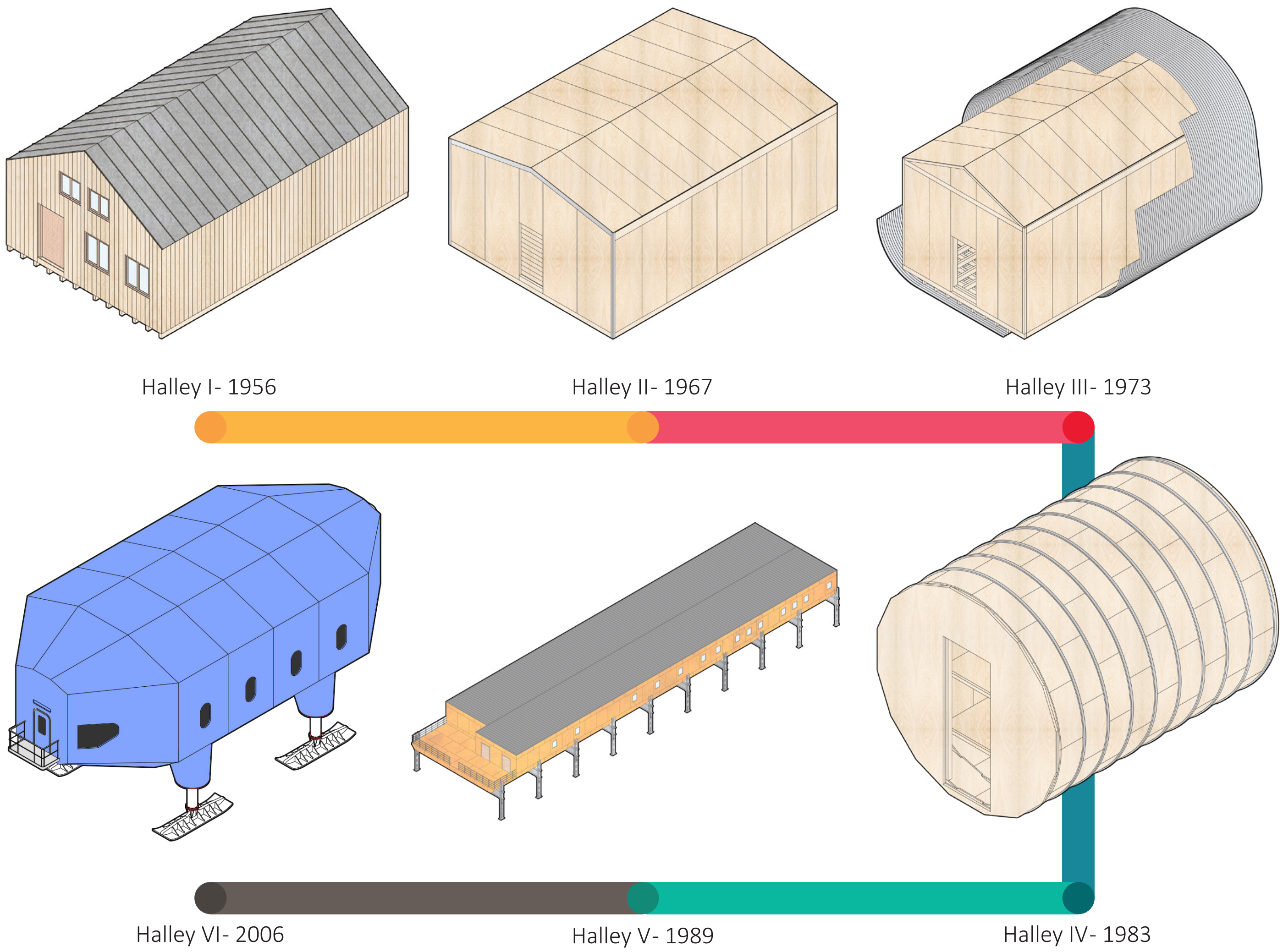
AN INVESTIGATION INTO EVOLVING DESIGN AND CONSTRUCTION OF RESEARCH STATIONS IN ANTARCTICA AND THEIR APPROACHES TO ENABLE HUMAN HABITATION OF EXTREME ENVIRONMENTS



Abstract

The mysterious land of Antarctica symbolises the further development of human beings further afield. "***Antarctica has this mythic weight. It resides in the collective unconscious of so many people, and it makes this huge impact, just like outer space. It's like going to the moon***" (Jon Krakauer 2003). Since the last century, human beings have established bases in Antarctica to study climate change, astronomy, etc. Countries have gone through various design methods and multiple failures in this remote continent to enable them to develop the current research stations that can withstand extreme climates. Their evolution from the last century to the present allows us to better understand the history of their development and the reasons for design changes. The design of the station should not only consider its ability to withstand the local climate and protect the local environment and organisms. It should also take into account the psychological and physiological effects of people in extremely cold climates and difficulties encountered in the design and construction processes. The purpose of this master's thesis is to better understand the challenges and constraints associated with the construction and operation of research stations in Antarctica and to identify considerations for further development of research stations in extreme cold climates. In addition, extreme environments can be divided into many categories, and this thesis will define what is an extreme environment and which extreme environment Antarctica belongs to.

The aim of this research is to understand in order to utilise the application of these building methods for other extreme climate environments and further afield by studying research stations located in the most extreme climatic conditions on Earth. Although the current station has been developed to be more effective in withstanding extreme climates and solving energy problems than past stations, there are many elements to be solved in order to apply these designs further afield. With the advancement of technology, human beings began to plan to land on other planets and establish research bases as habitats for astronauts. The ultimate goal of human fascination with exploration is to be able to colonize other planets. Exploration can push human beings to seek knowledge in unknown fields and push the limits of science and technology. Take the Apollo program as an example. It has influenced human pursuit of space travel, expanded technology, and created new industries. Therefore, humans constantly exploit the evolution of these research stations as outposts of the final frontier to achieve the idea of enabling interstellar travel. However, Antarctica is often studied for space travel as an extreme climate region, but the environment in space is more extreme than conditions in Antarctica. Therefore, how can the current stations be developed further to improve further and apply them to further afield.

This thesis will help the further development of stations by analysing current and past research stations to help with details to be considered in extreme cold climates. Past research stations have focused on Halley I to V to understand how to conceive new designs and improve construction methods after they fail to withstand extreme weather. The case studies will compare how current research stations are designed, built and operated in different geographical environments of the Antarctic continent to find the best methods for withstanding extreme weather methods and the best way to operate a station, and summarize and recommend how these research stations can be further developed and used for further afield.

Declaration of Authorship

22900/AB947 Dissertation 2021/22

MArch in Advanced Architectural Design

Declaration

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Acknowledgements

Thank you to my mentor, Andrew Gillespie for his guidance and support through the thesis process. This is the first time I have learned about the Antarctic environment and research stations through this topic. During the whole process, I gained a lot of knowledge, which made me more and more fascinated by the continent of Antarctica. I got his feedback and suggestions through the process of moving my thesis towards this approach. There was a period when I was so depressed that I felt like I couldn't finish the thesis. However, Andrew often encouraged me to say "you can do it" in the course of the tutorial. I felt so positive every time I got his encouragement. I always felt like I couldn't let him down, so even if I feel lost and tired in the process, I'll brave it out and get it done. I would like to express my sincerest thanks to you.

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1.0. Introduction

From history, it is not difficult to find that human beings have a natural inclination to explore. Antarctica was first discovered in recorded history in 1820. In 1895, seven men from a Norwegian whaling and seal whaling ship were recognized as making the first confirmed landing on the Antarctic continent. The first person to reach the South Pole was Norwegian Roald Amundsen, who successfully reached the South Pole on December 14, 1911, and became the world's first explorer to reach the South Pole. Antarctica is recognized as the final frontier on Earth because it is the only continent in the world that is not inhabited by humans and a great variety of species and unknown environments have yet to be discovered. Only the place where scientists go for research does not have any sign of human life.

Because of its extreme environment, it is so difficult to reach Antarctica. Extreme environments mean life in harsh environmental conditions as a habitat. Its conditions are beyond the range that humans can survive and develop. It can be divided into extreme temperature, extreme pH, extreme pressure, and high radiation, and Antarctica belongs to the extreme cold environment. The Antarctic continent also has strong winds, high altitudes, driest and blizzards, factors that make it the harshest environment on earth. Human knowledge and the history of activities in this place are still very shallow. The reason why humans are lacking knowledge of this extensive and long-term frozen region is the influence of the extreme weather there. As the most remote continent in the world, Antarctica also has many fascinating mysteries. It has the most extreme climate, which makes it inaccessible. Since the last century, several countries have established research stations to understand its mysteries and study geological, climate change, biological, ozone layer and oceanographic research.

Antarctica is sometimes called "White Mars" because it is difficult to land on. Due to the environment and constraints similar to Mars, space agencies of different countries have always conducted different simulated Mars mission experiments here. In the past, scientific teams have provided a simulated Martian environment with months of isolation, confinement, and extreme conditions in Concordia station for astronauts preparing for a journey to Mars to study physiological and psychological effects on their behaviour. The establishment of a research base in Antarctica is an important step towards landing on other planets. With its climatic and conditional constraints, these factors can be applied to other extreme environments and other planets to study the feasibility of establishing bases there. Since the beginning of the last century, there have been huts made of stone and wood as bases for expedition teams. They frequently lack knowledge of the Antarctic climate, resulting in a variety of issues such as poor ventilation, poor insulation, inability to withstand strong winds, and poor snow management. As time advances, the research station is also more capable of withstanding extreme environments than before. From the development sequence of the Halley research station, it is better to understand the continuous failure in its development process to develop to the current research station. These research stations have been developed into research stations built on stilts and made of prefabricated components which are made of composite materials. They all have the ability to withstand harsh climates and provide stunning living and working spaces for residents.

1.1. Objective and problem description

The purpose of this master's thesis is to study how future and current Antarctic research stations respond to extreme climate and condition constraints and to understand the construction and operation of past Halley stations and their failure and success factors to understand how research stations evolved to be able to withstand extreme environments. A set of criteria was established from the Halley station to analyse the current research station to identify areas for improvement. Explore whether existing research stations apply new building techniques to withstand extreme environments, achieve sustainable development and reduce environmental and biological threats to Antarctica. The aim is to enable the further development of the research station for applications in other extreme environments and further afield.

1.2. Limitations

The limitations for the master thesis are as follows:

- The construction and operation of the Halley Stations is synthesised from the oral histories of the expedition members and the newspapers.
- These indicative and representative models, rather than completely imperially accurately, have been produced to the best of the ability using available resources- oral histories, photographs, videos et al.

Chapter I- Challenges and Restrictions in Antarctica

2.0. Challenges and Restrictions in Antarctica

So far, no human civilization has been found in Antarctica and no aboriginal people have been found. Humans have established scientific research bases in Antarctica for less than 120 years. Scientists from nearly 30 countries are currently stationed here. More than 150 scientific research stations have been established here. There were no buildings in Antarctica before 1903. It's not hard to understand why there was no human activity here in the past. There are strong Beaufort scale winds most days of the year since Antarctica is the coldest place on Earth. Survival in this environment is the most important condition. It is difficult to establish habitat in this region in this harsh climate. Early Antarctic buildings were very shabby and crude, such as Omond House. The first Antarctic base, "Omond House" was built on Laurie Island in the South Orkney Islands in 1903 by a team led by William Bruce of the Scottish National Antarctic Expedition. The base was built by hand-excavating hundreds of tonnes of stones from the nearest local glacier and timber from the expedition ship, then sledding to the site. Since the signing of the "Antarctic Treaty" by many countries in 1959, scientific expeditions to Antarctica have also become active. In addition to scientists, there are also some architects, engineers, and designers who come to Antarctica to combine design aesthetics with practicality in this coldest place.

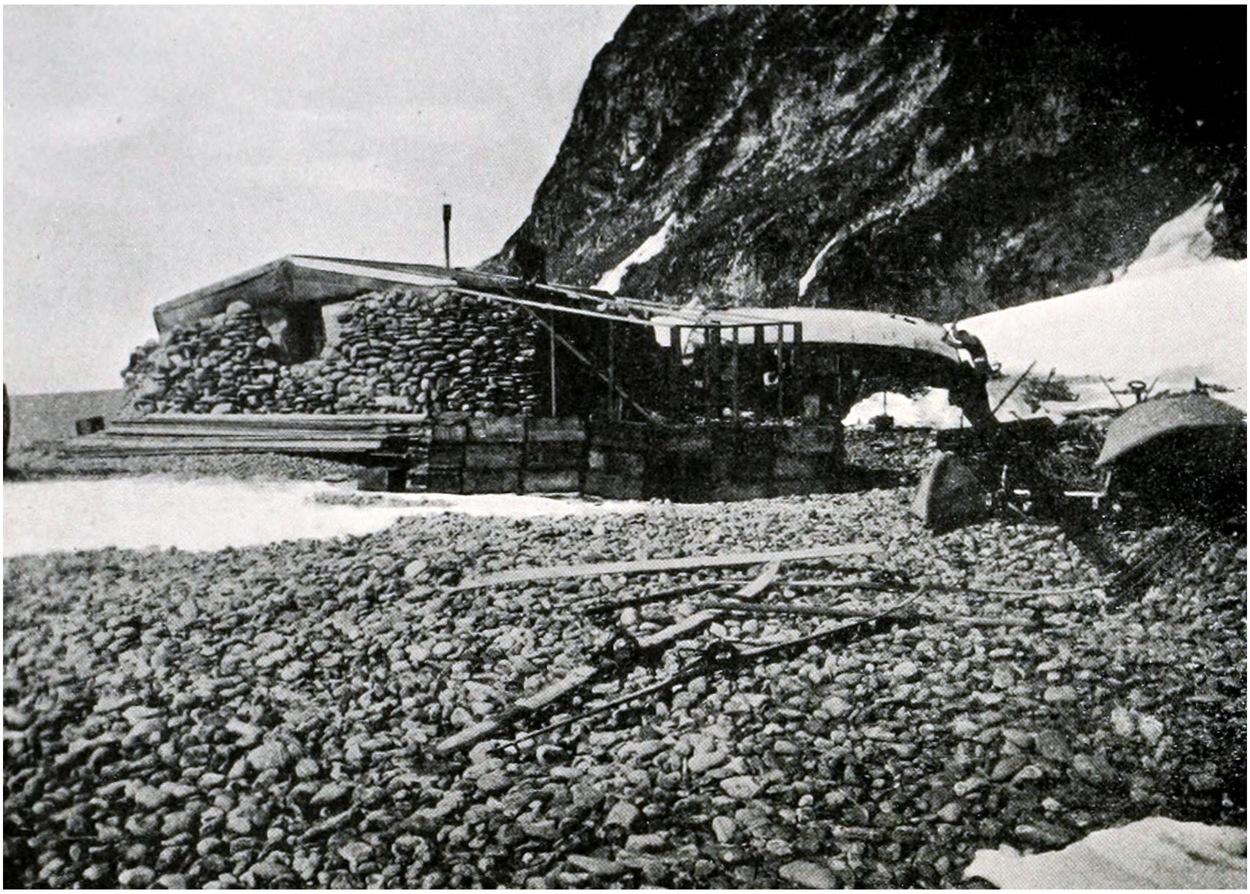


Figure 1. Ormond House. Photographer unknown. Photo copyright by Scott Polar Research Institute. Source: https://www.coolantarctica.com/Antarctica%20fact%20file/History/antarctic_whos_who_scotia.php

Setting up a research station in Antarctica is much more difficult than in the Arctic Circle. The harsh environments bring particular challenges. The climatic (heat dissipation, low humidity, moving ice, low temperatures, strong winds), proper building materials, waste disposal, renewable energy, physiological effects of extreme cold on the human body, possibility of planting for consumption by station staff, logistical (transient population, communications, access, remoteness) and psychological (sensory deprivation, isolation) considerations are important for the principle building design for the Antarctica region. In addition, environmental protection must also be taken into account, which complicates any Antarctic construction process.

3.1. Seasons and Day and Night

People all over the world are probably used to seeing the sunrise and sunset every day. However, there is only one sunrise and sunset per year at the North and South Poles. These are phenomena lasting more than 24 hours called polar nights and polar days. These phenomena only happen within the polar circle. The South Pole (or North Pole) has no sunrise for 6 months of the year, and the North Pole (or South Pole) doesn't have a sunset. Antarctica is divided into two seasons; March to October is the winter season; October to the end of March is the summer season. In the winter of the south pole, there are continuous nights (polar nights), and dazzling auroras often appear near the Antarctic Circle until winter. The summer is opposite to the cold season; there are continuous days (polar days), the sun is always slanting lighting and the sun will be parallel to the horizon at a certain time. The psychology of people in Antarctica during these unique seasons is easily affected. In addition, vessels cannot approach the Antarctic continent on polar nights. This leads to why Antarctica is called "White Mars."

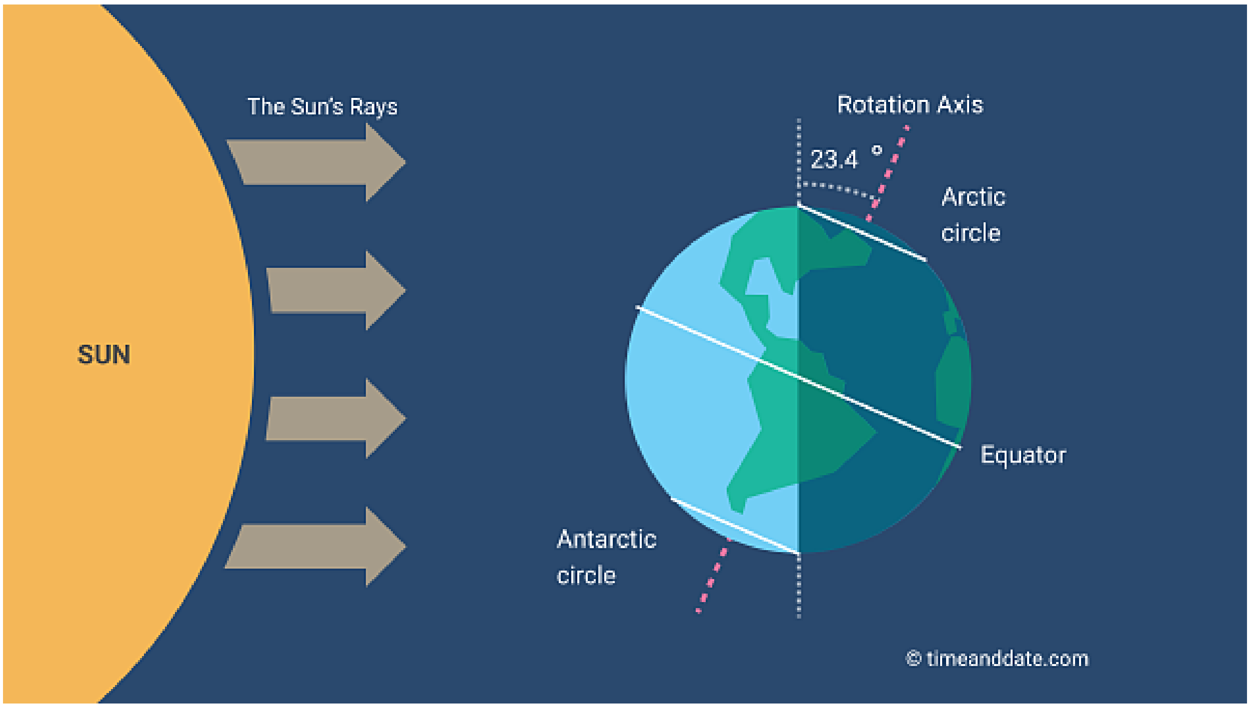


Figure 2. The angle of the earth rotation axis is not vertical causing polar nights and days at the poles. Photo attributed to timeanddate.com. Source: https://www.timeanddate.com/calendar/december-solstice.html

2.2. Climate restrictions

Antarctica is the southernmost point on Earth and has the coldest and driest climate of all the continents. Most regions of Antarctica suffer from a severe lack of precipitation. The average annual precipitation across the continent is 55 mm. Almost all the precipitation is snow and hail. The lowest temperature recorded in the south polar region is also the lowest on the planet (-89,2°C). The annual minimum temperature in the middle of the continent in winter is usually around-80°C. In addition, it is the windiest region in the world. The middle regions are dry, like a frozen desert, and the coastal areas are windy.

The winter in the Arctic is almost equivalent to the summer in the Antarctic. Why is the Antarctic so much colder than the North Pole? The north and south poles are cold because the angle of incidence of sunlight is low, the sunlight is weak, and there is a polar night, which are the common reasons for the coldness of the north and south poles. In addition, the Antarctic has its own unique features, so it will be colder than the North Pole. Firstly, the Antarctic continent is not only far away from other continents but also surrounded by ice shelves and floating ice for several kilometres, or even hundreds of kilometres. The Antarctic continent is surrounded by the Antarctic circumpolar current, which means this cold current blocks all the influence of the warm current from low latitudes and exacerbates the reduction in temperature of the Antarctic continent. Secondly, the polar high pressure belt was formed because of the cooling and sinking of cold air. The severe storms from the Antarctic continent hit the surrounding area, forming a wall to block the low-latitude warm current from entering. Thirdly, 98% of the surface of the Antarctic continent is covered with ice and snow. The reflectivity of the ice and snow layer to sunlight reaches 80%-84% and less than 20% of it reaches the surface. Most of the solar radiation is reflected back into space to cause a long-term low temperature in the environment. Fourthly, the entire Antarctic continent sits on a large ice sheet with an average altitude of 2350 meters, and thin and dry air make it difficult to preserve heat in the environment. This extreme location is difficult for the human body to adapt to. The dry air and high altitude of the polar regions make daily activities much more difficult than in the tropics. The air can cause instant pain to the body’s exposed skin. Human exposure to the outside environment can become very dangerous because of the thin air that makes it difficult to breathe.

2.3. Adaptability of animals and plants

Antarctica can be roughly divided into three regions according to the distribution of animals and plants on land. There are sub-Antarctic islands farther away from the Antarctic, including the Maritime Antarctica, including the west coast of the Antarctic Peninsula, some near-shore islands, and Continental Antarctica off the west coast of the Antarctic Peninsula.

The climate of the sub-Antarctic islands is not too harsh. The amount of rain and snow is relatively abundant so that vegetation can grow. The major plants include herbs, mosses, lichens, seaweed, and even some flowering plants. The maritime Antarctic usually has more precipitation and milder temperatures. This climate is more conducive to terrestrial plants and microscopic animals. Continental Antarctica can only sustain sparse mosses and lichens. Antarctic plants are designed to adapt to harsh environments. For example, some mosses can photosynthesize normally at-2.5°C and some lichens can photosynthesize at-17°C. There are three factors that determine the distribution of plants in Antarctica. The first factors are climatic factors like the frequency and duration of freeze-thaw cycles and temperature. The second factor is soil factors like soil type and underlying geology, and the last factor is biological factors like the influence of other plants and animals. The most important of these factors is the primary factor of water availability, which can determine whether a plant will survive or not in Antarctica.

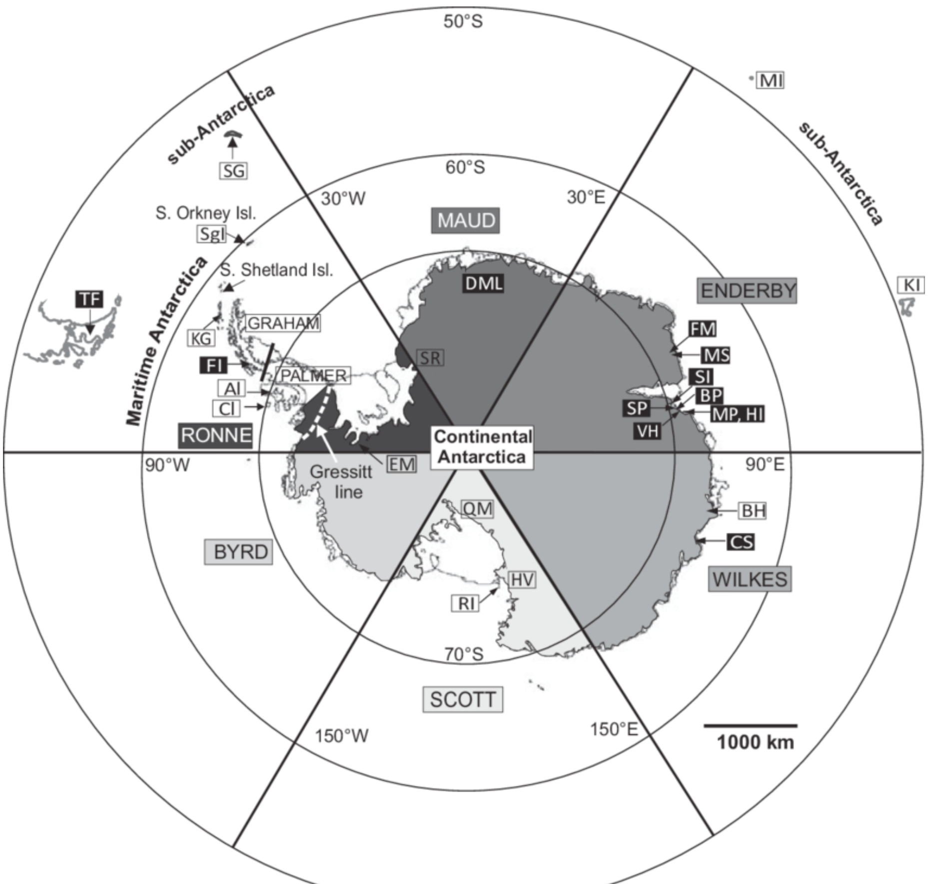


Figure 3. Antarctic animals and plants are distributed in six regions, Antarctica continent has fewer species of plants than sub-Antarctica. Photo attributed to Alejandro Velasco-Castrillón. Source: https://www.researchgate.net/figure/Map-showing-six-sectors-for-continental-Antarctica-shaded-in-grey-the-Antarctic_fig1_287796409

The fierce cold wind in Antarctica can reach -60 °C, which makes people's teeth chatter, but there are many species of animals and vegetation which can adapt to the extreme cold of the Antarctic environment. They are able to rely on their body structure to keep their bodies warm, unlike humans who rely on a lot of clothes. Adaptation enables animals to make changes in their environment to adapt to the environment for survival. For example, penguins need very good insulation in order to swim in cold water to hunt prey. Other penguins, with the exception of the Humboldt penguin, which lives in the deserts of South America's west coast, live in freezing temperatures. In particular, emperor penguins hatch their eggs in the Antarctic winter with temperatures as low as-60 °C. Insulation includes a thick layer of fat under the skin, a layer of feathers on the skin to keep air in and an outermost layer of waterproof feathers to keep cold water out. The penguins still have no problem keeping warm with these layers of insulation despite the temperature dropping to-10°C. In addition, penguins have a special circulatory system that prevents their feet from freezing and reduces heat loss from their feet to the ice. Penguins have a habit of huddling together to keep warm in freezing temperatures. In a crowd of penguins, the penguins standing inside and outside will gradually switch their standing positions so that each penguin will take its turn to stand inside and outside.

2.4. Physiological effects of extreme cold on the human body

Humans are essentially tropical animals without the body structures of animals in cold regions, such as a thick layer of fat and dense feathers on the skin that allow us to withstand cold climates. Humans are able to adapt to extremely cold climates because of proper clothing and shelter.

Successful survival in extreme cold has to require two factors at the same time. First, high-calorie foods need to be absorbed to generate enough body heat. Second, proper clothing and shelter are required to prevent heat loss. The human body produces a physiological response based on two factors, which are the duration and degree of exposure to low temperatures.

If the human body is exposed to a cold environment without the protection of suitable clothing and shelter, the body will begin to respond physiologically by shaking to generate more heat to maintain a normal temperature. When the body is repeatedly exposed to such an environment, it is unable to return to its normal temperature. Blood flow to the extremities will be reduced to reduce heat loss and minimise cooling. Finally, if heat continues to be lost despite the above steps the body has taken, the body will slow metabolism to minimise the need for fresh blood flow and oxygen supply requirements. Symptoms of mild hypothermia will begin to appear when the body continues in this environment. Shaking, numbness of hands and other extremities will appear and reduce basic movement ability. It is often difficult for patients to discover that they have started to suffer from hypothermia. If mild hypothermia is not recovered, it can deteriorate to profound hypothermia. At this stage, the body has stopped trying to keep itself warm and is taking its final steps to avoid death. The heart rate and breathing will become so slow that the patient will not notice it at all. Difficulty breathing is like being at a high altitude. The skin becomes very pale and cold; the limbs and trunk are stiff; the pupils do not respond to light. Metabolism has slowed to an almost hibernating state. Irregular heartbeats can happen at low temperatures, which can lead to uncoordinated twitching of the cardiac muscle, preventing it from pumping blood normally and resulting in death. Even if this doesn’t happen, the heart may stop beating completely at around 20°C, resulting in death. In addition to hypothermia, frostnip can directly reflect physical damage to the human body. Frostnip happens when a part of the body becomes cold, causing blood flow to slow down because that part is losing too much heat. Ears, fingers, cheeks, nose, and toes are the first to be affected by frostnip. Superficial frostbite is a serious condition in which ice crystals form within the cells of the body. It is recoverable, but the part of the wound is very painful, itchy, and swollen. Deep frostbite can cause loss of fingers, toes, and even parts of the limbs.

2.5. Psychological impact

People who have worked in Antarctica in the past have faced challenging living and working conditions that pose risks to their safety, performance, and mental health. People who spend the winter at Antarctic stations are vulnerable to psychological problems. Their main stresses come from the monotony of their physical environment, lack of social variation, restrictions and limited privacy, and emotional and physical deprivation. This response is generally triggered by three factors: isolation, confinement, and the environment. Extreme cold and long dark seasons often lead to common reactions such as depression, distraction, confusion, irritability, adoption problems, and difficulty sleeping. These reactions are known as “winter-over syndrome.”

During winter, at some station locations, people may be completely cut off from the outside world. It is difficult to have a private space in the station. The thin walls of the station always feel like the presence of other people does not allow much privacy. In addition, polar nights and weather conditions severely limit the possibility of reaching the location. Supplies can sometimes not be delivered to the station and may not be evacuated in an emergency. Although the communication between the station and the outside has greatly improved in recent years, these systems may fail and make it impossible to seek support and assistance from outsiders.

Space layout is an important detail to solve the psychological impact when designing a station. In addition to considering the work space in the station, appropriate private space, entertainment facilities, and even the colour of the room should be considered in the station.

2.6. Waste disposal

Regardless of whether they are staff from the station or tourists, they have to deal with waste disposal in Antarctica. According to the Protocol on Environmental Protection to the Antarctic Treaty, it stipulates that the signatories must comprehensively protect the Antarctic environment, establish the principles of environmental protection, make Antarctica a nature reserve for peace and science, prohibit all commercial mineral resource activities, and require all activities to carry out environmental impact assessments. One of the annexes to the agreement specifies the establishment of rules for waste disposal and management. Land or sea dumping of waste or chemicals or burning of waste is strictly prohibited. All waste should be source segregated and then shredded or compacted to reduce its volume before being shipped back to signatories for disposal or recycling. Antarctica is only a short journey for tourists, so the waste generated is generally recyclable and food waste, which is not difficult to take away and disposal. On the contrary, it is much more difficult for the staff who work at the research stations. They usually have to stay for the whole season or longer for scientific research, so the waste generated includes waste fuel, oil, hazardous waste, etc. Before the annex of the treaty, most of the waste was disposed of in three ways: if the waste was flammable, it was burned; if it was not flammable, it was thrown into the sea; or put aside. Stations require special treatment and methods to dispose of the waste after the agreement is established. The British Antarctic Survey has established the following guidelines for waste disposal: Waste fuel and oil are sent to the Falkland Islands for safe disposal. Hazardous waste will be shipped to the UK for safe disposal by a licenced waste contractor, and items that are recyclable or reusable will also be sent to the UK for recycling. For waste management in remote areas, the authorities use a portable hydraulic drum crusher that can be easily disassembled. The device is loaded into an aircraft and then flown to remote sites to crush waste.

2.7. Logistics

Logistics in Antarctica is not like other continents that rely on a variety of transportation networks to get goods to their destination. Research stations in Antarctica rely mainly on expedition vessels each year for food, fuel, repair materials, and personnel shifts. However, arriving vessels in Antarctica continents are not like sailing in normal seas. It is impossible to reach the continents of Antarctica except in the summer between November and March because sea ice forms around Antarctica in the winters from April to October, making it practically impossible for ships to reach land. And winter is the constant darkness of the polar night that belongs to the Antarctic. Extremely low temperatures and frequent violent storms will cause additional obstacles. Therefore, vessels are practically unable to reach the shore, and winter is the polar night of the Antarctic, with constant darkness, extremely low temperatures, and frequent fierce storms presenting additional obstacles. Sailing in conditions of massive sea ice and constant darkness is like suicide, but from November to March, the sea ice melts enough for vessels to pass, and the icebergs are large and easy to spot. In addition, it is also difficult to unload the cargo onto the Antarctic continent. For example, the Halley Bay shore is full of ice cliffs, which increases the difficulty of unloading. The crews must use ramps and cranes from the vessel to unload the cargo on the ice cliff. Unloading under the ice cliff also has the risk of the ice cliff collapsing and causing damage to the vessel.

Figure 4. In some parts of Antarctica, supply vessels need to unload next to ice shelves. Photo attributed to International Polar Foundation. Photographer unknown. Source: http://www.antarcticstation.org/multimedia/picture_gallery/unloading_is_always_an_adventure/

2.8. Energy

Reliable energy is really a matter of life and death in the Antarctic. The Halley station at Halley Bay once experienced a loss of power including heat at-32C. The power outage has left staffs living and working in extremely difficult conditions. In this environment, there is even a chance that people's lives may be endangered. At present, most of the generator of the research stations is using durable and suitable generation capacity of diesel generator sets. Each research station is equipped with multiple generators which take turns to generate power and ensure the uninterrupted power supply of the research station 24 hours a day during the year. Although this power generation method is relatively stable and reliable, it has the logistical problem of fuel supply interruption. Fuel needs to be delivered by vessel once a year in summer. If the icebreaker cannot pass through the ice, there is a risk of a power outage at the station. It must be disposed of and shipped back to the country where the station belongs after the fuel is consumed. The cost of transporting fuel is also rising every year, which also increases the operating cost of the station. The high volume of diesel fuel limits freight capacity and places extreme logistical and performance pressure on staff, scientific research and station. The problem continues to worsen as the station's electricity demand increases. Therefore, the new research station must apply a power generation method that is clean, renewable and does not need to rely on logistics to reduce power generation costs, fuel consumption, harmful air emissions and fuel requirements.

2.9. Human impacts and threats to the environment

The Antarctic environment is near pristine and therefore particularly sensitive to the effects of pollution. The human footprint is most clearly reflected in its impact. Besides tourism, the most direct impact on the environment is the scientific base and planned infrastructure development such as buildings and related facilities construction, roads, fuel storage, runways, and waste disposal, etc. The effects of general waste can last for years. For example, organic materials disappear in a few months in the tropics but it can take decades in Antarctica to fully decay. In past Antarctic projects, valuable items were removed from the station once it was no longer needed. Only its buildings and all items were left behind. These abandoned items could be blown miles away by extreme weather and cause permanent damage.

Every detail of building a station can directly cause environmental damage. If the station is located in a remote location, it will cause logistical impacts such as the construction of runways and roads and the transport of vehicles will also cause significant damage to the environment and wildlife. The location of a station can contaminate the soil. The geological beneath the construction site can also have an environmental impact. Building a station on ice sheets and ice shelves is considered more environmentally friendly than coastal ice-free rock and gravel areas. The impact of building a station in these areas should also be considered in some sites with biodiversity and some sites with near-sterile areas. Construction of stations should include buffer zones such as applying buffer zones around major structures and applying stilts and frames in smaller structures to reduce ground contact.

2.10. Proper building materials and construction method

It is common for buildings in cities to stand on a site for a century, but it is not common for a station in Antarctica to stand on a specific site for more than ten years. To understand why specific materials and construction methods are important in Antarctica, it is important to understand the reasons from the history of the research station. From the first shabby permanent building made of wood and stone with no insulation to the current station made of steel frame and steel panel with multiple layers of insulation and the use of modern construction techniques, the station has evolved. To understand why the previous stations were closed due to materials and construction methods and how various materials and construction methods adapt to extreme cold environments, Materials Can it withstand the Antarctic climate such as blizzards, extreme dryness, extreme cold, etc. Will the design of the station ensure that it will not be buried by accumulating snow, or should it be designed to be buried? How will the station withstand the weight of snow if it is designed to be buried? Can its construction method be relocated to another site due to the collapse of the ice shelf? Building teams can only build stations in Antarctica in the summer each year, and is there any way to complete the entire station during this period? Whether the station can provide a ventilation system and a comfortable environment to solve the psychological impact of the staff? Will it have an impact on the surrounding environment and creatures?

3.0. Methodology

This master's thesis aims to understand the iterative experience of research stations in extreme environments and develop countermeasures. It aims to provide ideas for future research stations in extreme environments on Earth and further afield. This thesis first identifies the crises that people will encounter in Antarctica and the various challenges and constraints faced by the construction of the station, like physiological and psychological impact; climate restrictions; season; logistics; waste disposal; energy; construction and material application; etc. The literature review is then used to find out how past stations were built and operated. The factors behind their failures and how their subsequent designs can be improved from the lessons of the past after their repeated failures. Analysing how current research stations are constructed and operated in different locations through the case of existing stations. Analyse their advantages and disadvantages according to their treatment in different locations and then compare every detail to find out the best method for design, construction, and operation of a recently built station in Antarctica. The key factors for the further development of research stations will be mentioned by comparing the various limitations and advantages of the past and current stations.

Past Halley I to V research stations are used in literature reviews. Based on oral histories of past Halley station members in various positions, Antarctic historical reports and articles analyse how it was constructed, materials used, logistics, operations and reasons for closure. Information from oral histories, articles, photographs, and documentaries speculates on the construction process and material application of Halley I to V to create a detailed digital model. The detailed digital model will generate axonometric drawings to analyse the design of its stations and the reasons for their inability to withstand extreme weather. The evolution of the Halley station is made clearer by analysing the design and construction of each Halley research station and the resulting sequence.

In the current research station chapter, various stations will be selected for the case studies in this thesis according to the following criteria. All stations considered as cases must be built after 2000. The locations of its stations must be in different regions of the Antarctic continent and in different geographical environments such as ice shelves, coasts, high altitudes, ridges etc. In addition, the location of the station will also consider whether there is biological habitat and the existence of biodiversity. These stations are constructed in different ways according to their sites, so their construction methods will be compared on a case-by-case. This is used to find out the advantages and disadvantages of their construction method and whether it minimises the impact on the environment. Also, the station materials applications will be compared to find out if these materials can withstand extreme climates. These stations will also have different methods of operation due to different locations, so how they deal with energy, water production, waste water treatment, and waste disposal will be analysed in order to compare the treatment at different locations. The intention is to find the best method of operation for the further development of the station.

Chapter II- Literature Review

4.0. Literature Review

4.1. Introduction

This master's thesis analyses how research stations in Antarctica are constructed, operated, and improved under extreme cold climate and condition constraints. This review will survey the literature on the Halley I to Halley V research station project. The history of each station, construction process, operation, and reasons for closure will be analysed through a detailed digital model. They act as forerunners for existing and future research stations, analysing their advantages and disadvantages in various aspects to find out what future research stations need. To use them to demonstrate how to withstand the constraints of the Antarctic climate and conditions to provide further development for future research stations. The design thinking behind these case studies may provide a design approach for extreme environments in other regions and planets beyond Earth in the future.

Most of the literature for these case studies includes oral histories of past Halley station members published by the British Antarctic Survey Club; the documentary "Halley Bay expedition film" published by the Royal Society; articles "Halley Research Station" published by the British Antarctic Survey (BAS); and articles "Antarctic a News Bulletin" published by the New Zealand Antarctic Society.

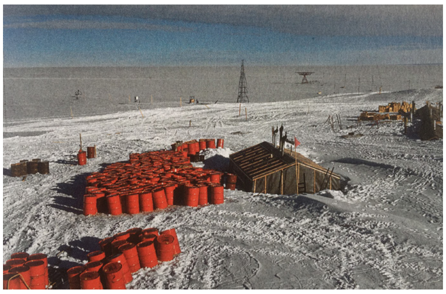


Figure 5 (Left), 6 (Middle), 7 (Right). Halley I, Halley II and Halley III. Photographer Leslie Barclay, Maurice Sumner and David Brown. Photo copyright by Ruth Slavid. Source: Ice Station the creation of Halley VI Britain's Pioneering Antarctic Research Station

Figure 8. Halley IV. Photographer Doug Allan. Photo copyright by Ruth Slavid. Source: Ice Station the creation of Halley VI Britain's Pioneering Antarctic Research Station

Figure 9. Halley V. Photographer David Maxwell. Photo copyright by David Maxwell. Source: https://www.coolantarctica.com/Bases/Halley/halley-V-construction.php

4.2. Halley I

4.2.1. Departure and Preparation

In November 1956, the Royal Society IGYE Advance Party formed an Antarctic expedition to find a suitable site and establish a base for the UK's contribution to the International Geophysical Year (IGY) (Royal Society 2017). The expedition team set off from Southampton and boarded the Norwegian 500-ton expedition vessel MV Totton, which carried some deck cargo, mostly timber, supplies and three tractors. Some timbers had to be abandoned because they failed stability tests. The team had to buy a new one from a local store to replace the timbers. They officially cast off the dock and set off for Antarctica when everything was sorted out (Stan Evans 2011). The destination of the expedition was to land at Coats Land, now called Halley Bay[1] in the Weddell Sea (Royal Society 2017).

4.2.2. Construction of the Hut

The team started setting up a camp and started building the first research station at this site. They planned to build a highly insulated wooden main hut that is 135 feet long and 27 feet wide. The initial plan for the construction of the hut was to build the first four enclosed compartments to provide a basement and a kitchen so they could move in from the tent (Stan Evans 2011). They first placed plenty of heavy timbers on the ground to form the foundation of the hut (Figure 10). Multiple truss shoes are then placed in the centre of the foundation (Figure 11) in preparation for the girders supporting the roof (Royal Society 2017).

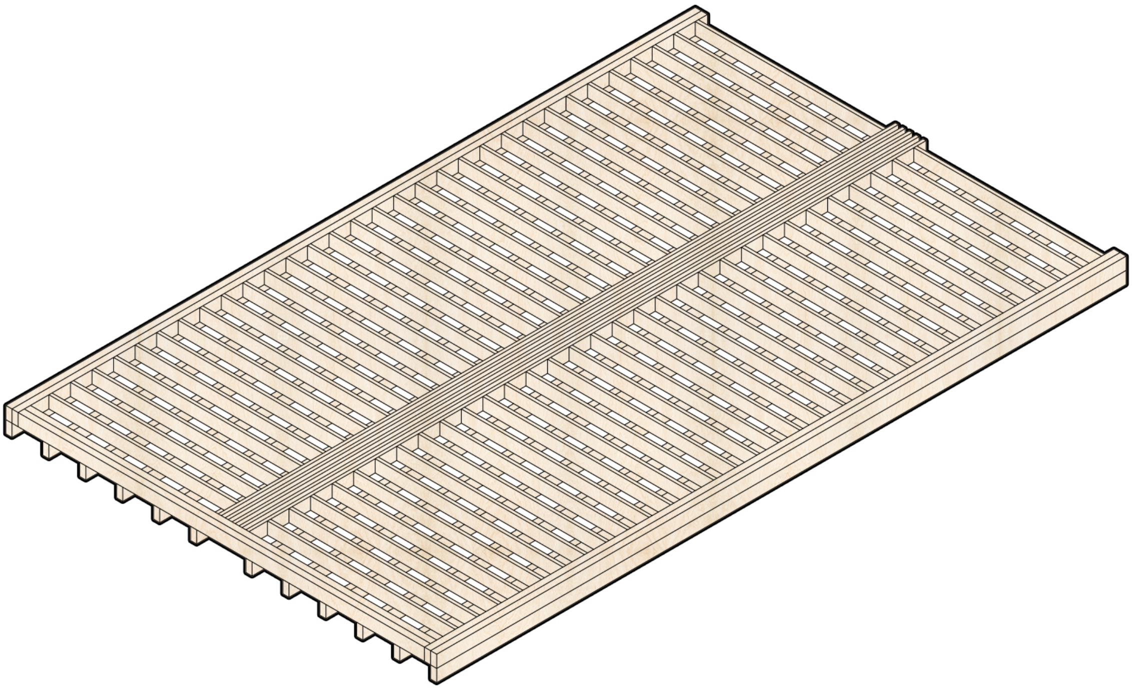


Figure 10. Construction stage 1 placing plenty timber on surface to form hut of foundation. Original author

[1] Halley Bay is named after astronomer Edmond Halley who discovered Halley's Comet

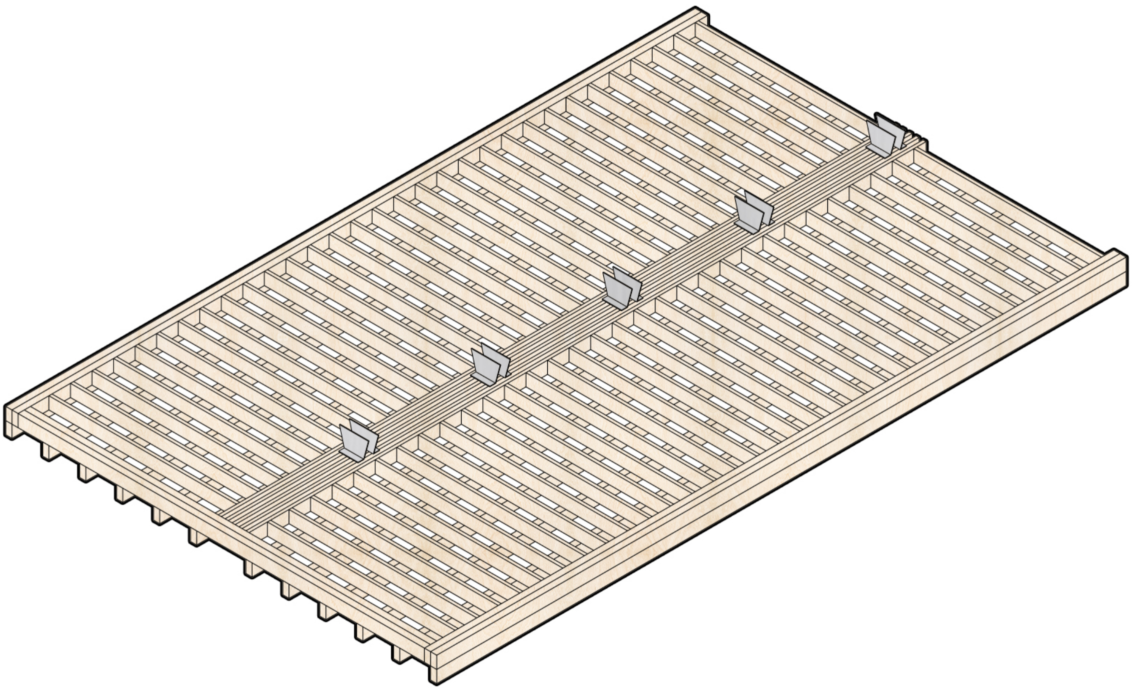


Figure 11. Construction stage 2 placing truss shoes in centre of foundation. Original author

They started assembling the frame on snow for the entrance after finishing the foundation and then lifted the entire frame up using cables and manpower. A high-lift device on one of the tractors was used to hold the frame to lift this massive timber and place it in position (Figure 12)(Royal Society 2017).

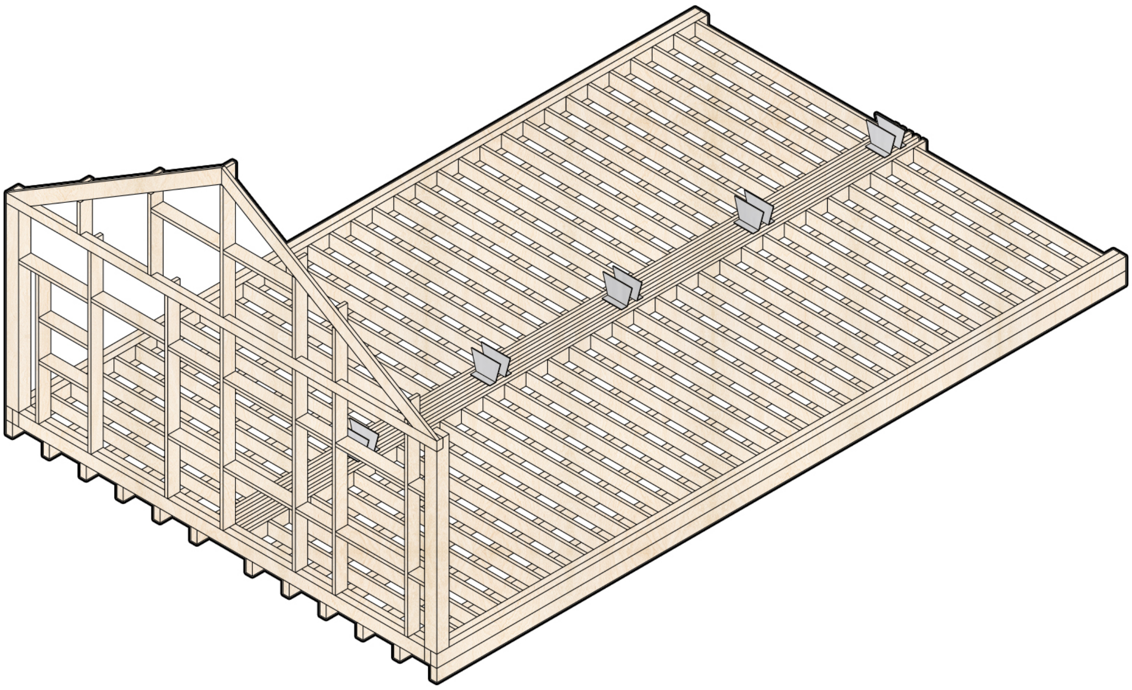


Figure 12. Construction stage 3 placing the frame of entrance to the position. Original author

There were 30 half trusses to erect in the truss shoe at the centre of the foundation. They assemble the half truss with timbers first and place the bottom position on the truss shoe and hinge on that and erect the entire half truss (Figure 13). At this time, after the top chord had been connected to the other side of the half truss, the person working on the top of the half truss had to install the gusset plate as quickly as possible (Figure 14). At the same time, a timber column must be installed for primary support immediately under the angle cleat between the top chord and bottom chord of the half truss (Figure 13). Each half truss must be assembled as fast as possible with all the manpower available because the lifting device cannot be used. Otherwise, the half-truss will fall down because of insufficient strength. This repeated step takes 30 times to complete the basic structure of the hut (Figure 15)(Royal Society 2017).

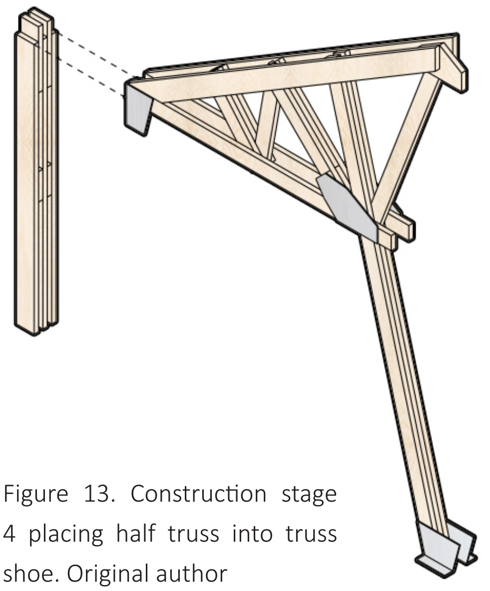


Figure 13. Construction stage 4 placing half truss into truss shoe. Original author

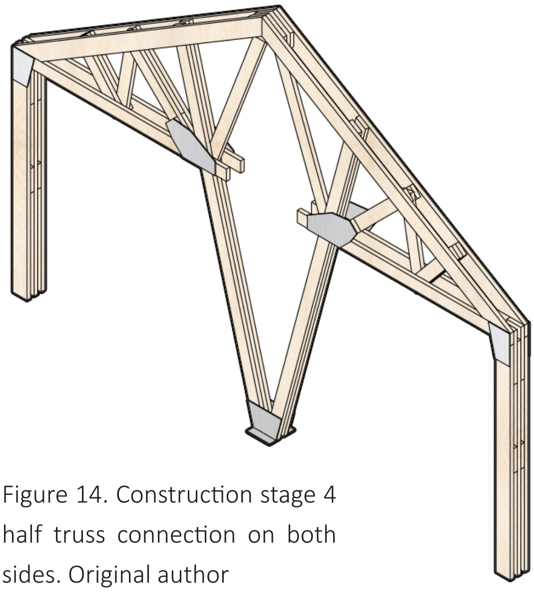


Figure 14. Construction stage 4 half truss connection on both sides. Original author

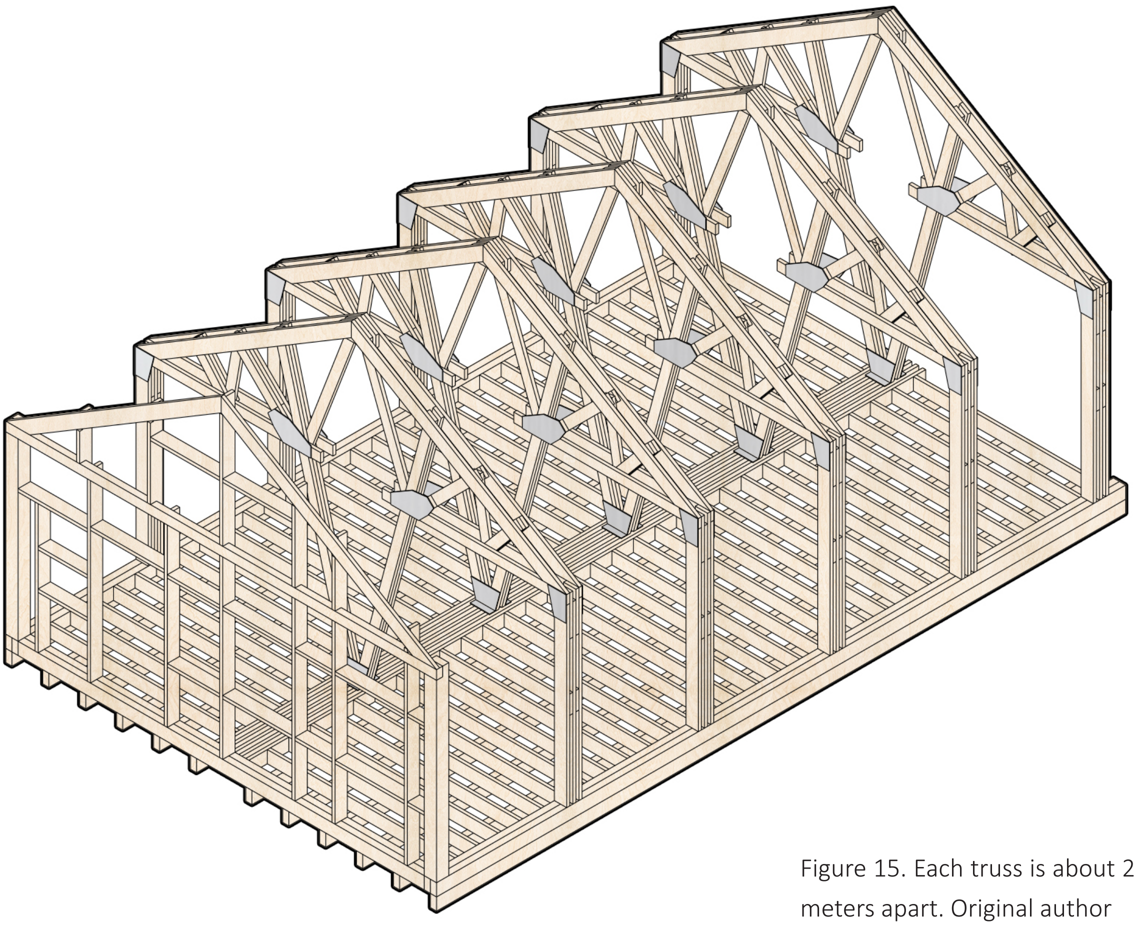


Figure 15. Each truss is about 2 meters apart. Original author

When most of the half trusses are installed, they need to start the work on the roof and facade as soon as possible because winter is coming. In terms of facade work, they assemble the wall studs first (Figure 16) and then place them between the half trusses for laying exterior finish, interior finish, and insulation. In terms of roof work, they use multiple rafters to fix on the top chord of truss (Figure 17) and then lay the planks over the rafters (Figure 18). There is a hatch opening in the pitched roof of the hut for observing the sky. Finally, the roofing felts were laid on the planks for waterproofing and protection (Figure 19) and the battens were placed on the roofing felts to fix them in place (Figure 20)(Royal Society 2017).

The shell was completed in early April, so most of the work can continue indoors. Finally, planks were laid on the joists as the floor finished. With part of the hut completed first, the team could move in from the tents and move supplies and equipment in from the warehouse, except for an emergency dump 1 km away (Stan Evans 2011).

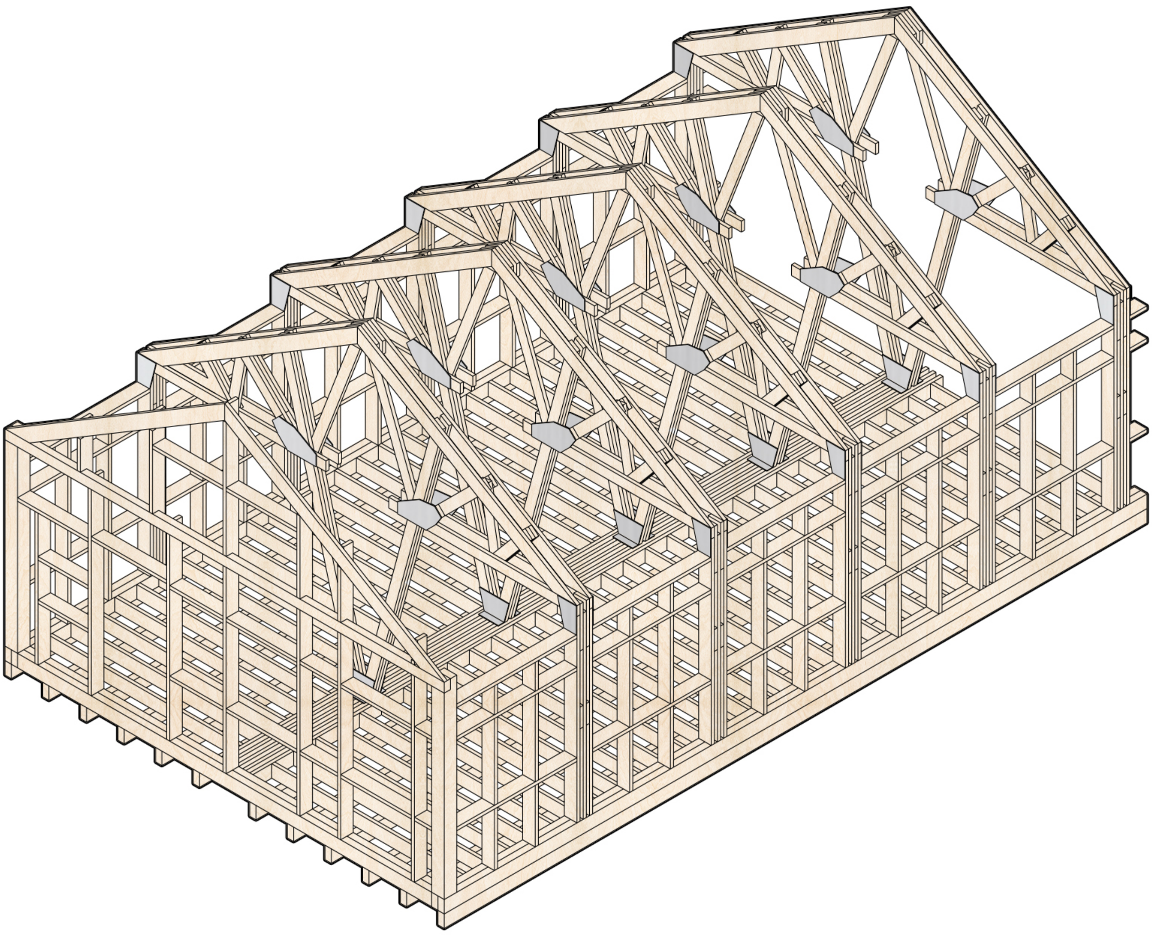


Figure 16. Construction stage 5 placing wall bracing between column to fix interior and exterior wall panel. Original author

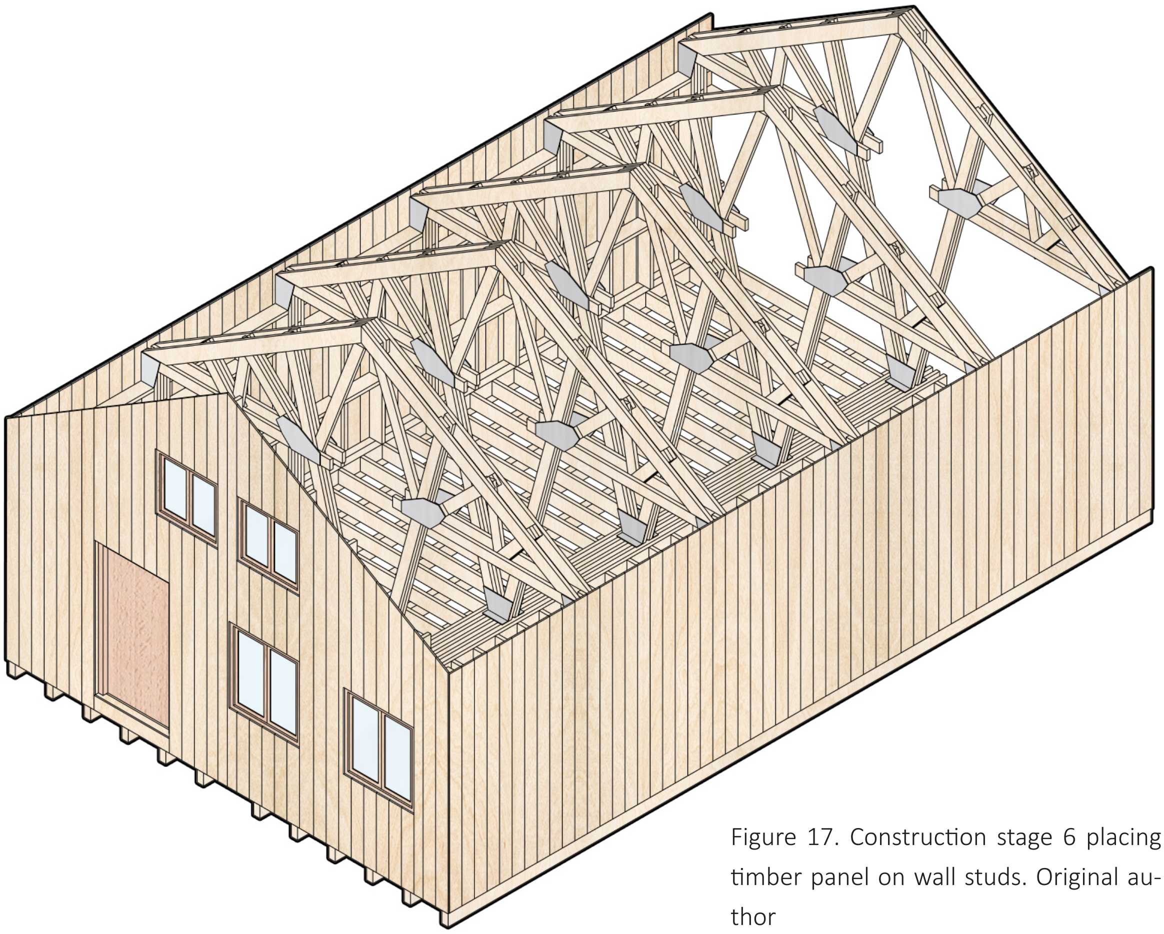


Figure 17. Construction stage 6 placing timber panel on wall studs. Original author

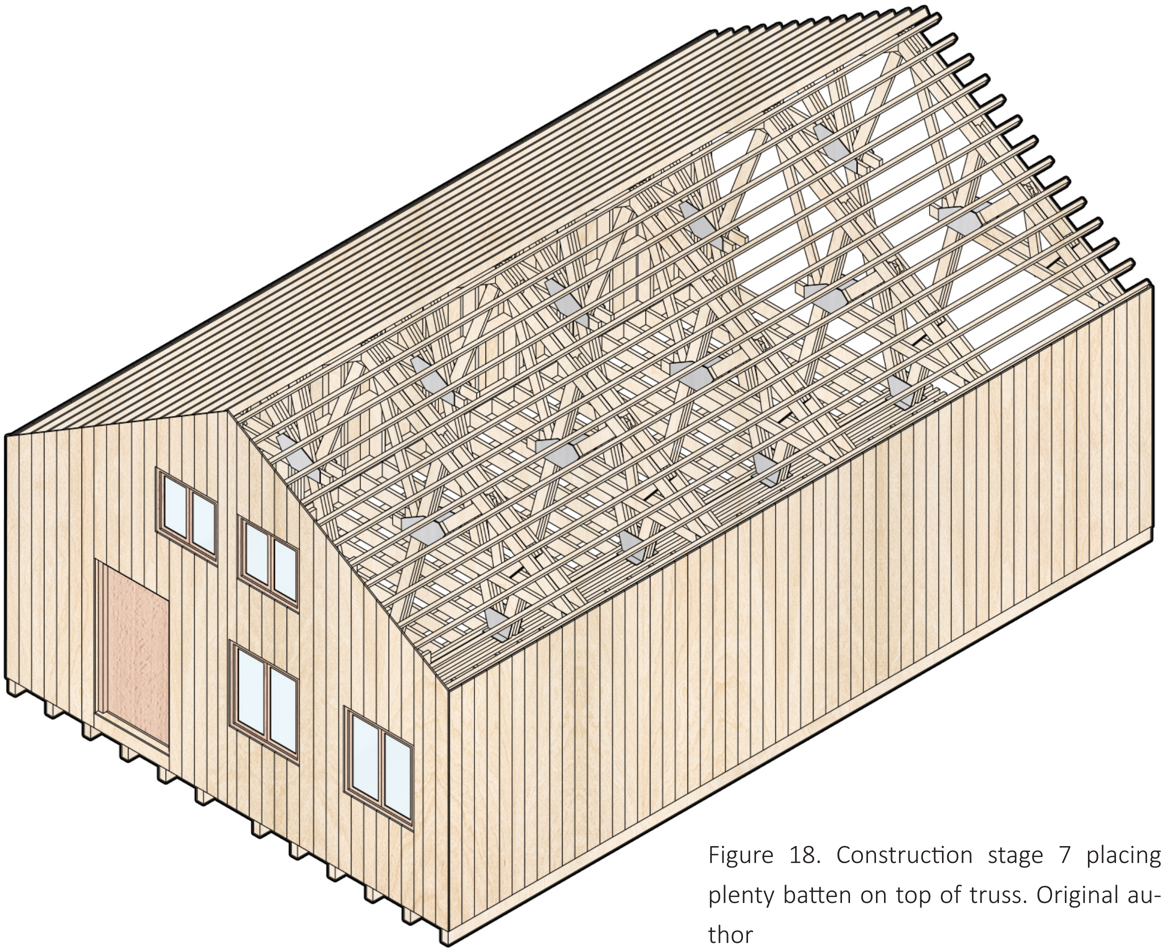


Figure 18. Construction stage 7 placing plenty batten on top of truss. Original author

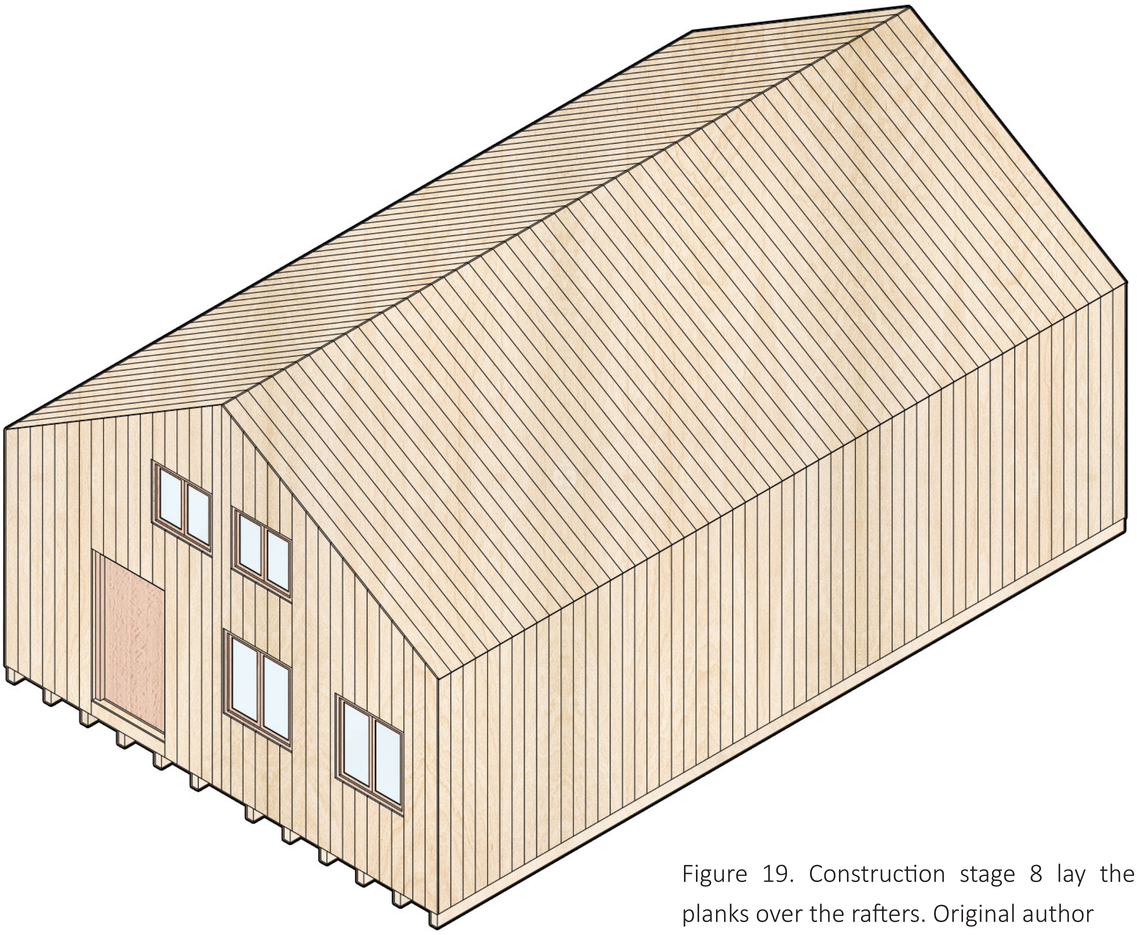


Figure 19. Construction stage 8 lay the planks over the rafters. Original author

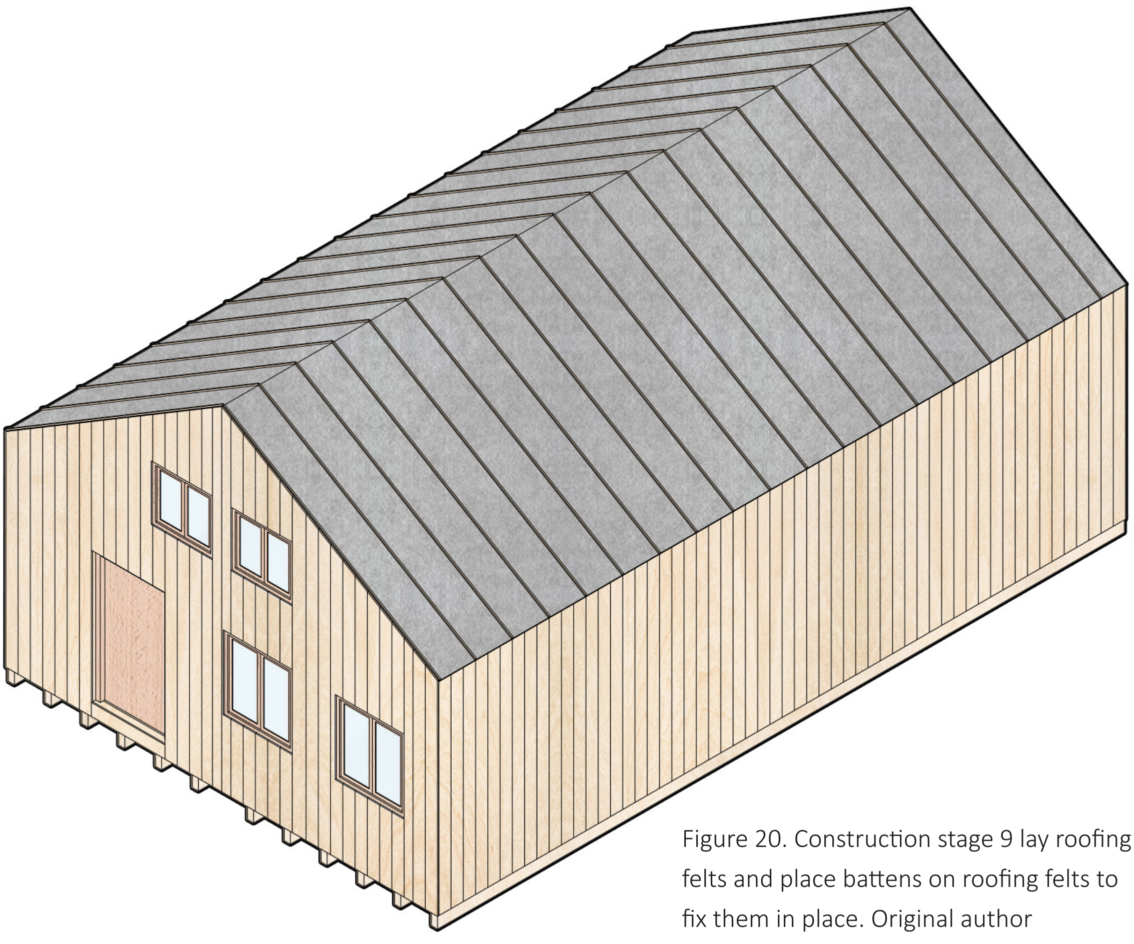


Figure 20. Construction stage 9 lay roofing felts and place battens on roofing felts to fix them in place. Original author

4.2.3. Operation of Station

There is a machine room with four diesel generators at the front of the hut (Ken Powell 2012). Cooking, water, and heating are provided by an anthracite convection stove. For the bathing aspect, they filled galvanised iron buckets from an adjacent boiler tank and poured them into their own making cavern beneath the floor. Regarding garbage disposal, in their daily life they generate rubbish, and food waste in Antarctica is no exception. There is an emergency dump 1 km away from the hut, and they regularly bring garbage there (Stan Evans 2011).

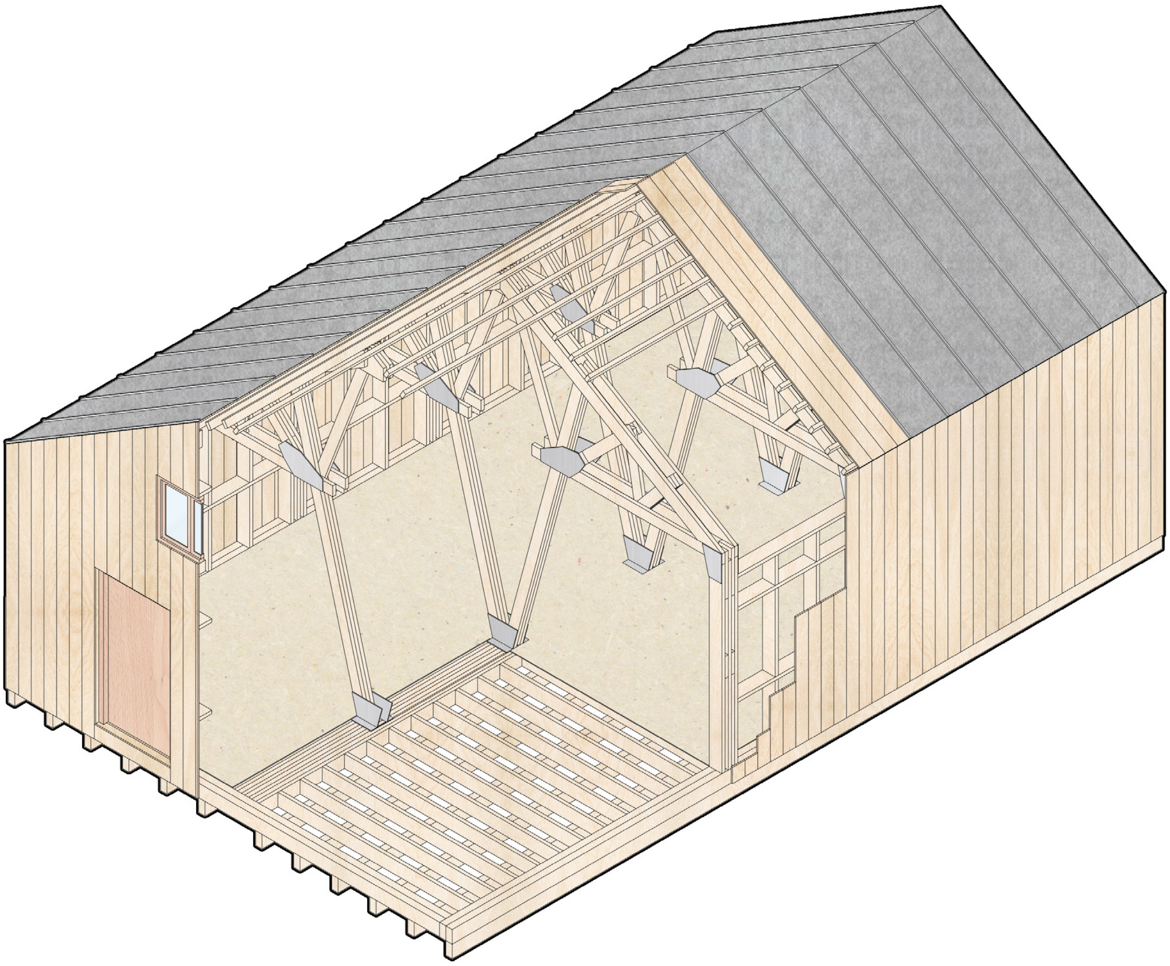


Figure 21. IGY hut after construction. Original author

[2] Halley I station consists of four separate huts and was later taken over by the British Antarctic Survey

4.2.4. The Base Gradually Loses its Function as a Shelter

The IGY hut[2] finally buried 18 metres underground. To get there is via a shaft with a ladder inside or another tunnel to the living hut and then a sloping tunnel to there. It is slowly cracking under the pressure of the ice, and it is already at risk of collapsing. Except the office hut on the ground and its loft are still available as an alternative sleeping area. The other huts are no longer available for normal activities (John Gallsworthy 2011). Eventually, it closed in 1968.

Halley I Station has shown that wood framing construction is the best option without assistant of construction equipment. In the 1950s, the construction did not have more mature technology and devices and the construction site was in remote, difficult to transport and harsh cold environments. Timber frame structures are generally much faster to build than blocks and bricks and lighter. In addition, timber frame structures can be easily constructed in harsh weather and environment. This structure requires good well insulation, otherwise the indoor environment will make people feel uncomfortable. However, the team did not consider that accumulated snow could cause serious problems. Snow often buried the hut and a large amount of snow was on the pitched roof which failed to clear the snow to the ground. They had to regularly remove the snow around the base and on the roof. After the first winter, all parts of hut except the roof were buried by snow. Eventually the hut was slowly crushed and severely deformed by the weight of the snow but still usable. Eventually the Halley I station had to be abandoned and replaced by the Halley II station but still can be used as a warehouse.

4.3. Halley II

4.3.1. Preparing to Build New Base and Organization of the Building Team

On the 6th December 1966, the Perla Dan vessel, which boarded the prefab components, materials for construction, and supplies, set off from Southampton to Halley Bay. The building team took the RRS John Biscoe vessel to Montevideo and then to the Falkland Islands to wait for Perla Dan to arrive and then transfer to the Perla Dan vessel to reach Halley Bay. After arriving at Halley Bay, the station staff greeted them on the ice cliff, and the crews unloaded building materials and supplies and transported them to the Halley I station to prepare for the construction of the Halley II station (John Gallsworthy 2011).

4.3.2. Construction of New Station

The new Halley base will be built with seven separate huts. Each hut is connected to the tunnel as the main access and provides shaft access to the ground when snow accumulates around the base. The original construction plan was to build a canteen with a kitchen and dining room, then two bunk room, generator hut, an office block, a garage, and finally a lounge with offices and a radio room (Figure 22)(Chris Sykes 2014). The entire station has no windows because it is expected to be buried in snow and it was called “grillage village” because the foundation of the hut looked like a grill when the station was completed (John Gallsworthy 2011).

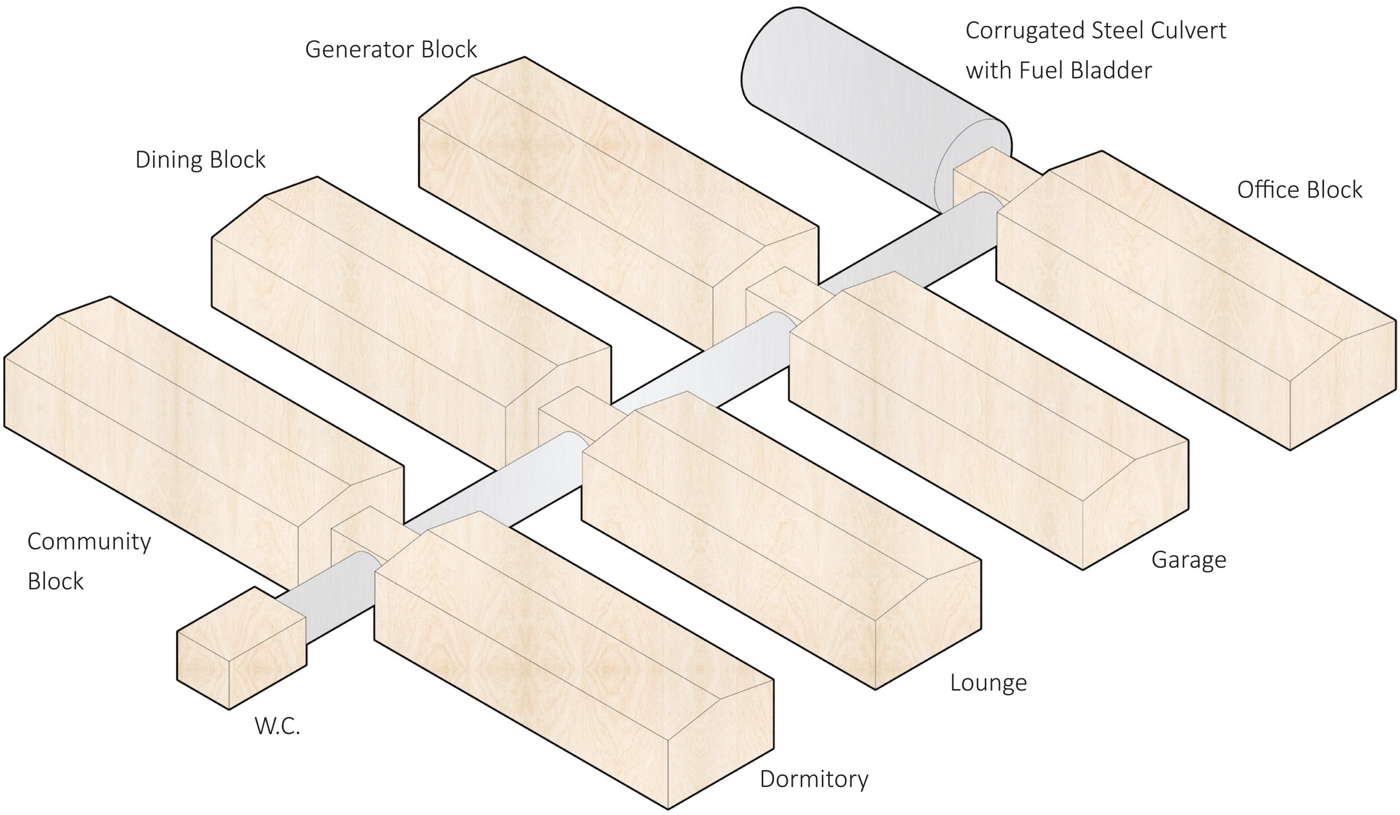


Figure 22. Halley II zone planning. Original author

The new base was built in the same way that the Halley I was built, directly on the ground, with grillage foundations applied to every hub. The building team first levelled the snow surface and laid down perforated metal sheet, and then laid all the beams on it as a foundation (Figure 23)(Tony Baker 2010). They then laid another layer of beams on top of the beams, which is a grill pattern as a base for the flooring. Then place panels on top of it as a base for the floor finish (Figure 25)(John Gallsworthy 2011).

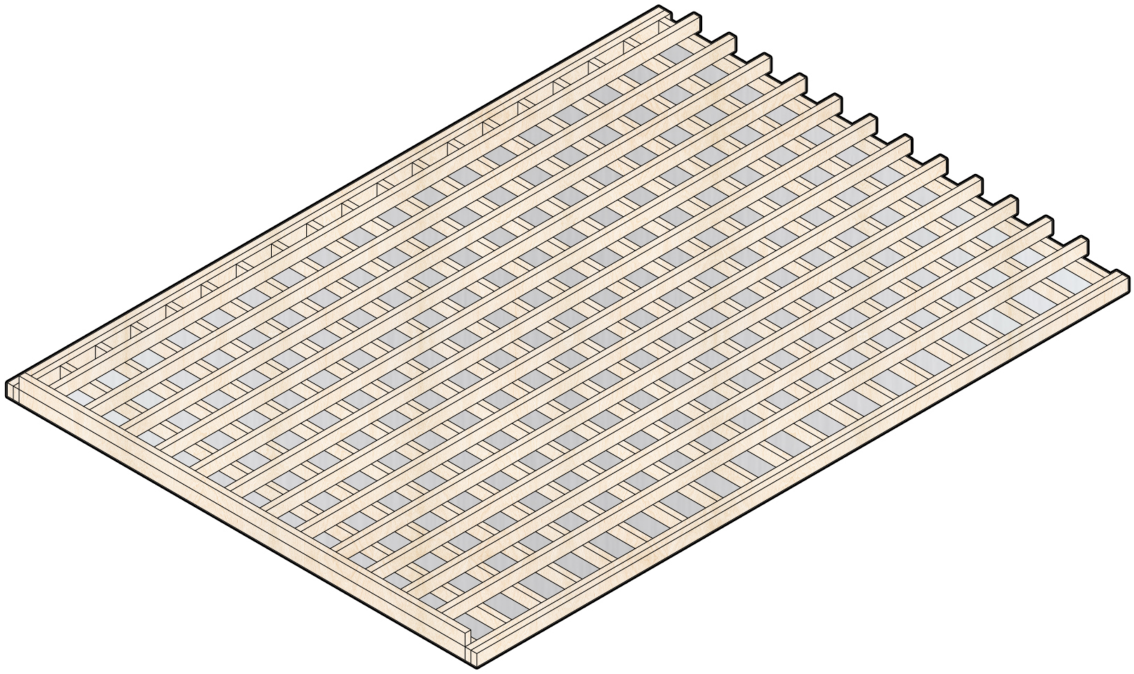


Figure 23. Construction stage 1 placing perforated metal sheet on surface and laid massive of timber on top of metal sheet to form foundation. Original author

Basically, after the foundation of the hut has been completed, the team starts to install the roof structure. The new base huts applied steel portal frames as the main structure for the roof (Figure 24). These steel frames are prefabricated for convenient on-site assembly. The team first assembled the components of the steel portal frame, and then they had to lift and pull them up by hand to install them on the foundation without the assistance of a machine. Every 2.5 metres, steel portal frames were installed. Once the frame was raised, they connected the rafter of the steel portal frame on the other side and fitted the apex haunch in the middle of the rafters (John Gallsworthy 2011). All the steel portal frames were already cut and drilled in the UK, and they just needed to bolt all the components together in order (Tony Baker 2010).

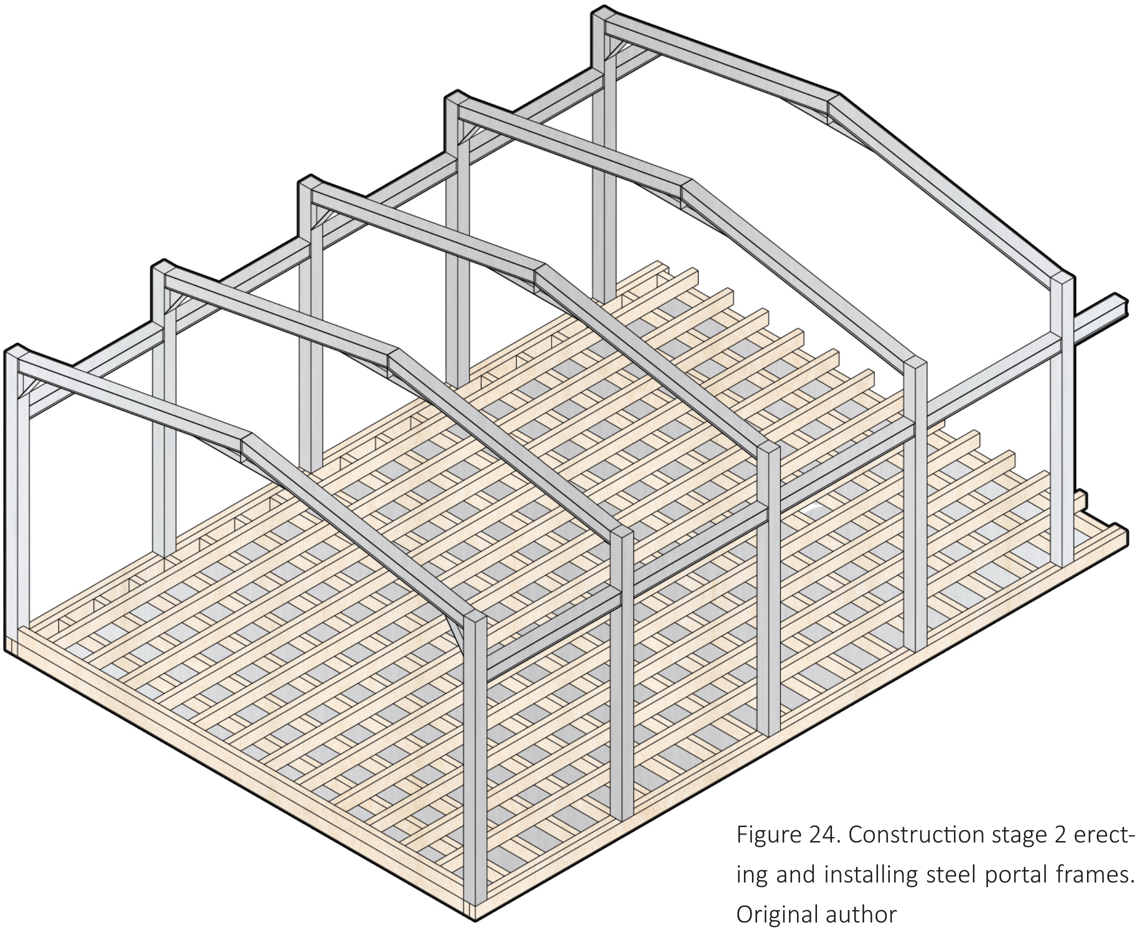


Figure 24. Construction stage 2 erecting and installing steel portal frames. Original author

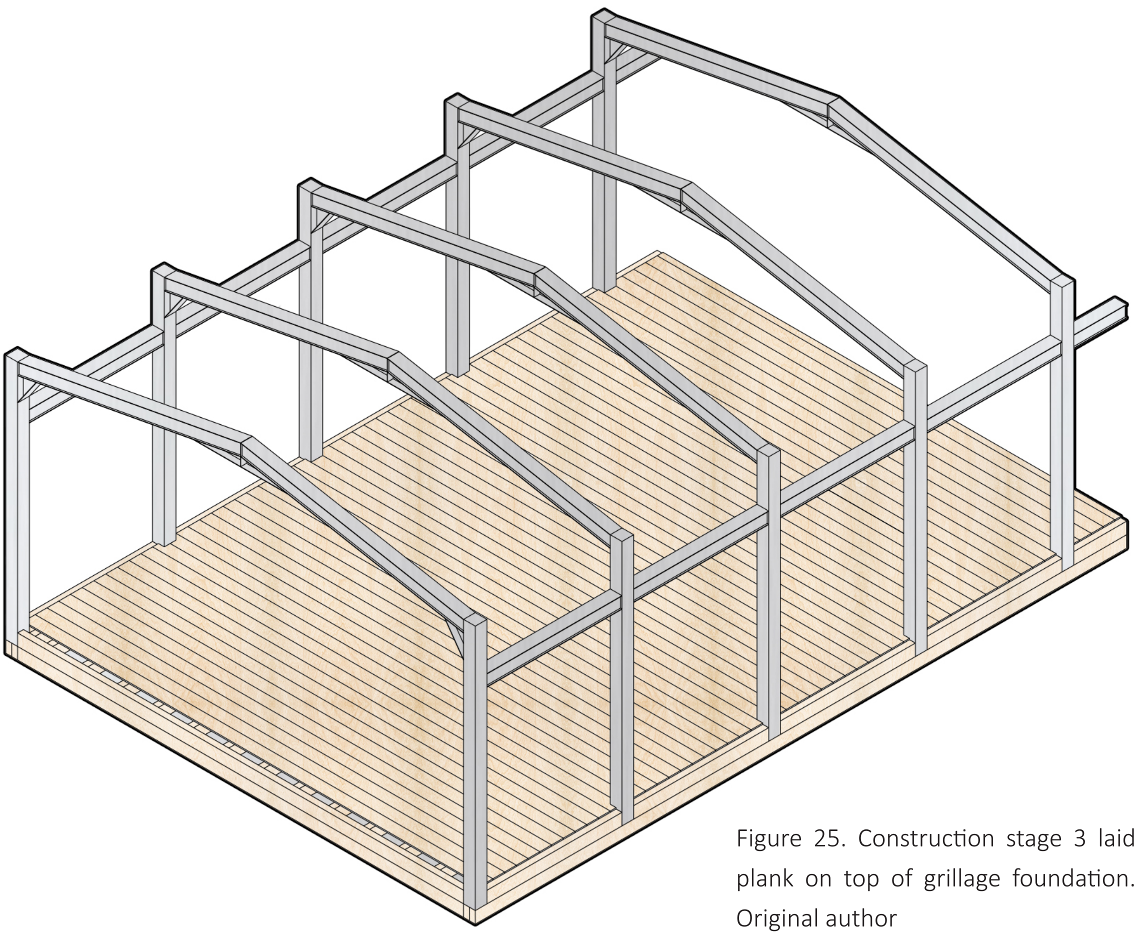


Figure 25. Construction stage 3 laid plank on top of grillage foundation. Original author

When the steel portal frames were installed, the wall bracing were installed between them as the foundation of the wall panel (Figure 26). A number of timber purlins are fastened with purlin cleats to the rafters of the steel portal frames as the base of the roof panels (Figure 27). Then 3 inch pre-cast insulation board panels were installed on the wall bracing (Figure 28). Massive planks were laid on the purlins (Figure 29), followed by roofing felt for waterproofing and protection, and battens were laid on the roofing felt to secure them (Figure 30). Finally, they laid massive planks on the battens as the roof finish (Figure 31)(John Gallsworthy 2011). Then they began to build access to the base. There is a timber-framed tunnel between the huts and a tunnel made of corrugated steel (Figure 32). This tunnel acts as the main access, connecting each hut to the shaft in the station. After the first winter, the access shafts were built to prevent the station from being buried and inaccessible (Chris Sykes 2014).

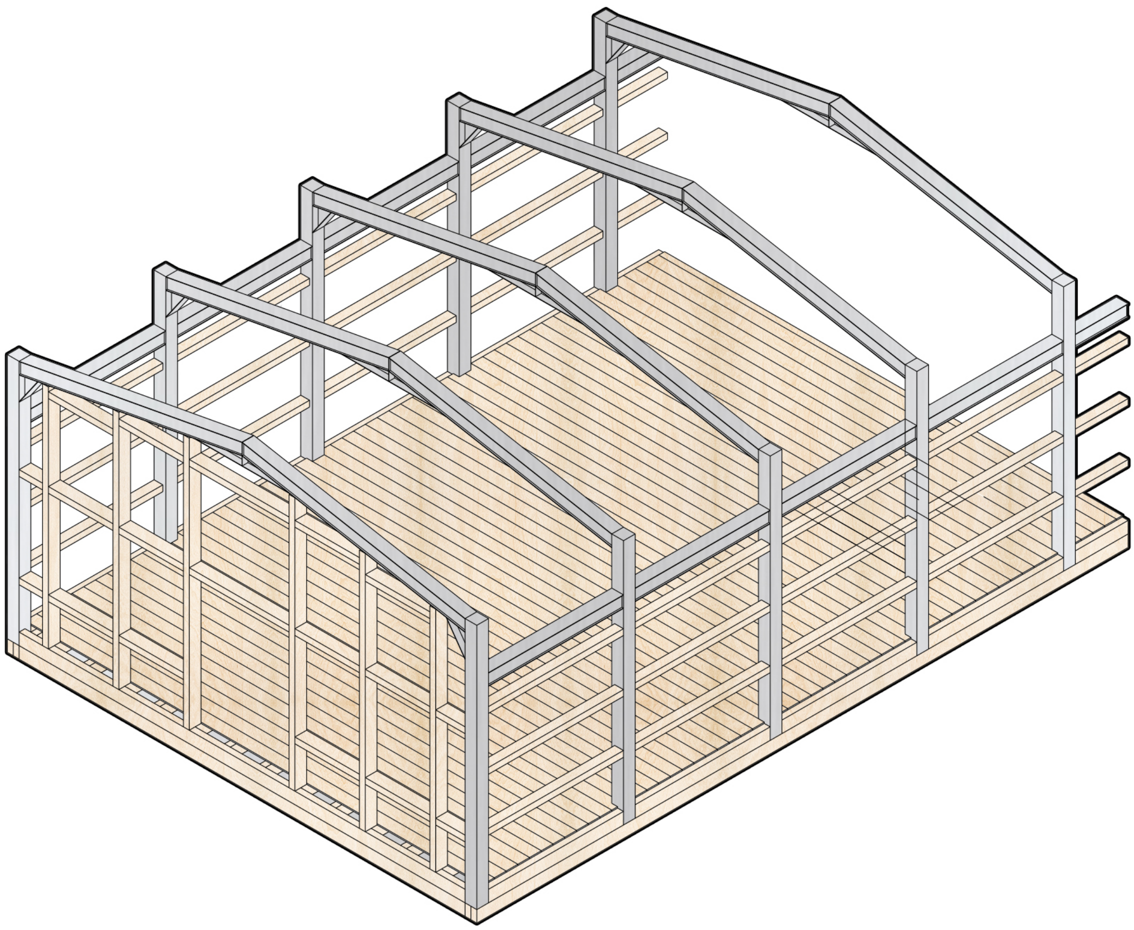


Figure 26. Construction stage 4 installing wall bracing. Original author

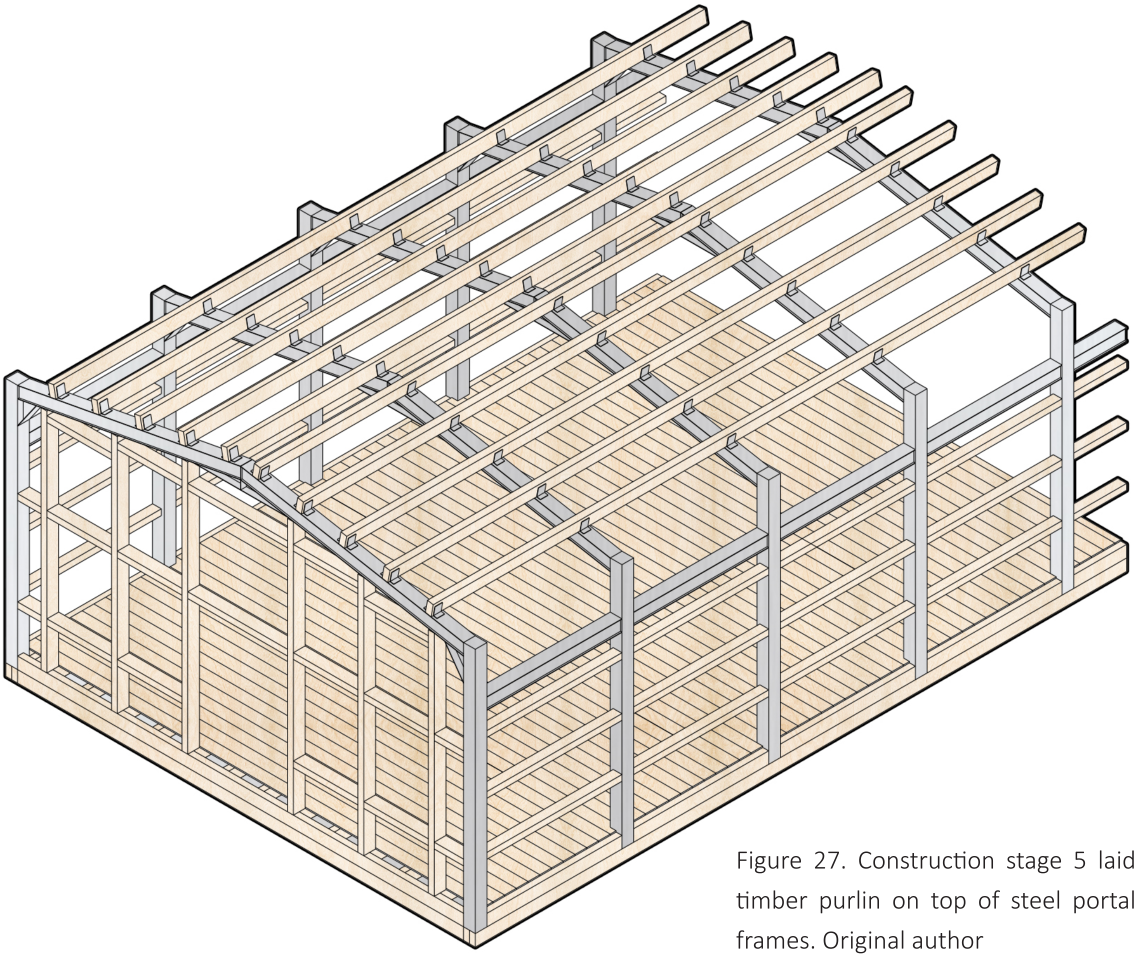


Figure 27. Construction stage 5 laid timber purlin on top of steel portal frames. Original author

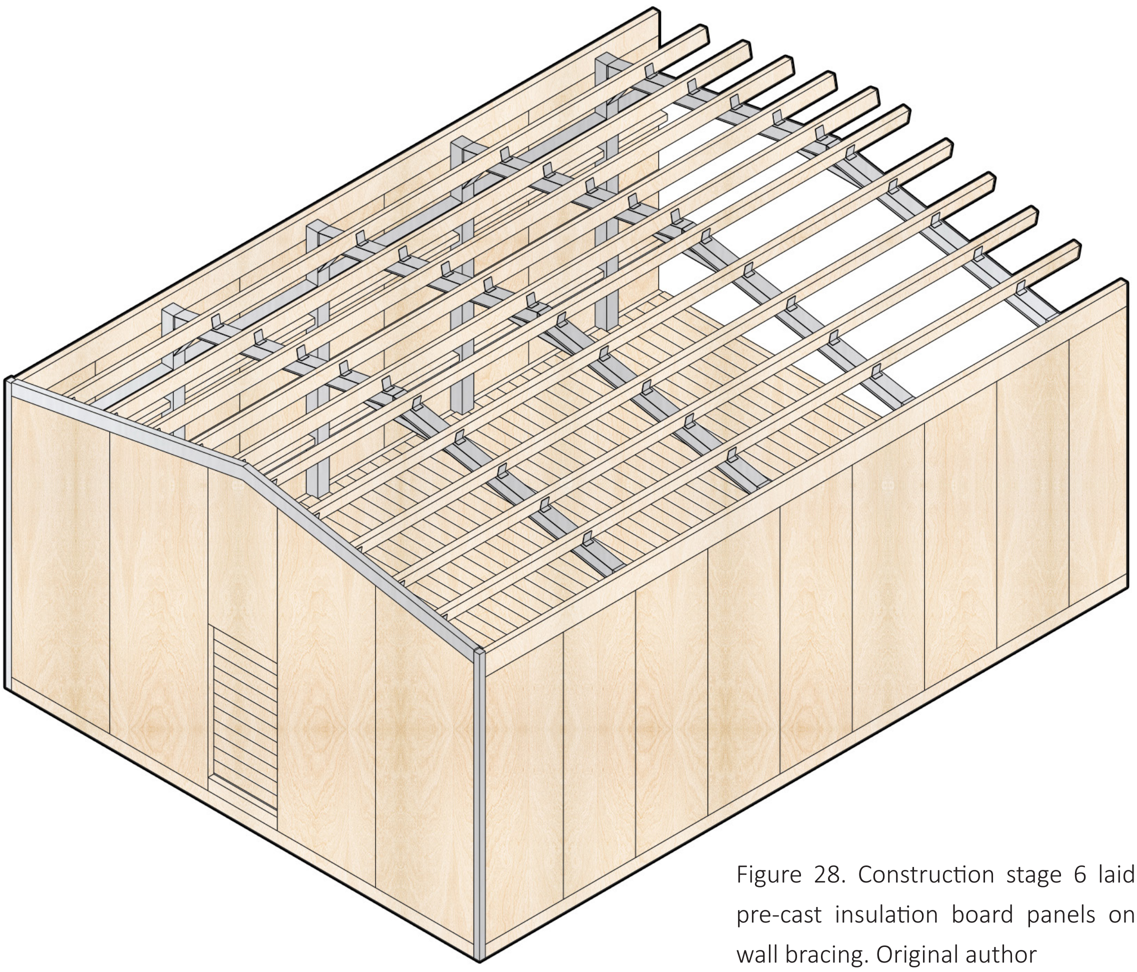


Figure 28. Construction stage 6 laid pre-cast insulation board panels on wall bracing. Original author

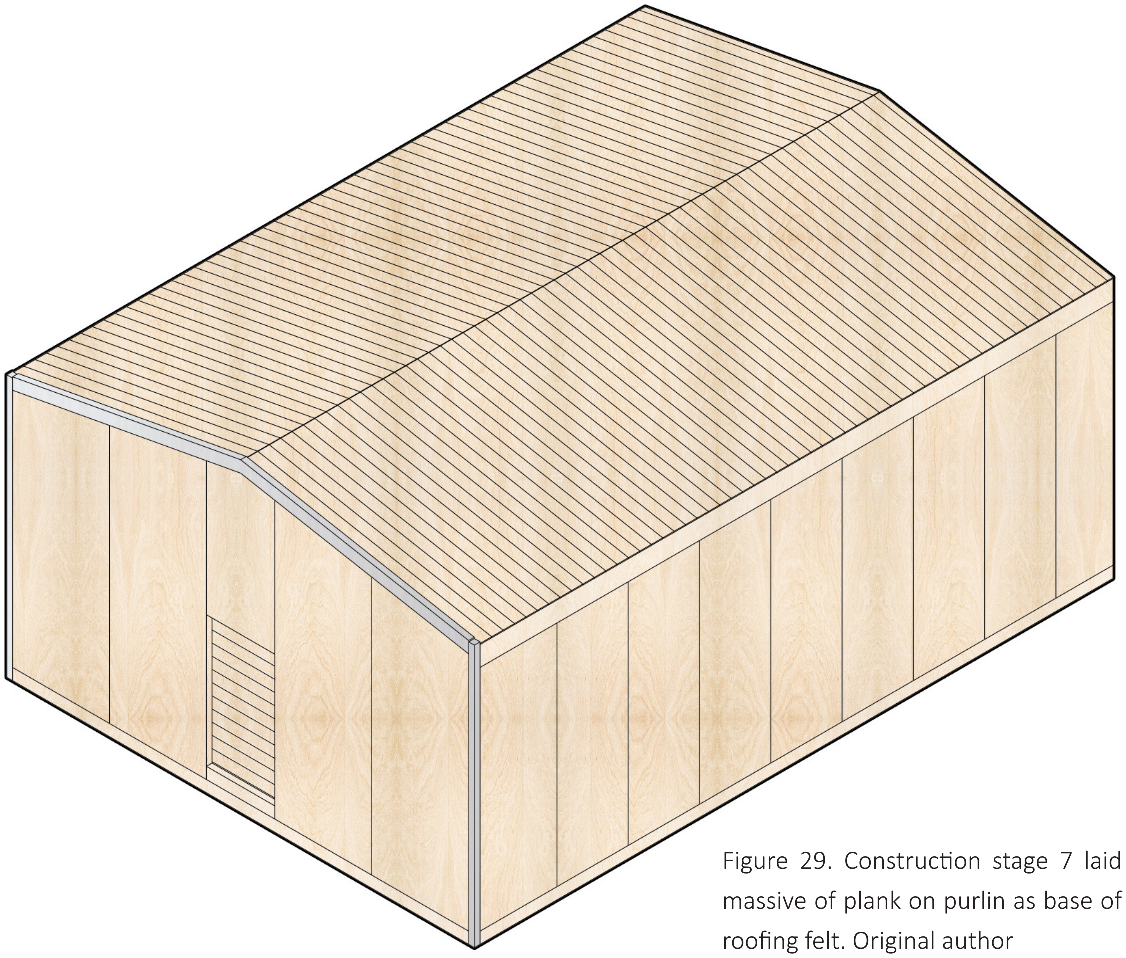


Figure 29. Construction stage 7 laid massive of plank on purlin as base of roofing felt. Original author

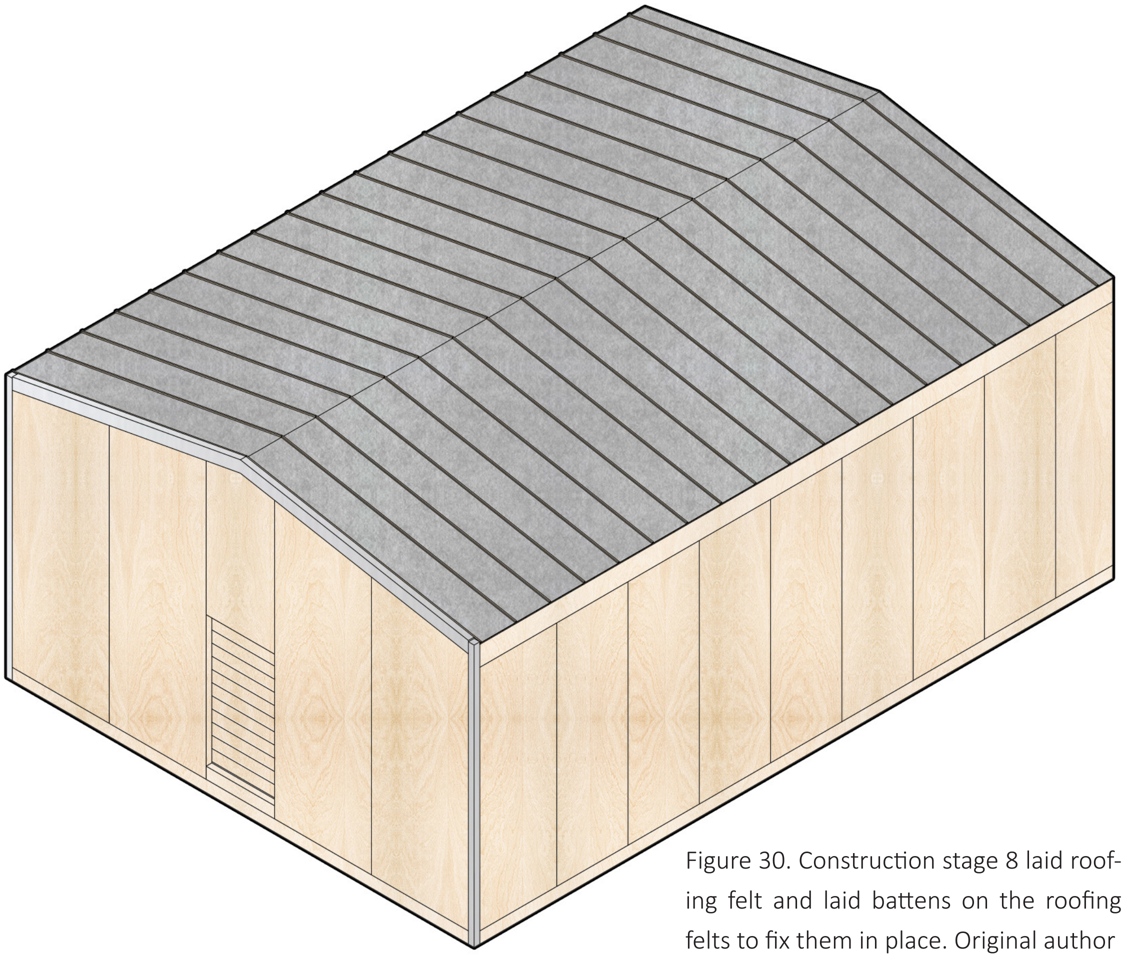


Figure 30. Construction stage 8 laid roofing felt and laid battens on the roofing felts to fix them in place. Original author

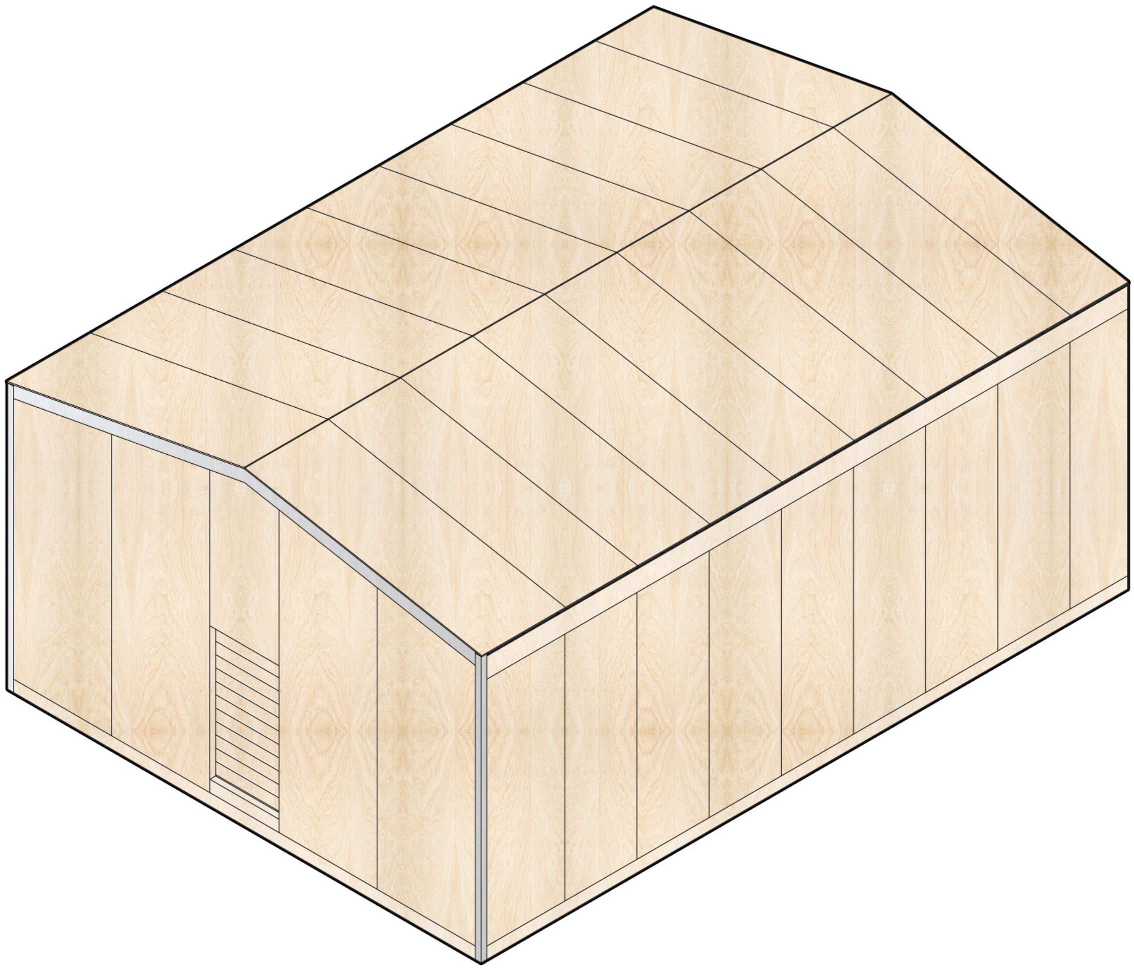


Figure 31. Construction stage 9 laid planks on the battens as the roof finish. Original author

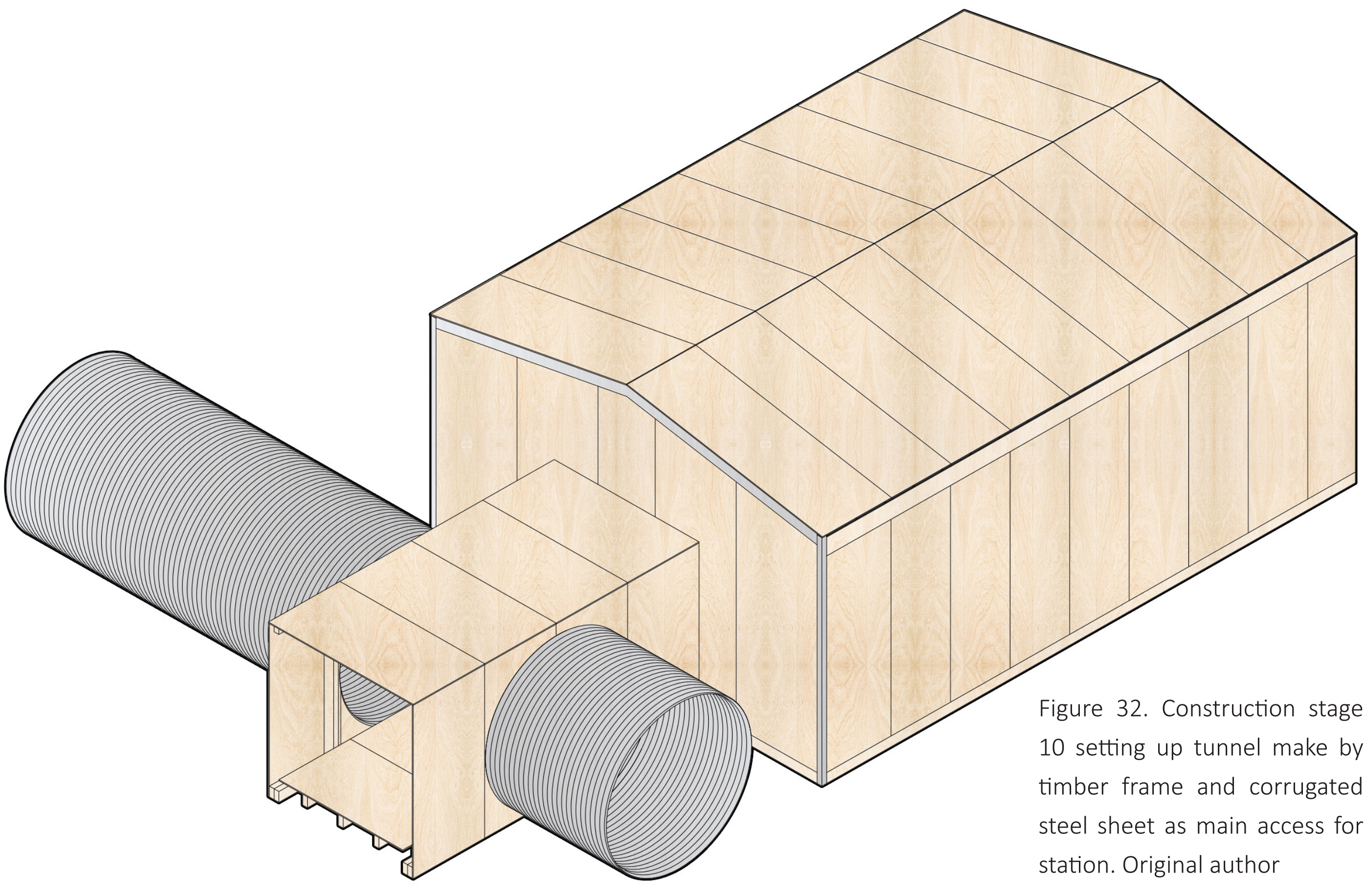


Figure 32. Construction stage 10 setting up tunnel make by timber frame and corrugated steel sheet as main access for station. Original author

4.3.3. Operation of Station

The station will have a separate hut for generators with three generators inside. One generator will provide power for the entire station; another will be on standby; and the third will be available for maintenance. However, with the demand for electricity still increasing and requiring other generators to operate to produce stable electricity, next to the generator hut is a corrugated steel Armco culvert with fuel bladders that stores a large amount of fuel to power the generator. It will also have a separate garage for tractors to park in (Chris Sykes 2014).

In terms of water supply, they would take water from melting water running down the back slope into a large tank in the summer, but water would be frozen before snowing in the fall. They would find some ice floes on the sea and chop them up and use them as water (John Brotherhood 2013).

4.3.4. Halley II Constantly Squeezed by Accumulated Snow

As the weight of the accumulating snow above the Halley II gradually increased, its pressure gradually crushed the base. It had been crushed and needed to be replaced with a new base when Halley II occupied Antarctica during these 7 years. All the beams in the base were cracked, causing water to enter the interior. The snow melted around the base as heat escaped from the hut due to cracks in the ceiling. The melted snow formed drops of water into the huts and hit the floor and refrozen. There is often an ice layer on the floor of the huts, making it very cold inside because all the insulation is broken.

This time, the construction method of the new station was built in components to reduce the construction time, manpower, and machinery. This method is faster, lighter, and more durable than Halley I. Although the station was built in the form of components, relying only on manpower without the assistance of machinery will inevitably cause the team to struggle. All huts are designed without any openings because it has been considered that they will be buried by snow. Since there are no openings, a well-ventilated system is required to operate at the station. The new base has a pitched roof reinforced with steel supports due to the experience of Halley I being crushed by accumulated snow. However, the reinforced pitched roof didn’t seem to be of much help and ended up being crushed by the snow. The station’s lifespan was shorter than expected, and eventually it was abandoned in 1973.

4.4. Halley III

4.4.1. Preparing to Build Halley III and Logistical Accident

In 1973, the RRS Bransfield vessel boarded supplies and construction materials for Halley III and the building team to depart from Southampton and arrive at Halley Bay in January. This year's Bransfield operation is risky due to repeated collapses of Halley Bay ice cliffs. A lot of material had to be unloaded as the base was to be rebuilt. A section of an ice cliff collapsed and a massive amount of ice fell on Bransfield. She was damaged until the ice was removed from the deck and then had to load her cargo near the Dawson-Lambton Glacier. The snow ramp where the vessel was usually moored has broken off. She had to approach a 30-foot ice cliff to unload. This ice cliff collapsed shortly after unloading began. Eventually, she had to approach a 45-foot ice cliff to unload the cargo. This section of the ice cliff also collapsed after unloading was completed. The ice fell to cause considerable damage to the bridge front, and the entire vessel capsized continuously (New Zealand Antarctic Society 1973).

4.4.2. Construction of Halley III

The BAS gained experience through Halley I and Halley II. The design team designed a very revolutionary station for Halley III compared to its predecessors (Paul Burton 2011). In 1973, the building team began building Halley III on the surface. The original construction plan for the station was to build a tunnel that is like an underground shopping street (Paul Burton 2011). The six huts with different functions in the tunnel are: the generator shed, workshop, dormitory, and doctor's surgery; the living area includes a kitchen, dining room, lounge, and radio room; the science block and garage (Mike Hood 2021).

The team first levelled the surface, then used a lot of prefabricated corrugated steel sheets and bolts and nuts to combine them together (Figure 33, 34)(Paul Burton 2011). As the station gradually formed into the shape of a tube, the team built working platforms and stairs on its surface and installed a derrick on a tractor to help with the part at the top. They had to leave the ends of the tube blank to make it easier to build a hut inside. Then they started to build the hut inside when the steel tubes were finished (John Gallsworthy 2011).

Since the bottom inside the tube was round, they first built a steel grillage framework for the hut. This allows the hut to sit there and build the hut on top of it (Figure 35). The huts were built in the same way as the Halley II, a timber-framed building without openings, but the roof was mainly composed of timber frames (Figure 36, 37, 38, 39, 40). The timber framework and planks were installed to close the space at the end of each steel tube when the hut was finished. Small steel tubes were then built to connect each hut as the main access to the station. Finally, they built the shafts next to the main access to connect the surface, and they built the steel tube between the garage and the surface for the vehicle entrance (John Gallsworthy 2011).

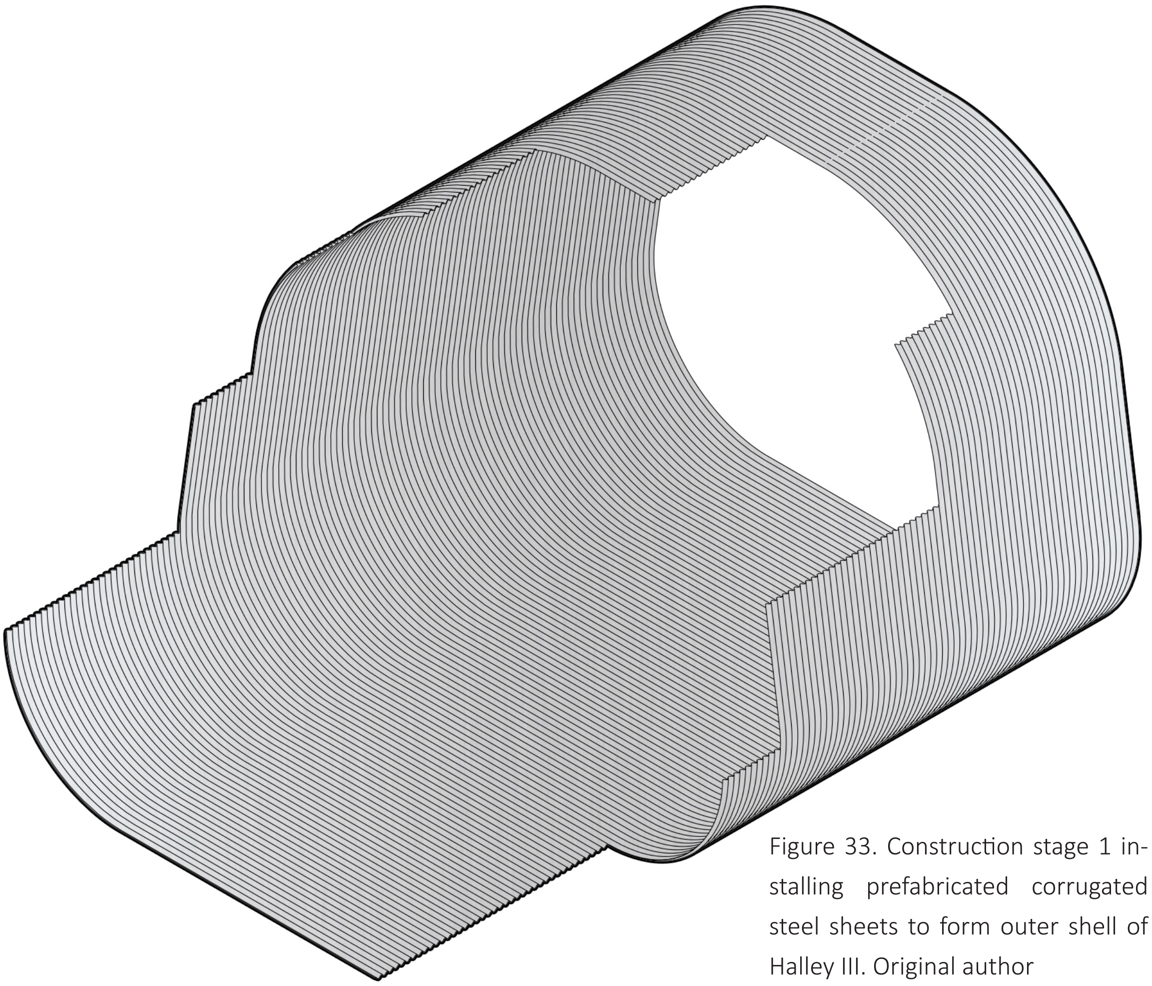


Figure 33. Construction stage 1 installing prefabricated corrugated steel sheets to form outer shell of Halley III. Original author

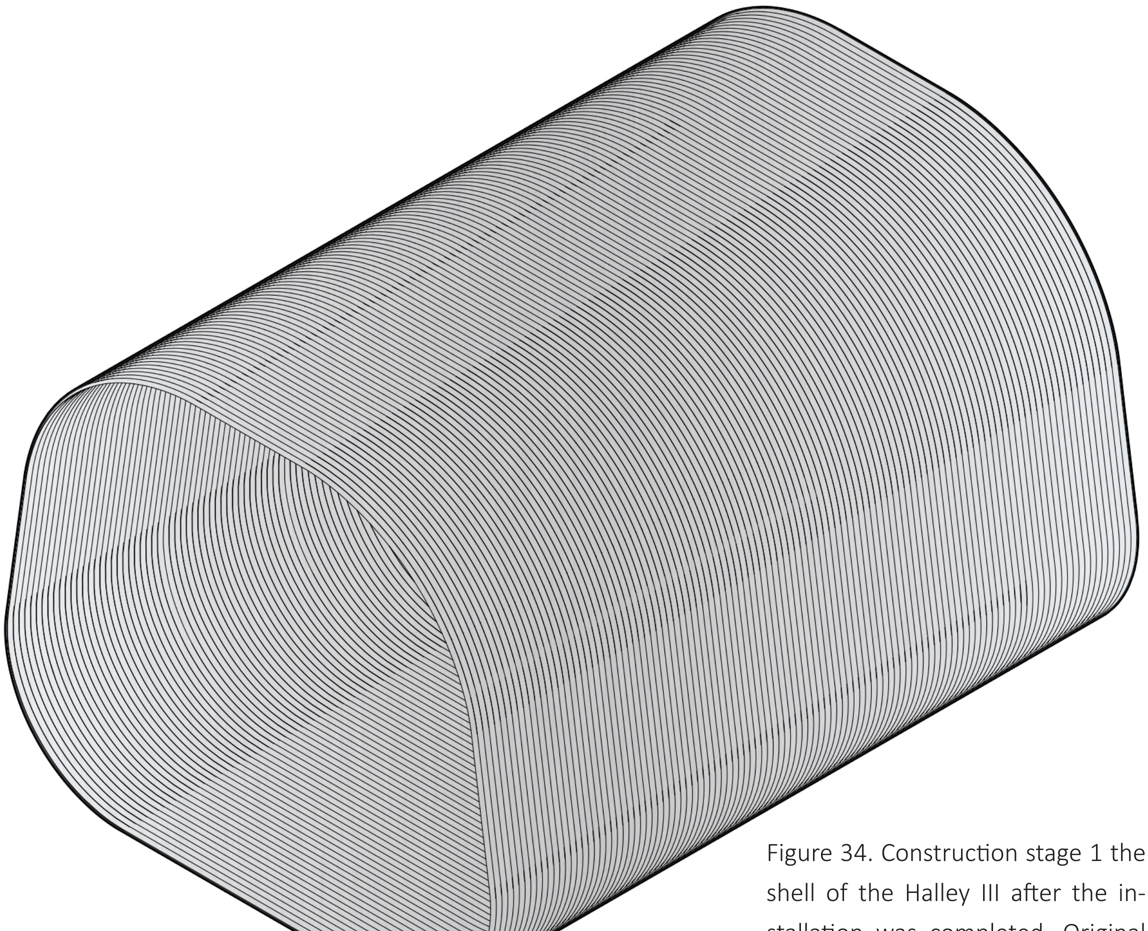


Figure 34. Construction stage 1 the shell of the Halley III after the installation was completed. Original author

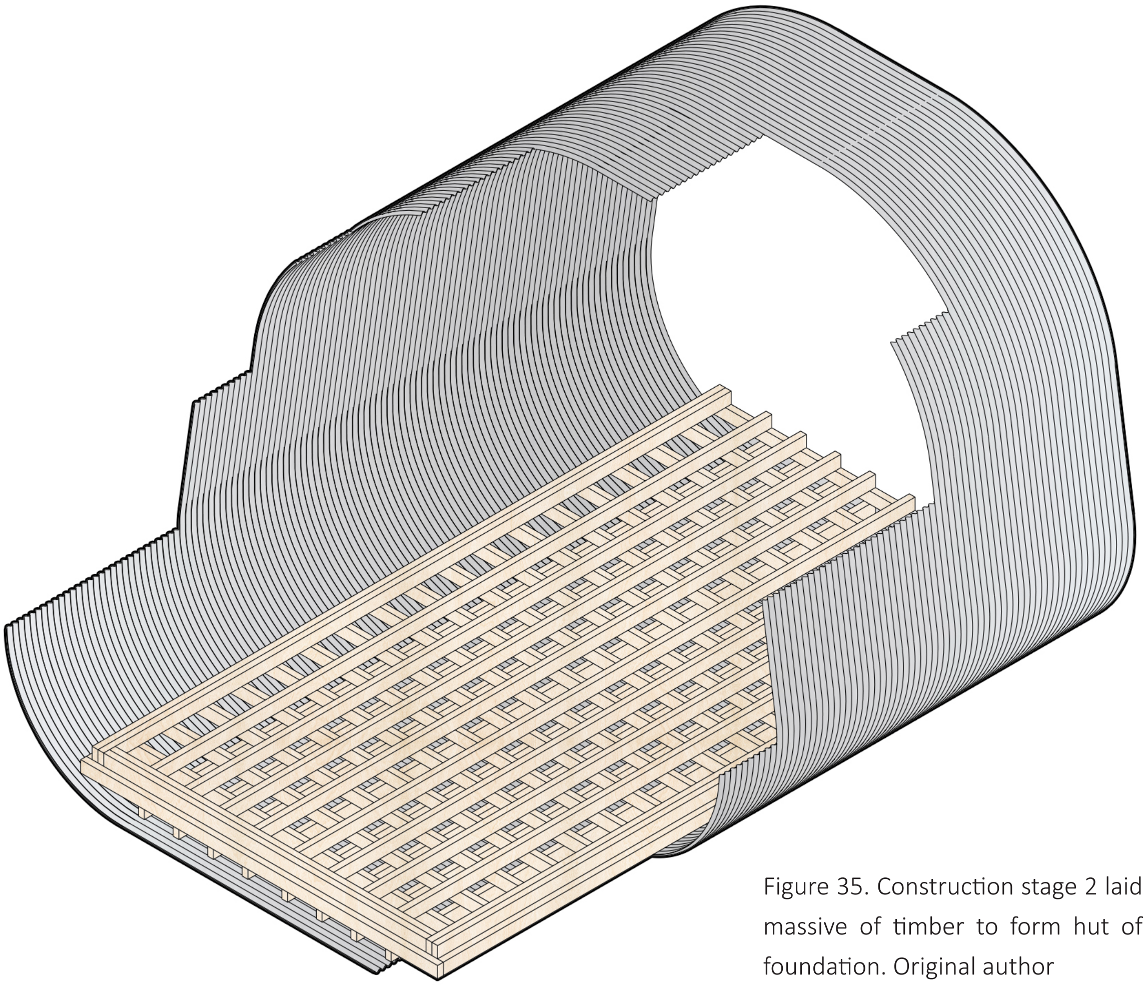


Figure 35. Construction stage 2 laid massive of timber to form hut of foundation. Original author

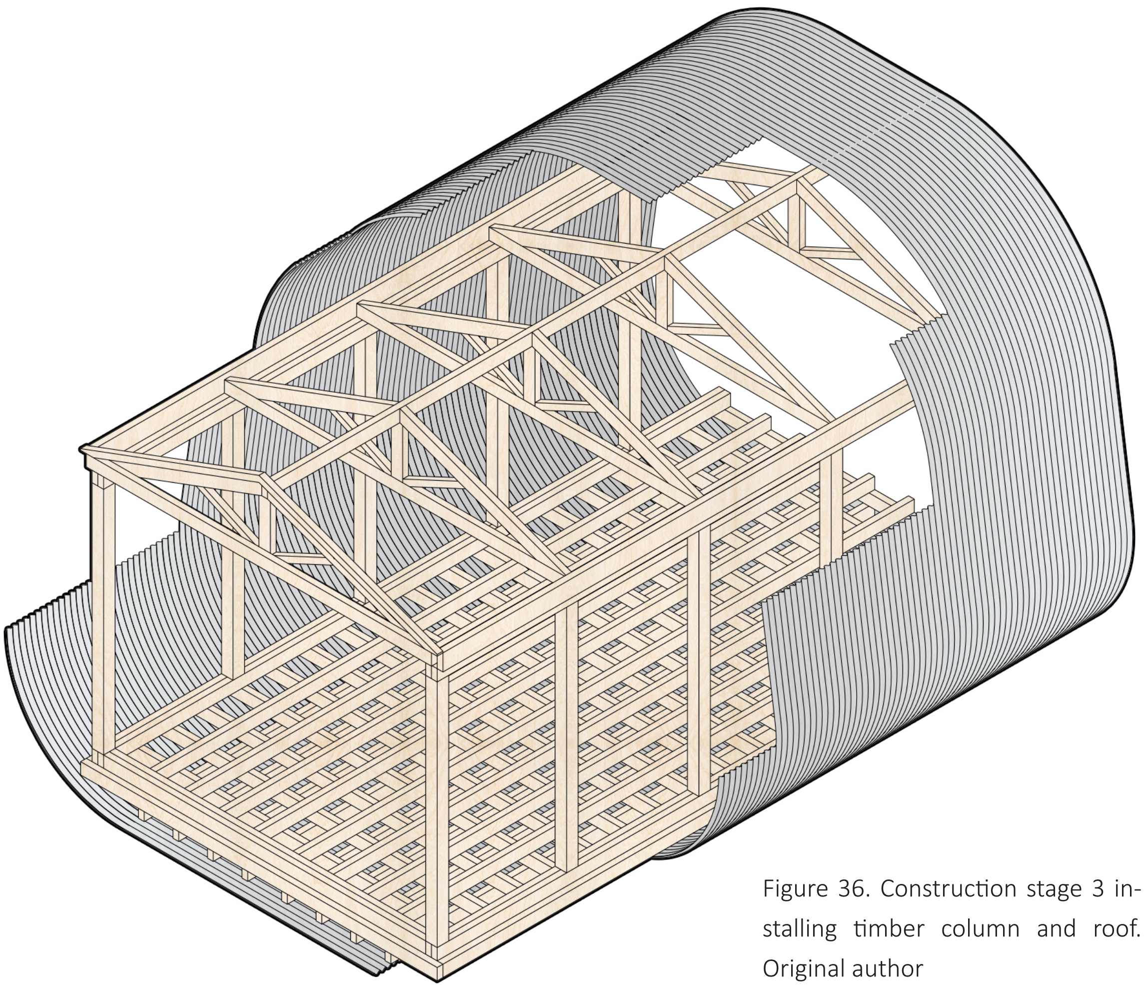


Figure 36. Construction stage 3 installing timber column and roof. Original author

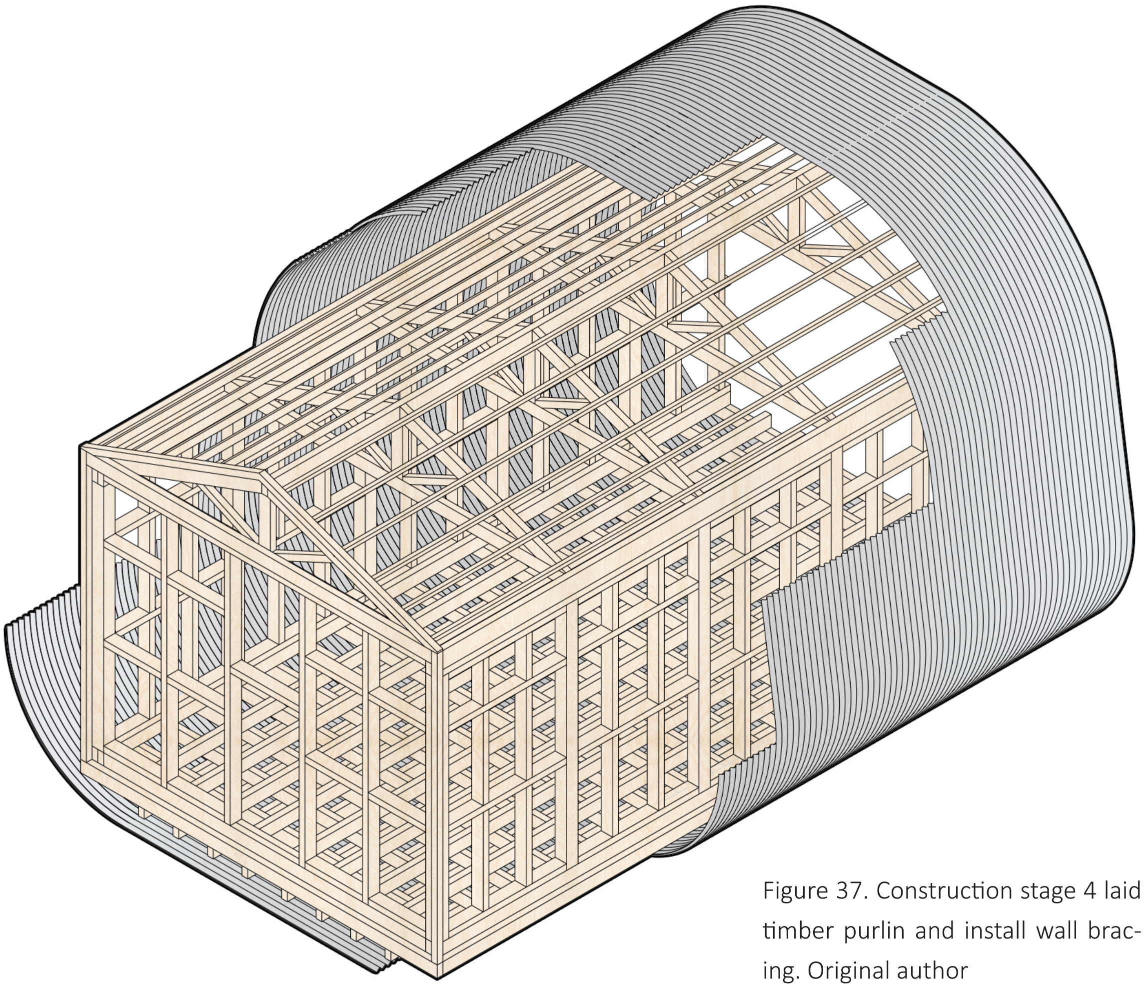


Figure 37. Construction stage 4 laid timber purlin and install wall bracing. Original author

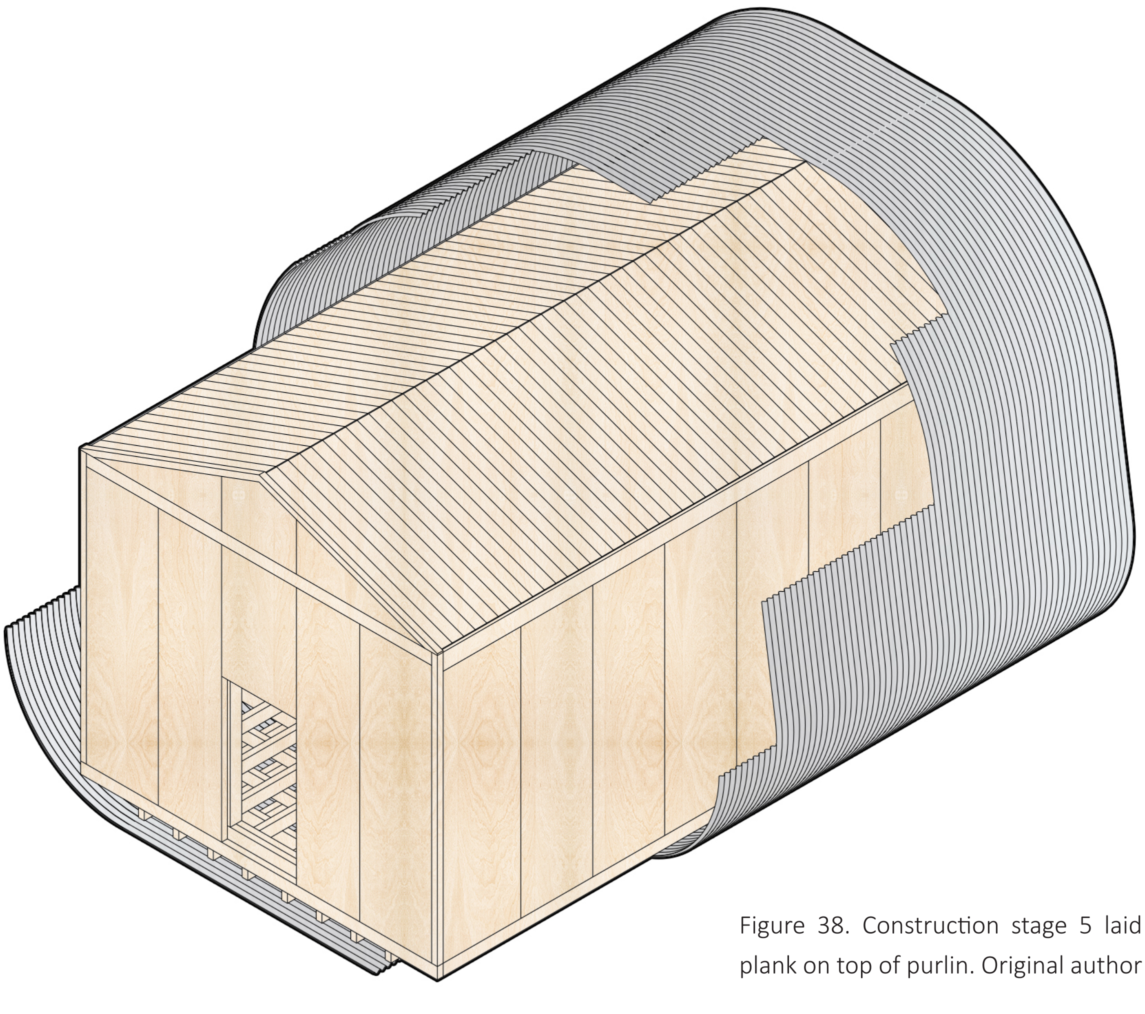


Figure 38. Construction stage 5 laid plank on top of purlin. Original author

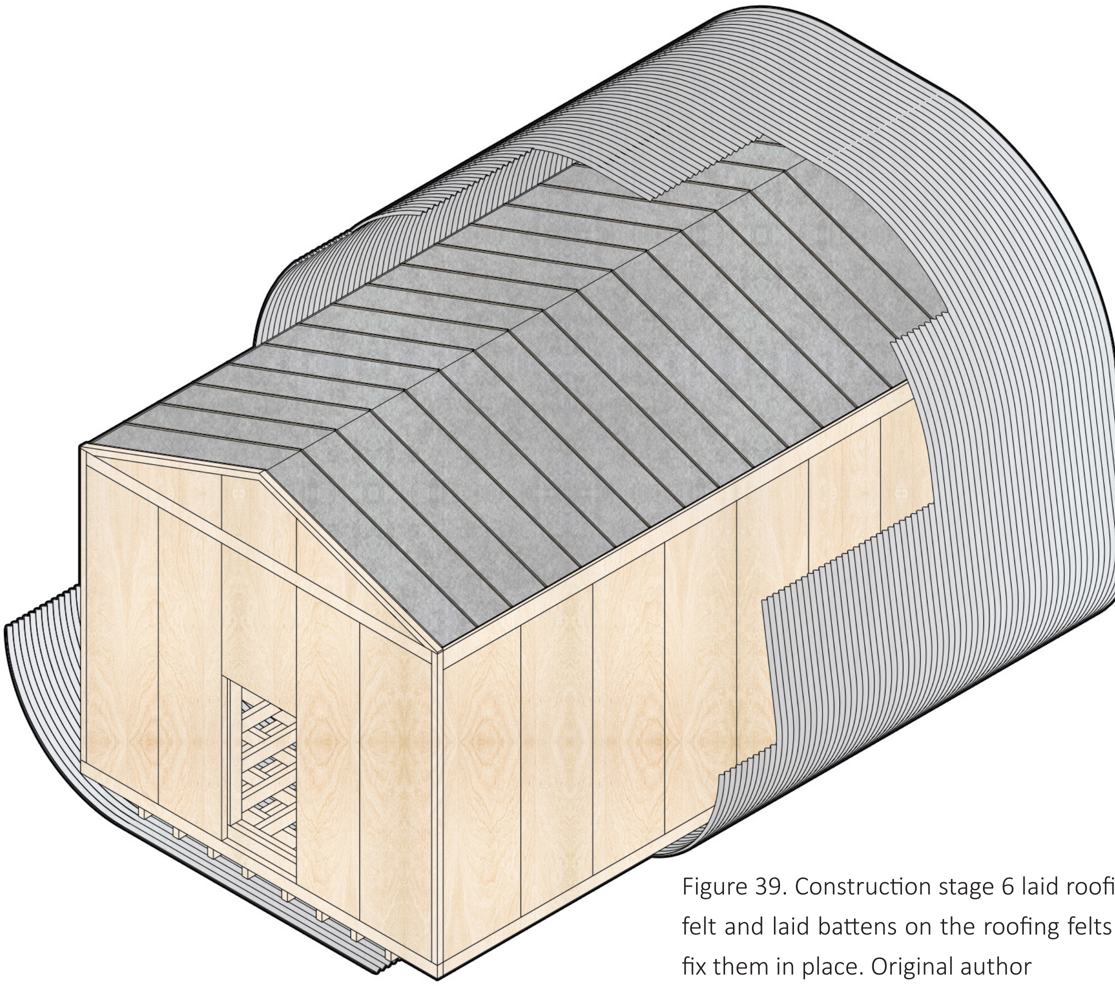


Figure 39. Construction stage 6 laid roofing felt and laid battens on the roofing felts to fix them in place. Original author

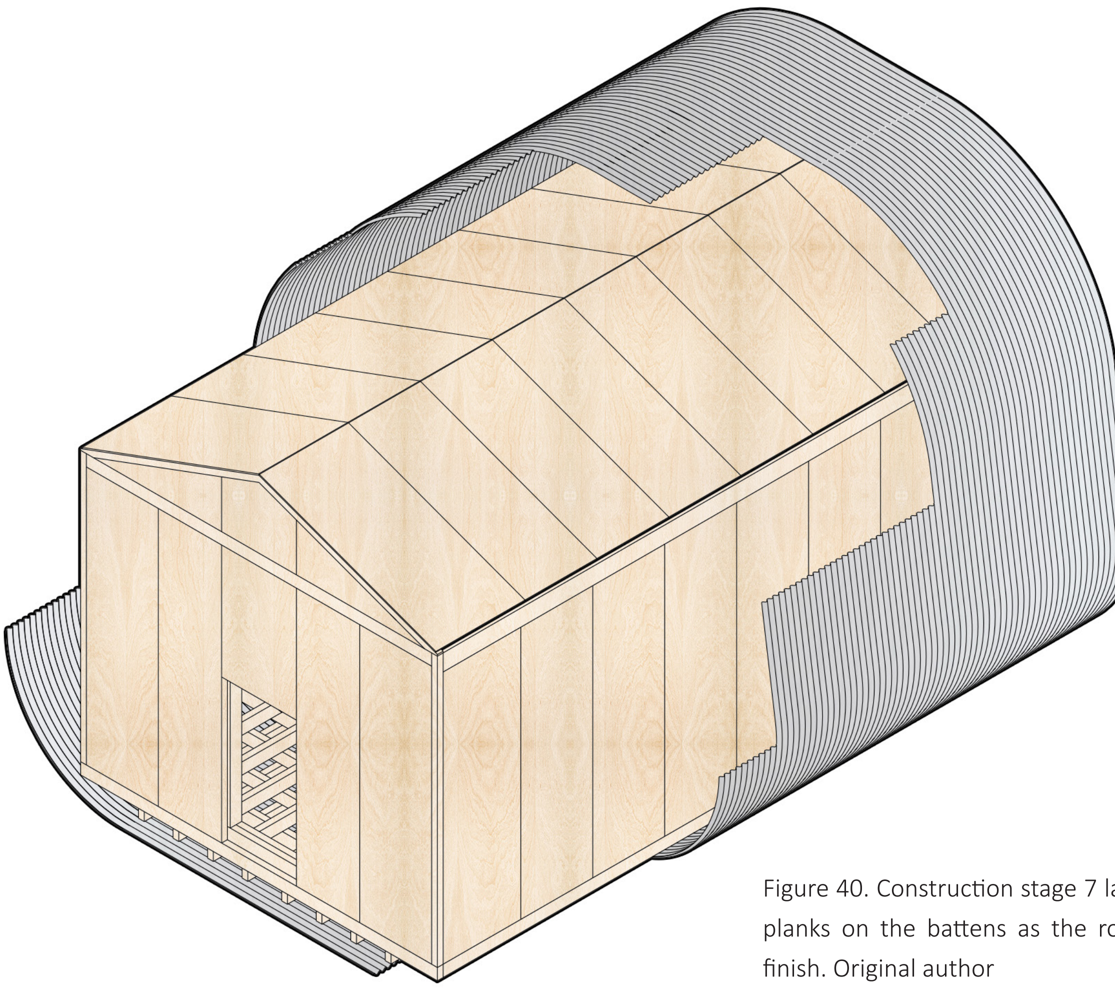


Figure 40. Construction stage 7 laid planks on the battens as the roof finish. Original author

4.4.3. Operation of station

After a few winters, the entire base was basically buried by snow. Hand lines are marked on the route to the huts and shafts so that staff can find their way in the whiteout and blizzard. In addition, the base is marked with perimeter drum lines so that people can find the perimeter drum lines before they get lost (Mike Hood 2021).

The base is powered by two single-phase diesel generators, which run on aviation fuel. The duty cycle of each generator was one week, one providing basic power to the base while the other was on standby for maintenance. The workshop hut was divided into two workshops; one was an electrical workshop, and the other was a woodworking workshop. The dormitory room is not very big just for sleeping. It is divided into twin rooms with bunk beds. The living area serves as an important facility for the staff over the long polar nights. All their daily lives are over here, and there is even a library available to them in the radio room (Mike Hood 2021).

Going to the toilet is a part of everyone's daily life. The flush toilet could not have appeared in the station at that time because the water in the toilet would have frozen and the entire toilet would have been scrapped. Therefore, covers from two fuel drums were cut off every week and then left with a few gallons of aviation fuel on the bottom, and they ended up sticking a wooden seat on top as a toilet (Mike Hood 2021).

4.4.4. Results of the Buried Challenge

Halley III takes up the challenge of being buried in snow. Steel tubes were designed to be covered by accumulating snow and withstand the pressure it brings. Although the concept worked well at first, it also revealed insulation issues. Heat escaping from the building causes the surrounding ice to move faster than expected, causing the structure to distort. Halley III was eventually crushed and emerged from the Brent Ice Shelf and was encased in a disintegrating iceberg (Hanne Nielsen 2017).

Halley III shows that corrugated steel tube is very suitable for use in extreme cold regions because its design and characteristics allow extreme temperatures and it is not as prone to burst in cold conditions as other materials. It also has a long lifespan, and it is often used to build tunnels. In addition, it is a very flexible design because it can be applied where bending is required to form a tube shape, which is good for ventilation systems. Although it effectively withstands the pressure of snow, its disadvantages become apparent over time. Problems with insulation and heat escaping cause the surrounding ice to move faster and distort the structure. Burying under the surface also presents problems with ventilation and exhaust. Since it is a buried design, massive ducts are used for fresh air and exhaust. Stations located 40 feet below the surface result in long exhaust pipes reaching the surface, resulting in high back pressure.

4.5. Halley IV

4.5.1. Halley IV of Construction Testing Feasibility

BAS designed a unique and innovative design for the Halley IV station before Halley III was ready to be abandoned. The station would be tunnels interlocked together by wooden components. Although with the new design, there is no way to know the feasibility of this design. Therefore, they commissioned a company in Ross-on-Wye called Structaply to make parts for it and did various tests locally. The design was eventually tested and confirmed to be capable of being built in Antarctica, and the company built massive parts and transported them to Southampton in preparation for loading onto the vessel (Doug Allan 2011). On November 7th, 1983, the RRS Bransfield vessel boarded massive building materials for Halley IV and the building team to set off from Southampton. She arrived at Halley Bay in January to unload supplies and relief for Halley Station (New Zealand Antarctic Society 1983).

4.5.2. Construction of Halley IV

The new base would be an advanced version of the Armco tunnel based on the design of Halley III. Basically, the Halley station consists of four tubes about thirty metres long and having a diameter of nine meters. A two-storey building is built within four interconnected plywood tubes with an access shaft to the ground (Doug Allan 2011). Each of its tubes is covered with Armco corrugated steel culvert pipes (Smith Alan 2009).

When the building team built the new base, the team made sure they had all the bits. The prefabricated panels were all installed together and tagged. Each tube is colour coded and numbered because they knew that one of the keys to building a Halley IV was that it had to be unloaded from the boat as quickly as possible. Then the prefabricated panels had to be laid on the surface for the builders to work on. The required drilling can be requested at the time of construction (Doug Allan 2011).

The prefabricated panels were sandwiched with insulation and laminated with industrial plywood. They assembled each prefabricated panel in the marked order (Figure 41)(Doug Allan 2011). Each piece of plywood panel interlocks together (Figure 42, 43) to give the structure both strength and flexibility in facing the crushing burden of ice (Financial Times 1983). The two-story wooden building will be built inside (Figure 44, 45) when the tubes are finished, and then they will cover the end of the tube with a timber frame (Figure 46). The shafts between the tubes are then connected with stairs. There is a staircase inside the shafts that leads to the ground when the snow buries the whole station (Smith Alan 2009).

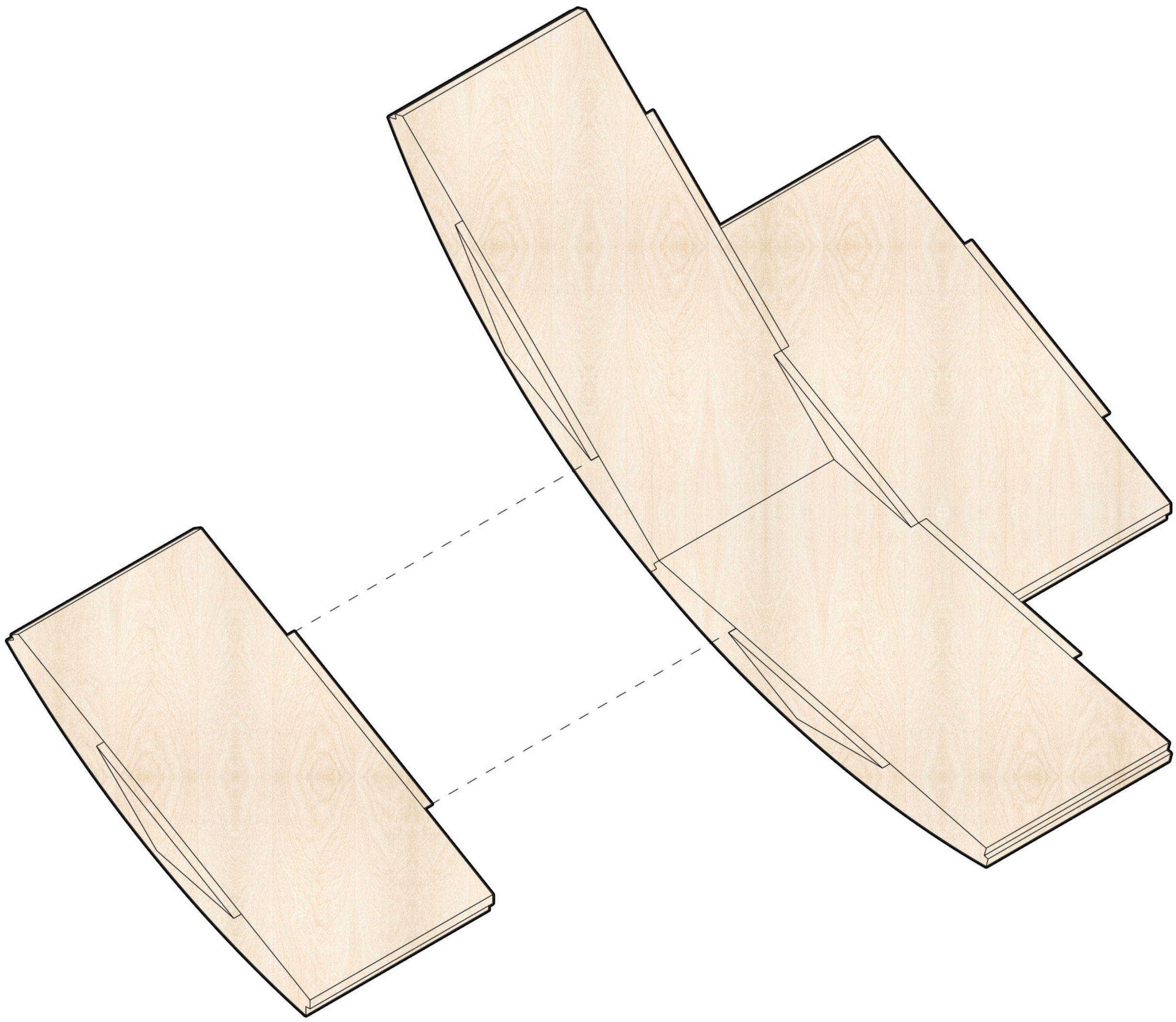


Figure 41. Each prefabricated panel can be interlocked together. Original author

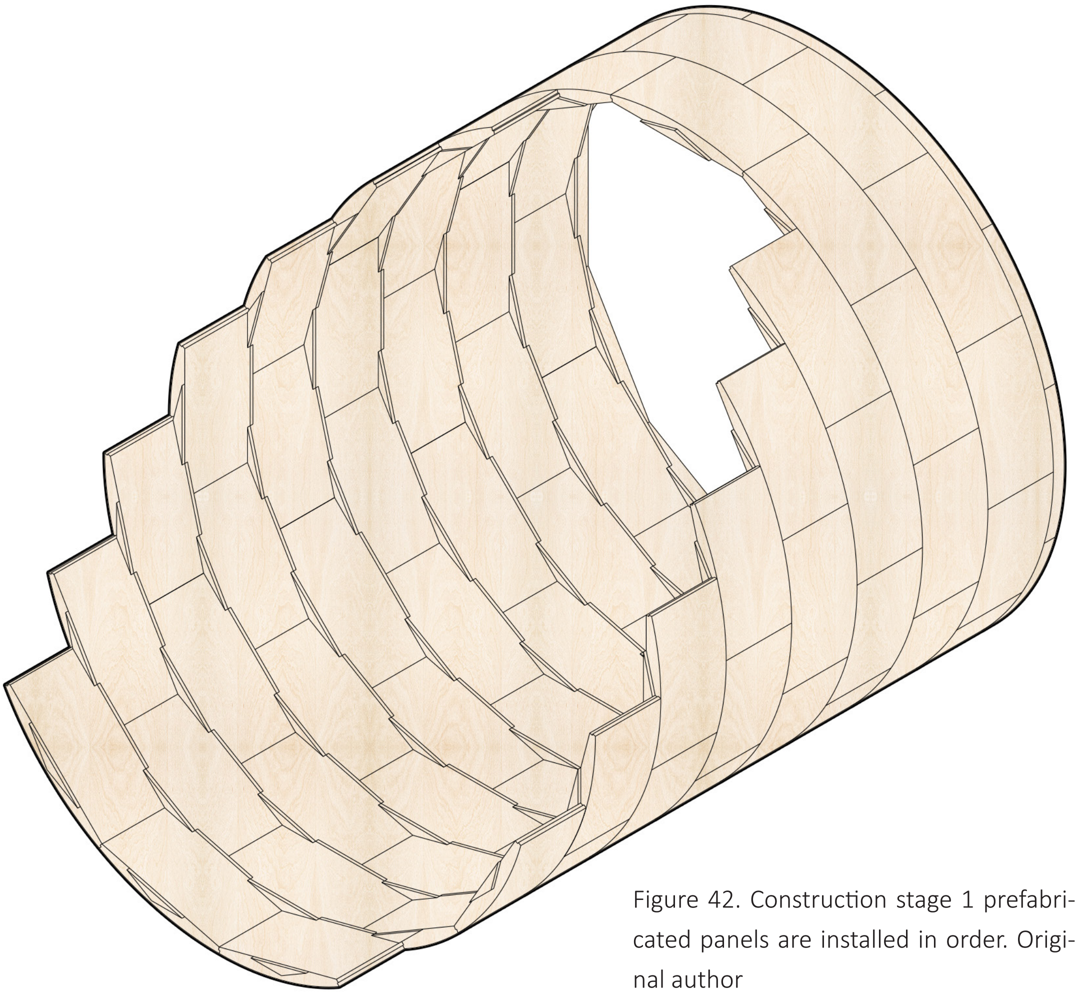


Figure 42. Construction stage 1 prefabricated panels are installed in order. Original author

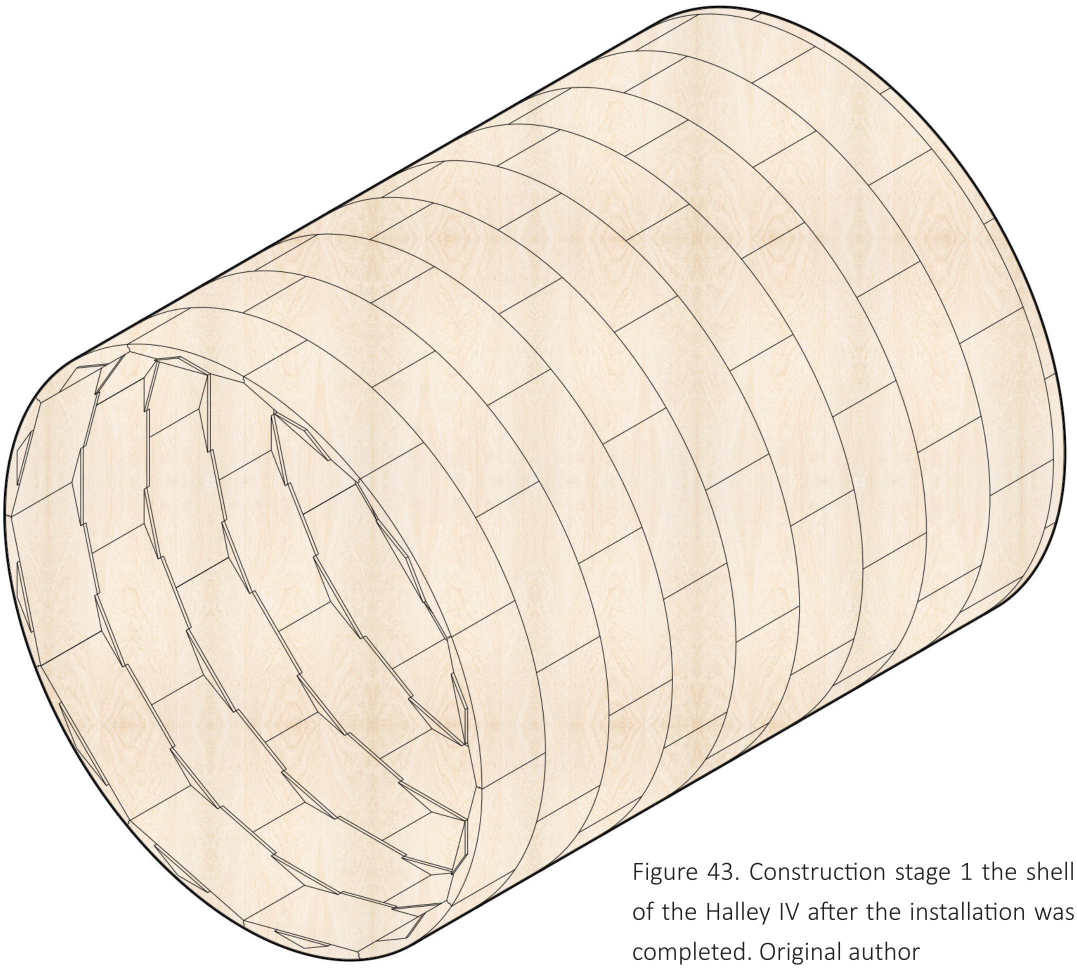


Figure 43. Construction stage 1 the shell of the Halley IV after the installation was completed. Original author

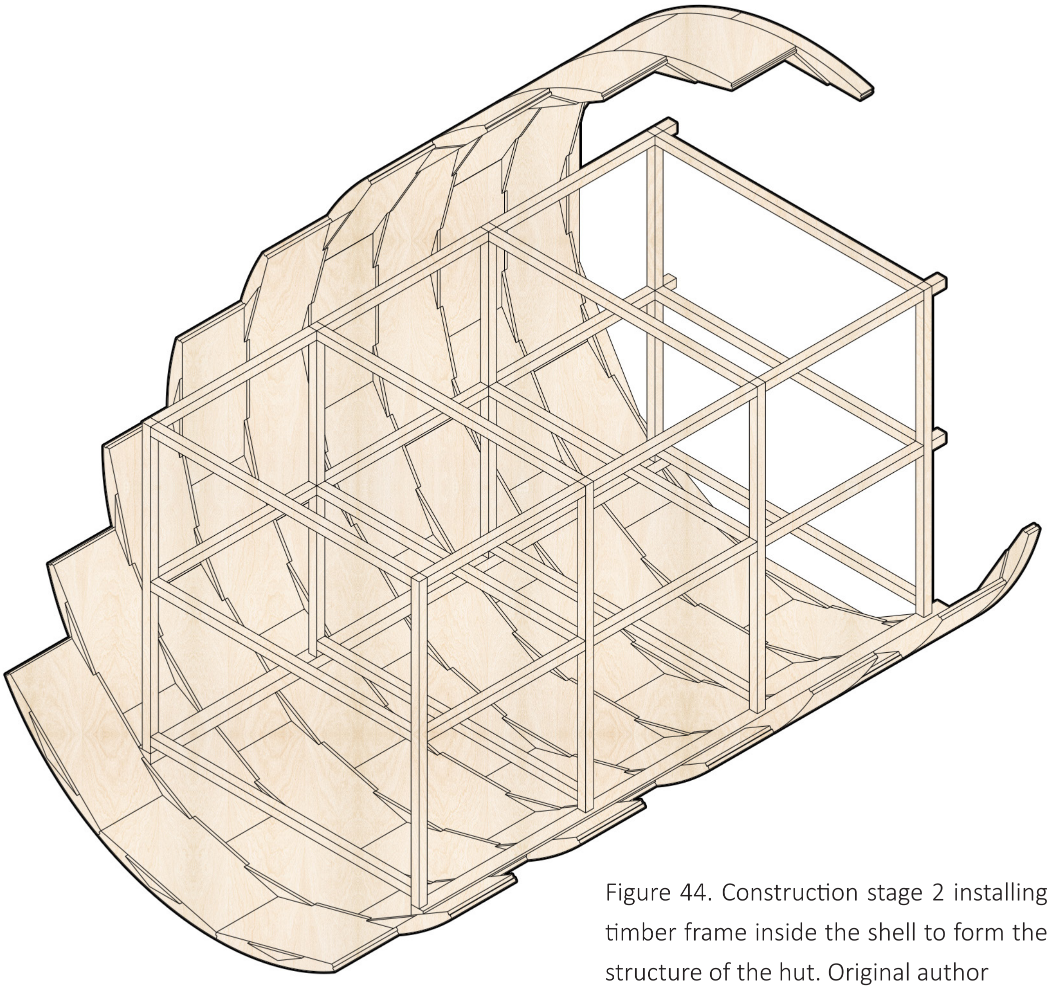


Figure 44. Construction stage 2 installing timber frame inside the shell to form the structure of the hut. Original author

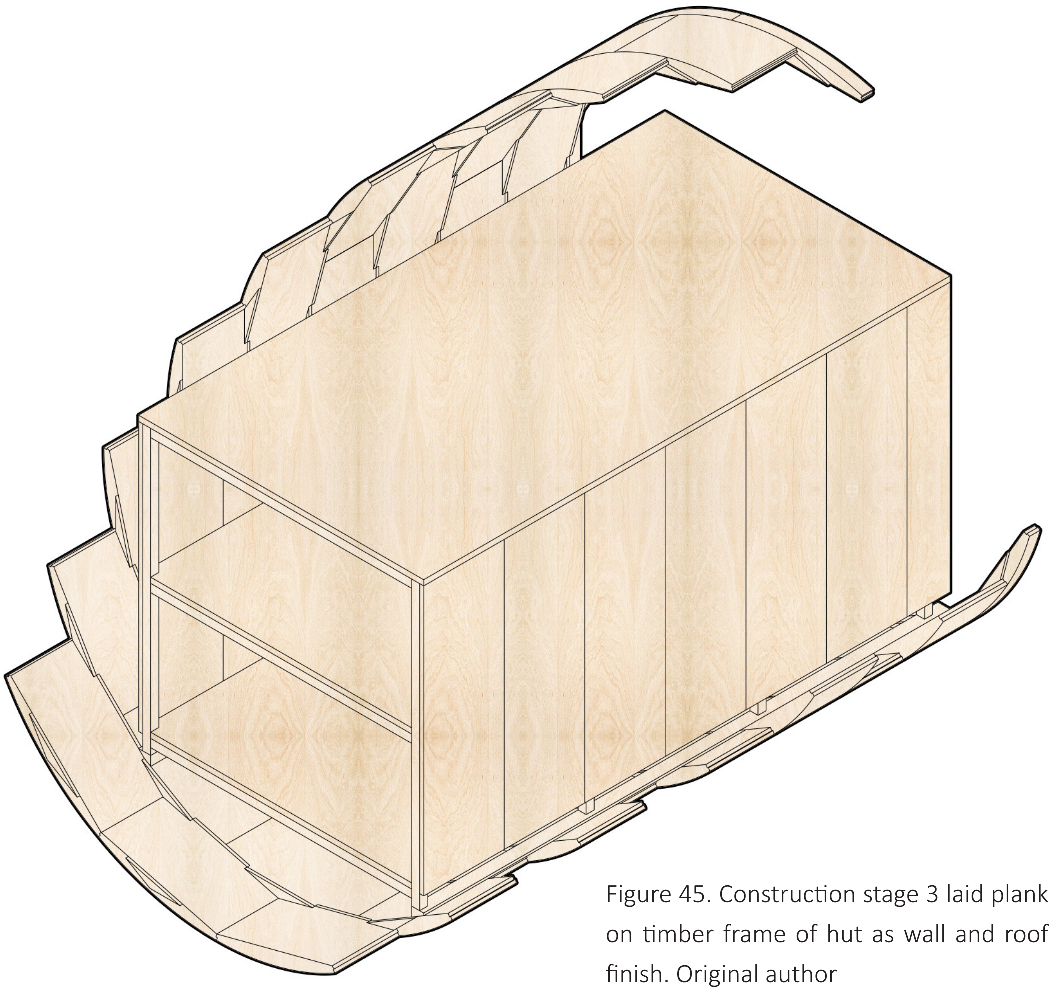


Figure 45. Construction stage 3 laid plank on timber frame of hut as wall and roof finish. Original author

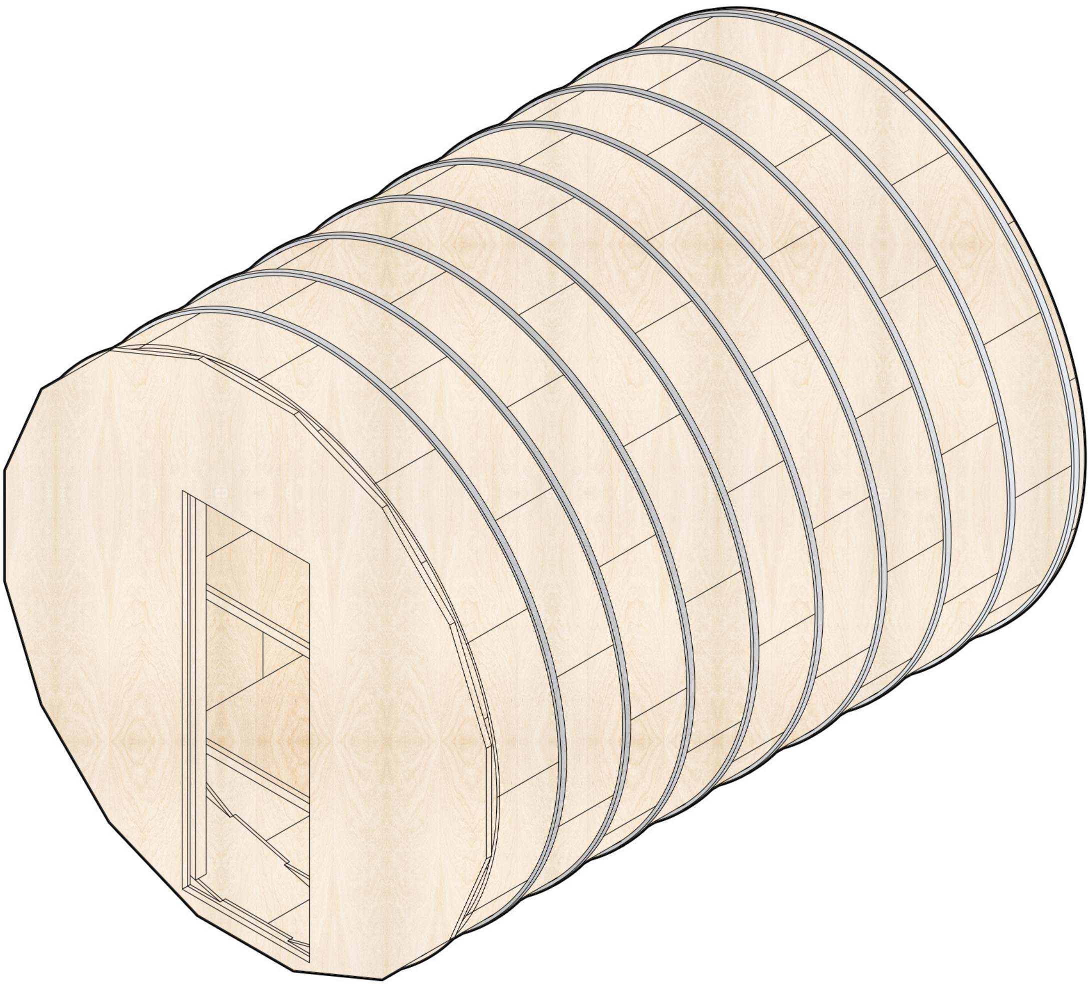


Figure 46. Construction stage 4 cover the ends of the tubes with timber frame and seal the gap of prefabricated panels. Original author

4.5.3. The structure of the Halley IV keeps warping

Its wood warped from strong winds, reducing the effectiveness of the cylinder shape, so the roof had to be regularly cleared of snow throughout its lifespan. The unexpected challenges of putting theory into practise in a harsh environment are difficult to control (Hanne Nielsen 2017). Finally, the station was closed in 1992.

The Halley IV demonstrates how to maximise prefabricated components to the greatest extent possible. Although its predecessors used prefabricated components, the materials had to be modified on site. The Halley IV used prefabricated components in each part, and the components were pre-marked and classified to facilitate on-site installation. In addition, it has been tested many times in the UK before applying this design to the Antarctic. This method can minimise construction time and reduce the dependence on construction machinery. However, the environment in Antarctica is much harsher than in the UK. Its components were warped due to strong winds, reducing the effectiveness of its cylinder shape. Although prefabricated components were well suited for use in Antarctica, it proves that burial design is not an ideal approach.

4.6. Halley V

4.6.1. Preparations for the Halley V design

The Halley V was further tested in the actual design portion of the design process. The team needed wind tunnel testing to simulate the environment of the Brent Ice Shelf. The station's stress and strains in this sort of area, climatic conditions in this case, make it difficult to find any flaws in it (Smith Alan 2009).

4.6.2. Construction of Halley V

The construction team was stationed in the first winter of 1990 to rebuild the Halley V. The 10 people from the building team spent their winter separate from the main party, which was stationed at the deteriorating underground Halley IV (British Antarctic Survey Club 2018). Various plumbing systems were installed beneath the main body on site prior to its construction (Simon Levitt 2011).

Halley V was very different from its predecessors. Instead of being buried in the snow drift, the station applied stilts so it sat 4 m above the snow (Figure 48). The stilts can be adjusted independently by a team of welders, allowing correction of height and any deformation caused by moving ice (Hanne Nielsen 2017). The station is mainly constructed of three independent jack-able steel platforms. The largest is the Law Building (accommodation), which is 59m long (Figure 47), 14.6m wide and 3m high. The smaller are the Simpson Building (meteorology and ozone studies) and the Piggott Building (upper atmospheric sciences), with specialised laboratories (British Antarctic Survey 2004). The superstructure was built before the platform was jacked up to normal height because the crane did not have enough distance to install the roof (Figure 49, 50, 51, 52)(British Antarctic Survey Club 2018).

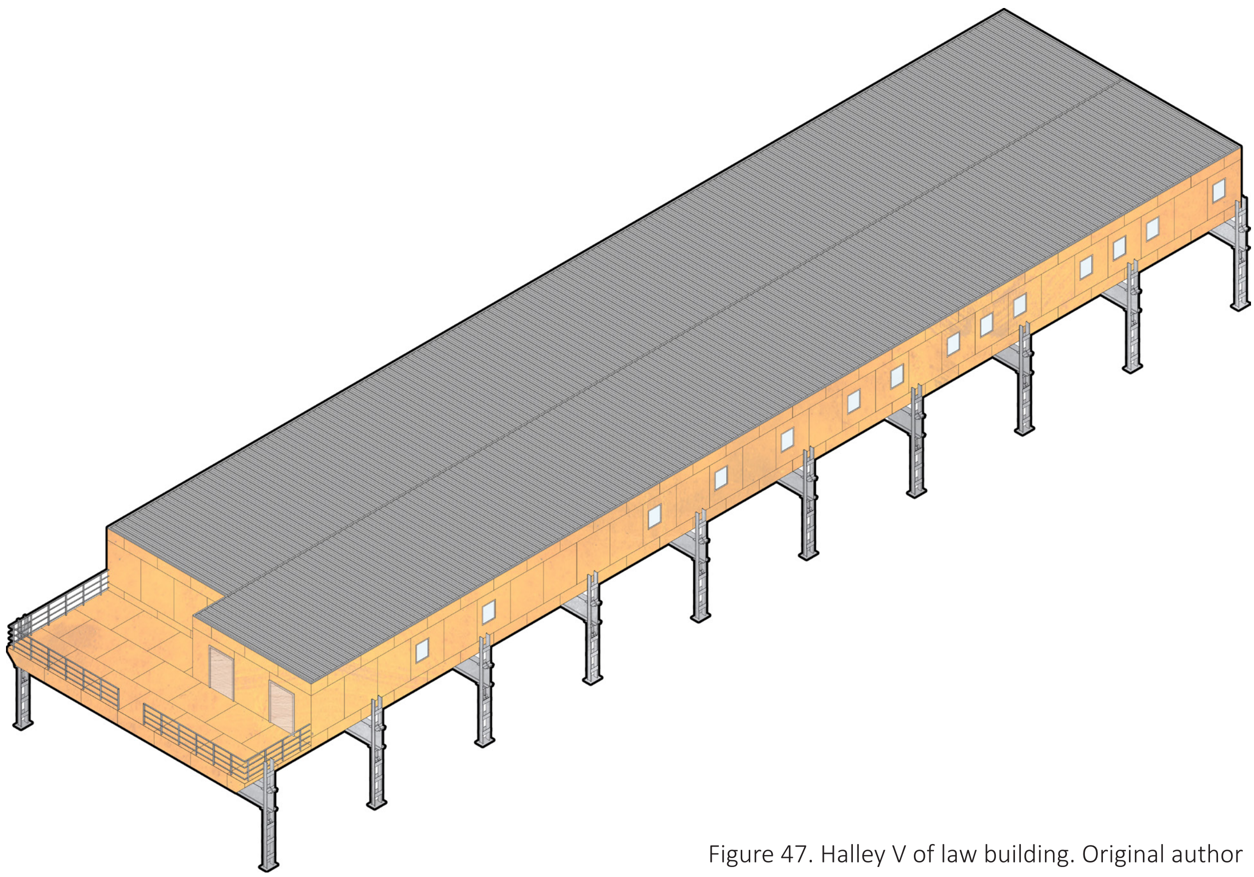


Figure 47. Halley V of law building. Original author

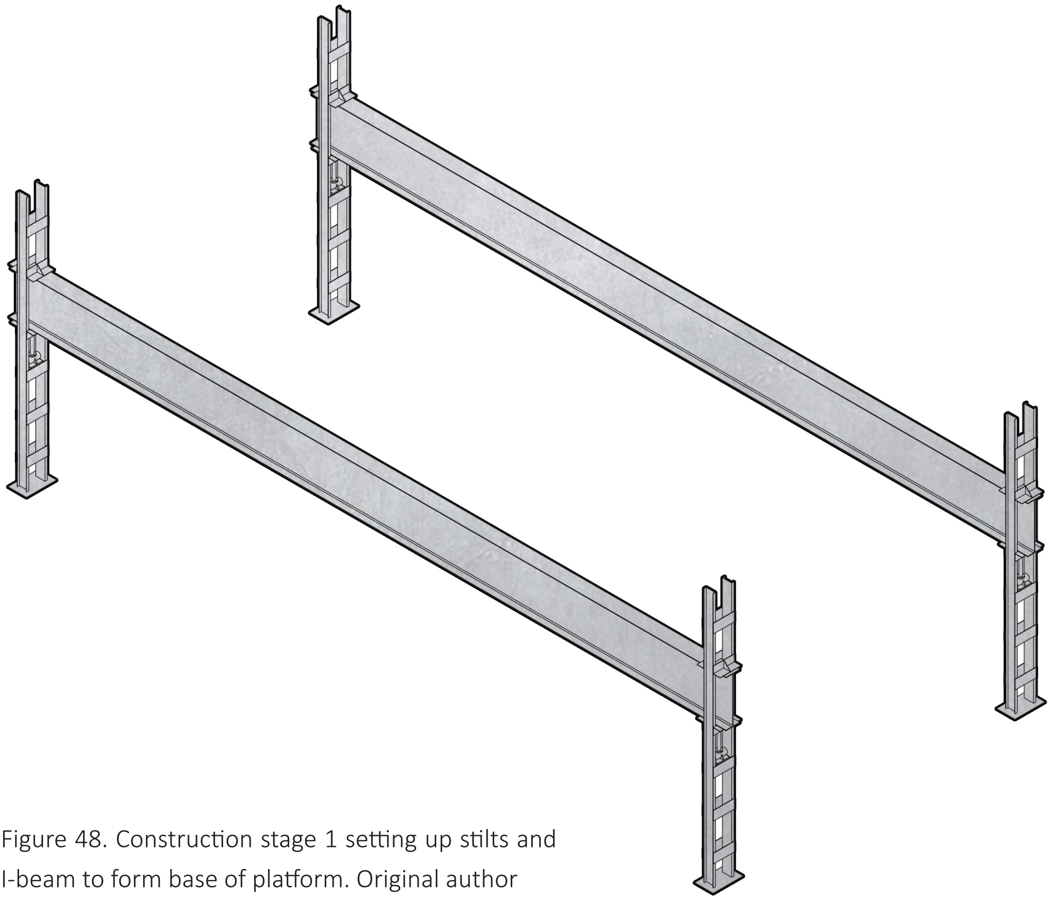


Figure 48. Construction stage 1 setting up stilts and I-beam to form base of platform. Original author

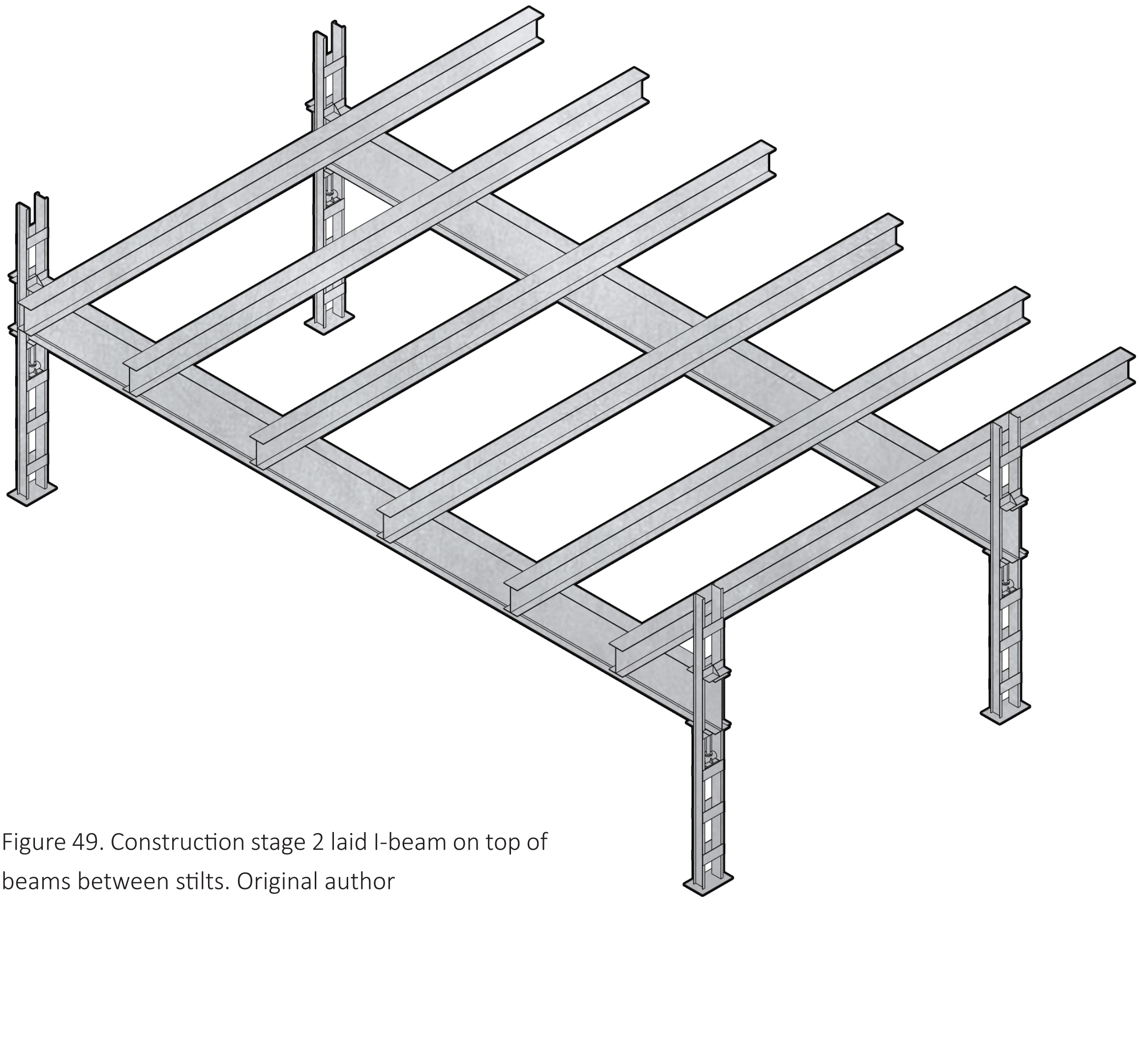


Figure 49. Construction stage 2 laid I-beam on top of beams between stilts. Original author

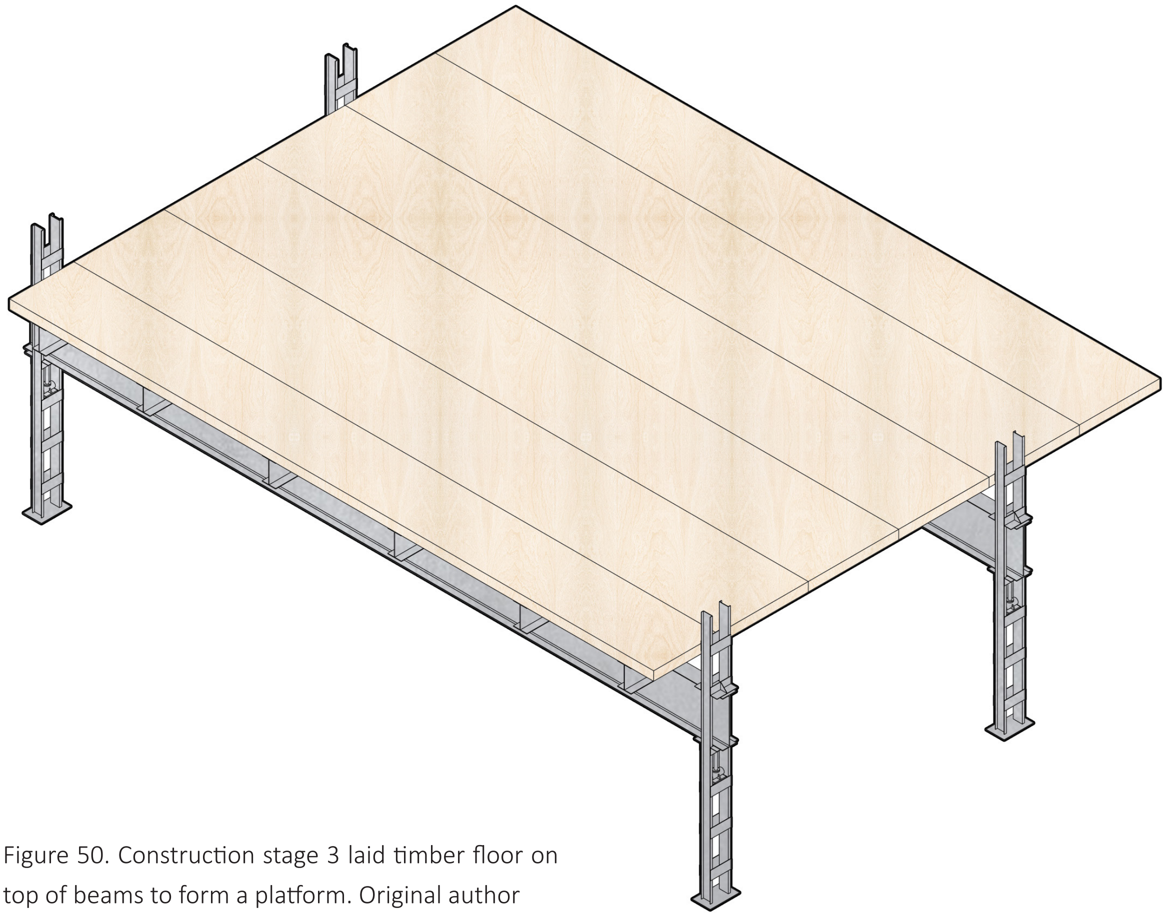


Figure 50. Construction stage 3 laid timber floor on top of beams to form a platform. Original author

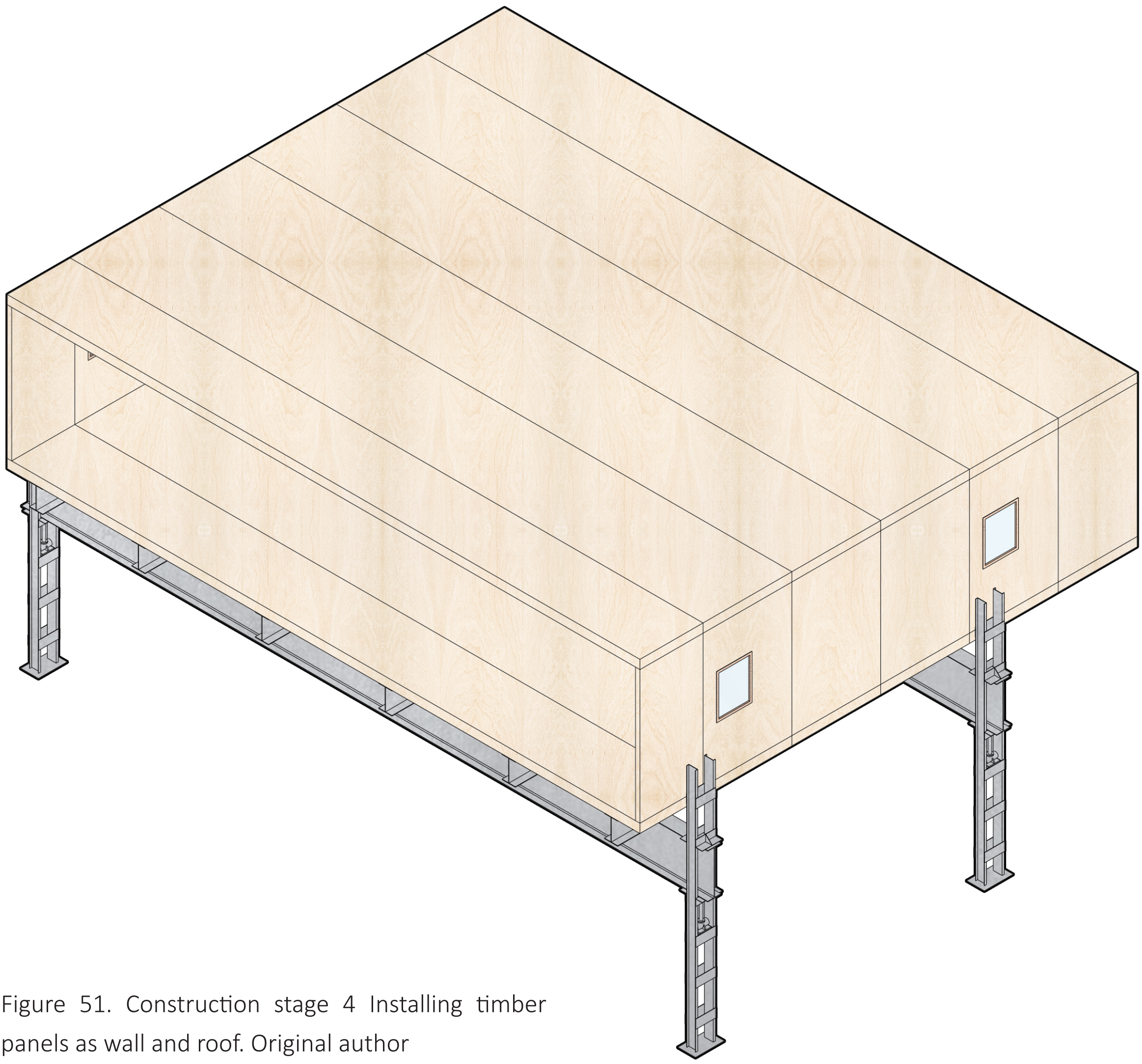


Figure 51. Construction stage 4 Installing timber panels as wall and roof. Original author

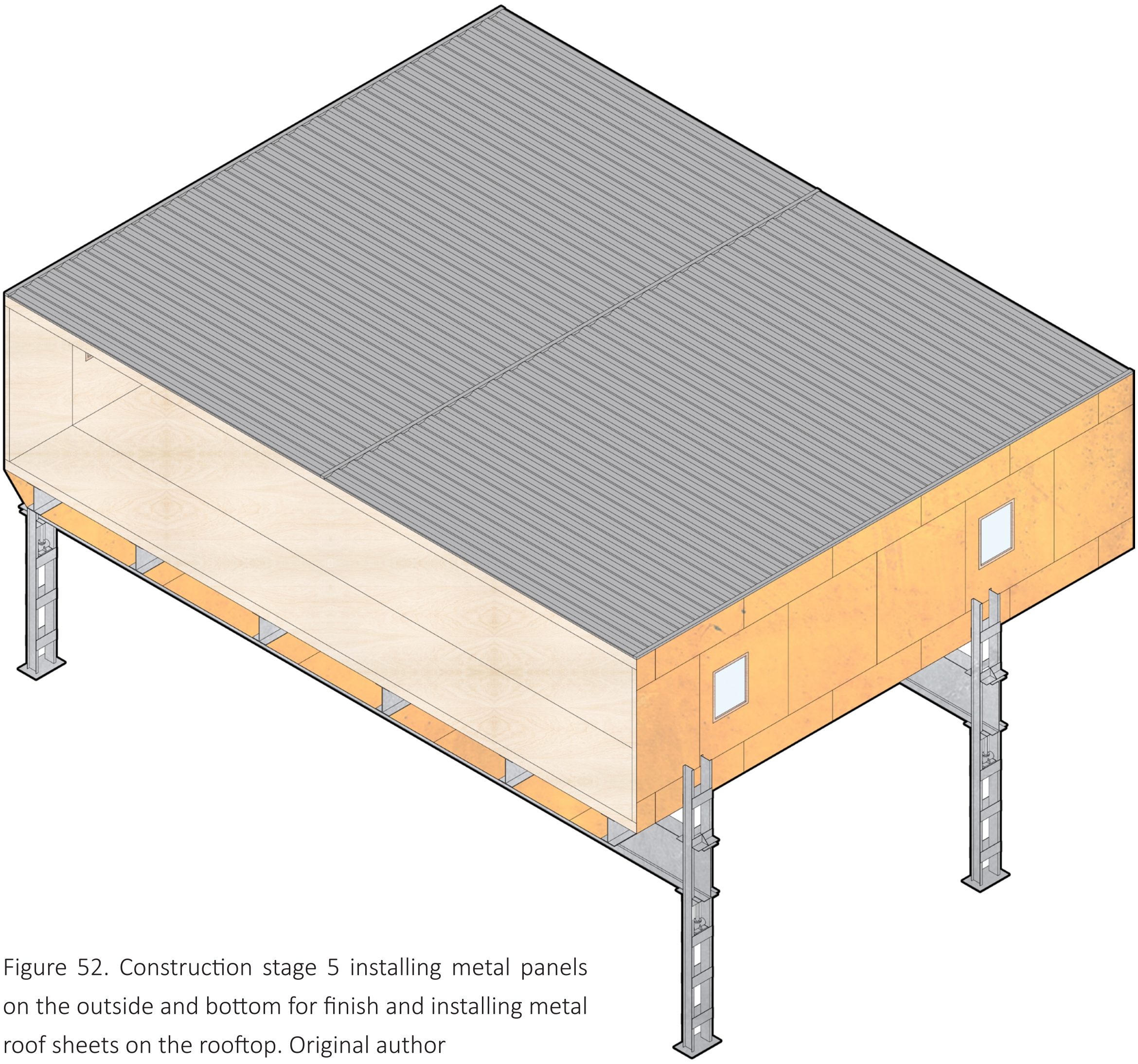


Figure 52. Construction stage 5 installing metal panels on the outside and bottom for finish and installing metal roof sheets on the rooftop. Original author

4.6.3. Operation of Station

The main daily operations of the station are in the Law Building, which consists of three parts, which include a service/technical support area, a living area, and a sleeping area. Electricity is mainly provided by diesel generators and the waste heat it produces warms buildings and melts snow to provide water (British Antarctic Survey 2004). Several tunnels run beneath the surface between the Law Building and the Simpson Building. Tunnels deliver water and electricity to the Simpson Building. The sewage ends up in a chamber outside the tunnel. The fuel bladder was placed in a corrugated steel tube to store the fuel for the generator (Graeme Hart 2020). Visitors would stay at the Drury Building during the summer. It is a self-contained building on skis that is towed to a new location each year to avoid burials and also serves as an emergency shelter (British Antarctic Survey 2004).

4.6.4. Ice Shelf Drifts Off Antarctica

As the Brent Ice Shelf moves out to sea, its site has flown too far from the continent to a location where there is a risk of iceberg collapse. Continuing to occupy the station becomes dangerous. The stilts of its platform were fixed on ice and could not be moved. Also, the station's activity had to be reduced to assist in building the Halley VI (British Antarctic Survey 2015).

The Halley V shows that the elevated platform design is more effective at withstanding snow problems than a buried design. The elevated design not only effectively uses jacks to lift the station from the snow every year but also directs the wind to pass through beneath the platform to blow the snow away. This design also gives other countries a reference for dealing with snow management so that the current stations are built on steel pillars. However, the station does not consider the location where the ice shelf will split from the Antarctic continent. The stilt frame was fixed to the ice shelf so that the station could not be relocated. The station had to be demolished early, so the new Halley station must take this factor into consideration to increase its lifespan.

4.7. Conclusion

To sum up, the Halley I to V research stations bring a different approach to construction to withstand extreme climates. Each station takes the experience of its predecessor's failure to design a further station. They each have their own unique design to withstand extreme weather and accumulating snow problems. Except for the Halley V, the results of all stations were eventually buried in snow. The lifespan of a station often depends on how it is designed to withstand the wind and snow.

Every design must take into account the impact of logistics and seasons to build as quickly as possible. The construction period was extremely rushed as only the summer season allowed the building team to access the Antarctic continent to build the station. In addition, factors such as the inability to use large construction equipment on site reflect that traditional construction methods are not suitable for use there. Halley I's IGY hut[3] was the traditional wooden structure construction method without large construction equipment and a lack of construction experience team. Part of the hut had to be built as a shelter for the team before winter came, so it was forced to use all personnel, including scientists with no relevant construction experience. Timber framing is used as one of the major structures in every Halley station. It can usually be built faster and lighter and can be easily built in harsh weather and environments. Therefore, it is best to use timber framing without the assistance of construction machinery.

Beginning with the Halley II, prefabricated components were used to build the station. This construction method has several advantages. All components are pre-fabricated in the UK and shipped to site, which reduces manpower and time to build the station and reduces reliance on construction machinery. The building team just needs to install the components in the right order. This will allow construction of the station to be completed in a limited time and allow personnel to evacuate before winter. This method has influenced the mainstream of the construction method for the station in the future.

[3] The first hut of the Halley I was built in 1956

The design of stations being buried in snow was the mainstream until the advent of the Halley V. The design of the burial must take into account snow management; otherwise, the station's lifespan will be shorter than expected. Halley I show that the team did not consider that accumulated snow could cause serious problems. The hut was often buried in snow, and a large amount of snow was on the pitched roof, which failed to clear the snow to the ground. They had to regularly remove the snow around the base and on the roof. After the first winter, all parts of the hut except the roof were buried by snow. Eventually, the hut was slowly crushed and severely deformed by the weight of the snow. Although the Halley I shuts down, there are new design stations to further withstand the pressure of snow. However, none of them were able to withstand the snow and eventually had a shorter lifespan than expected and were forced to shut down. In addition, the buried design presents problems with ventilation, exhaust, and personnel depression. As the Halley II began to be buried, there was no opening in the station. As the station continues to be buried deeper into the ground every year, longer pipelines are required to maintain a normal oxygen concentration in the station and discharge the exhaust gas. Halley III shows the generator shed is 40 feet below the surface, so the exhaust pipe is very long to reach the surface, causing high back pressure. More crews reported feeling claustrophobic and depressed on the station during the winter.

The Halley V design changes the way future stations to withstand extreme weather. It is built on a raised platform and jacks are used to raise stilts from the snow every year so that it will not be buried by the snow. In addition, the section below the station allows wind and snow to blow through to reduce snow accumulation and strong winds directly impacting the station. This method of construction sets a design criterion for Halley VI and other stations in extreme climates. Summarizing the construction method of the Halley station, its evolution process foresees the development direction of the current station. The elevated design, the prefabricated components, and the unique shape that can withstand the extreme environment will become the mainstream criteria of the current and future research station.

Chapter III- Current Research Station

5.0. Current Research Station

This master thesis analysed the history of Halley Station through a literature review to understand the challenges and solutions faced by the current Antarctic station. A few current Antarctic stations will be used in the case study to understand how to solve these problems and challenges. All cases will be permanent stations built in Antarctica after 2000. All selected cases will be based on terrain like ice shelf, shore, and ridge, environmental factors like strong wind, biodiversity, materials, and construction methods as selection criteria.

5.1. Case Study: Princess Elisabeth Antarctica

The Princess Elisabeth Antarctica is the world's first zero-emission polar research station. It is the first polar research station to be designed and built entirely on renewable energy without relying on logistics for fuel. Its sustainable design concept could be an innovation for polar research stations. It is located in Utsteinen Nunatak in Queen Maud Land in East Antarctica. The temperature in the region is in the range of 50 °C to-5°C. The station was designed, constructed, and operated by the International Polar Foundation. The design of the shell and underlying structure was provided by the Belgian architect, Philippe Samyn. The project started looking for a construction site in 2004 and was officially completed in 2009 after 6 summers. Its total usable space is 400m^2 in the main building and 1500m^2 in the technical area. Due to its location and facilities, the station not only provides scientists with advanced logistics and equipment but also access to the exclusive research environment of its site. It has an estimated lifespan of at least 25 years and can accommodate 25 to 40 people in the summer.

Figure 53. Princess Elisabeth Antarctica station of main building. Photographer René Robert. Photo attributed to International Polar Foundation. Source: http://www.antarcticstation.org/multimedia/picture_gallery/princess_elisabeth_station_perspectives_and_cliches

5.1.1. Station Design Principles

The station is designed with a hybrid concept to fulfil the potential of the site. The main building is located on a granite ridge, and the garage section is located under the snow surface. In addition, passive house standards were also applied in the design to reduce heat and electricity requirements. The station is most notably designed with zero emissions as its guideline. Unlike other stations, the entire station is powered by renewable energy.

5.1.2. Shape of Station

The shape of the station adopts the laws of aerodynamics. A number of different designs were tested under the biggest subsonic wind tunnel to test the effect of strong winds on the position of the ridge, orientation and shape of the station. The structure must minimize as possible from wind and snow, while conditions of maintenance, safety, and accessibility must be ensured. The rear of the station is higher off the ground than the front, so wind is directed and accelerated significantly. In order to reduce the wind force, the rear ground clearance is reduced by a wind conductor to better distribute the wind.

The station further takes the wind factor into account. In response to the effects of surrounding wind stress and snow erosion on the main building and garage, the structure of the station incorporates a combination of sharp and curved angles that control wind turbulence. Although these angles were not used on all exterior walls, they were strategically placed to reduce wind stress on the station. In addition, the station is located above a ridge facing east-west, so it can withstand strong south-easterly winds.

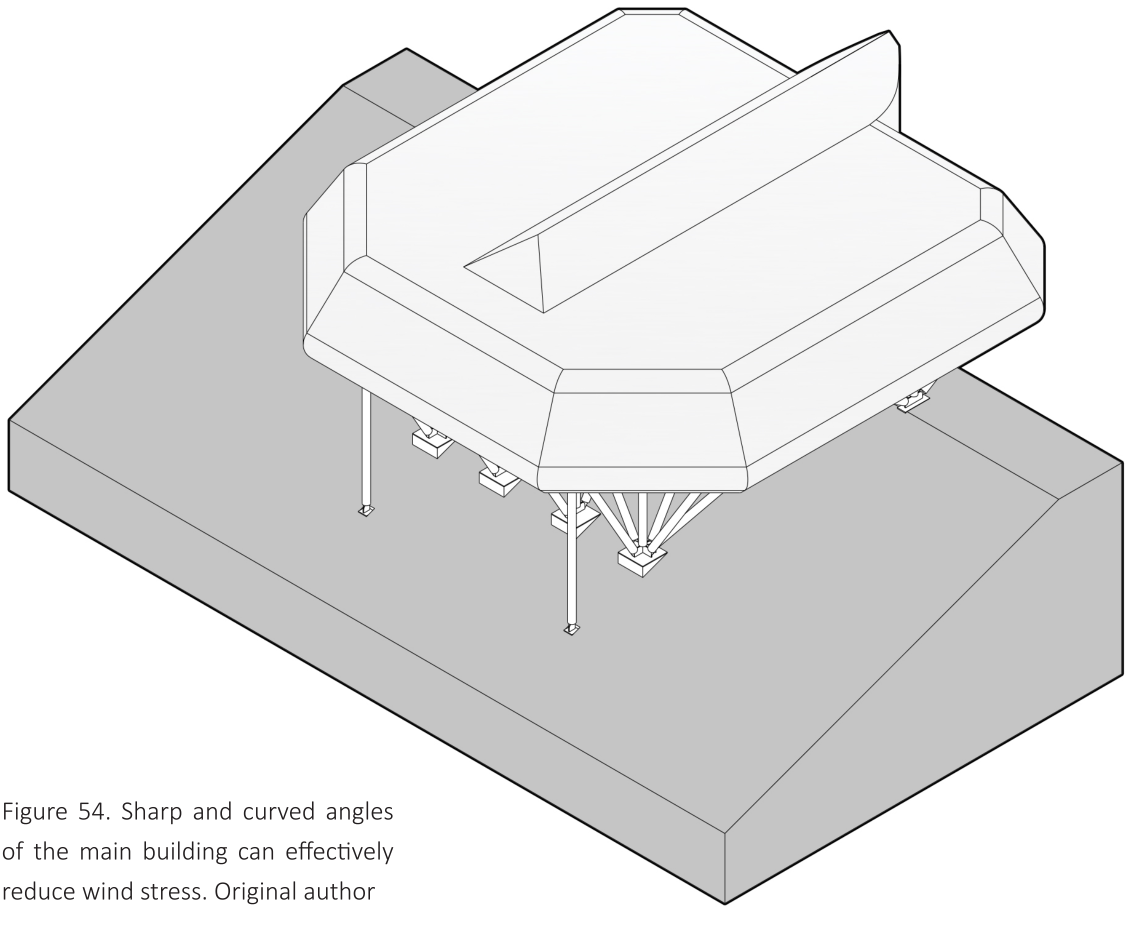
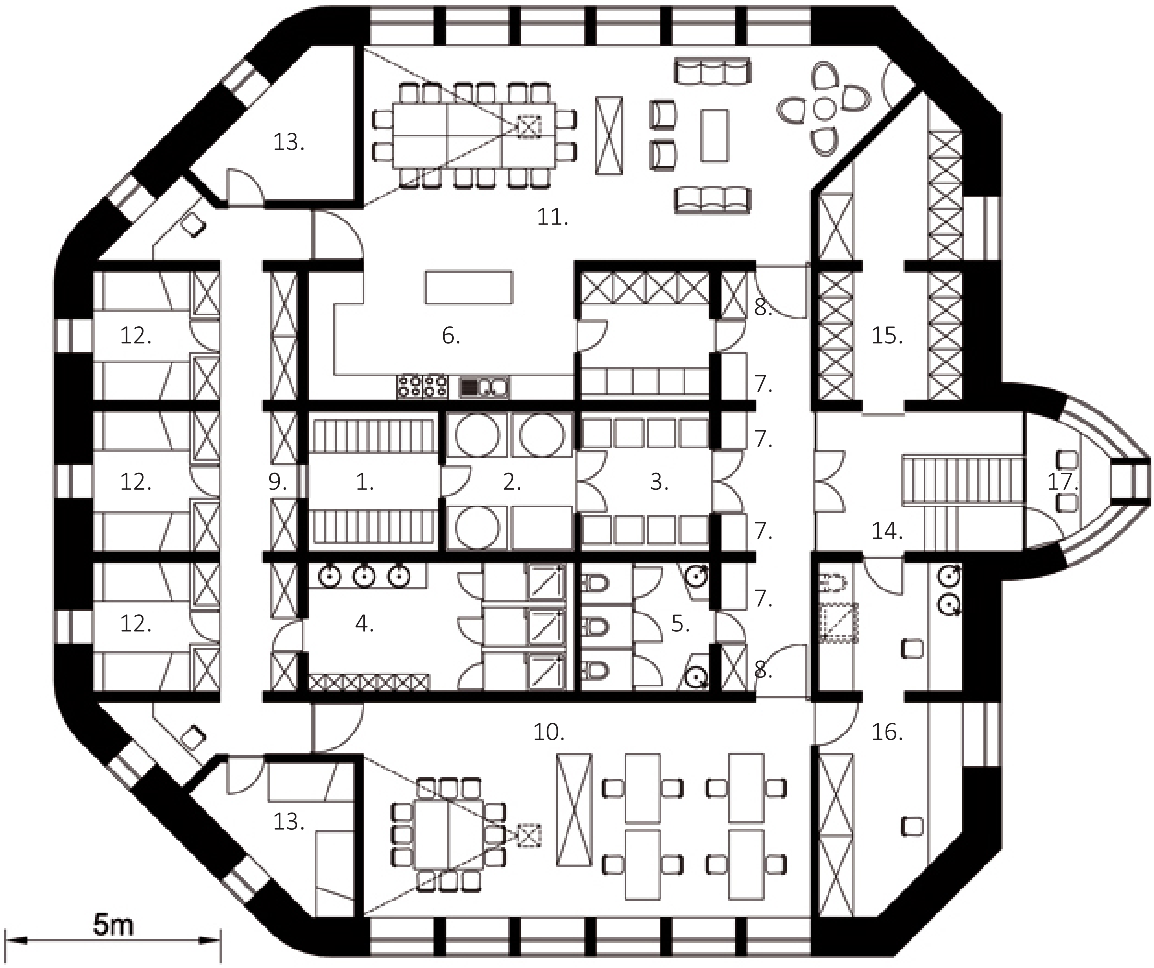


Figure 54. Sharp and curved angles of the main building can effectively reduce wind stress. Original author

5.1.3. Station Layout

The primary layout within the station is designed to ensure that it can withstand the impact of snow, reduce wind and optimise indoor and outdoor comfort. The main building was built on a granite ridge following the facility below, which is the garage. All renewable energy sources were installed on the north side of the ridge. A science shelter was constructed on the south side of the ridge to accommodate the main science experiments. The shelter is located 100 meters from the station to avoid any disturbance to the instruments.



Legend:

1. ESU (Energy Storage Unit)
2. WTU (Water Treatment Unit)
3. SCU (Station Control Unit)
4. Bathroom
5. Toilet
6. Kitchen
7. Laundry
8. Storage West
9. Storage East
10. Office
11. Living
12. Sleeping room
13. Polyvalent room
14. Entrance
15. Polar gear area
16. Lab/Infirmary
17. Station control room

Figure 55. Floor plan of main building. Photo attributed to Philippe Samyn and Partners. Source: https://www.arketipomagazine.it/princess-elisabeth-station/

5.1.4. Construction Method

Foundation

The first and most critical part of the station's construction is anchoring. Although the hardness of the Utsteinen granite caused multiple drill heads to break, the team managed to build the entire anchor with extreme precision in time for the wall module to be assembled.

The granite on the ridge had to be cut to make room for the station's tower. The hardness of the rock means that the cutting tool must be supplemented with a hydraulic drill. The building team applied concrete from local materials like moraine to build the support blocks on granite at a height not suitable for the placement of the pillars. On granite foundations, 2m to 6m high steel pillars were applied to support the entire station as a major structure (Figure 56). It was constructed by first drilling holes in the granite foundation (Figure 57, 58) for the steel pillars to be installed in the granite foundation, then backfilling the holes with resin that hardens when heated (Figure 59). In addition to the steel pillars' roles as the major structure and lifting of the entire building, its advantages are that the granite foundation increases stability and allows drifting snow to blow through under the station to prevent snow accumulation.

Pro: It improves the structure's stability and load-bearing capacity.

Cons: The manufacture of concrete blocks on site and the practise of drilling and cutting granite does not maximise efforts to reduce the impact on the geological environment.

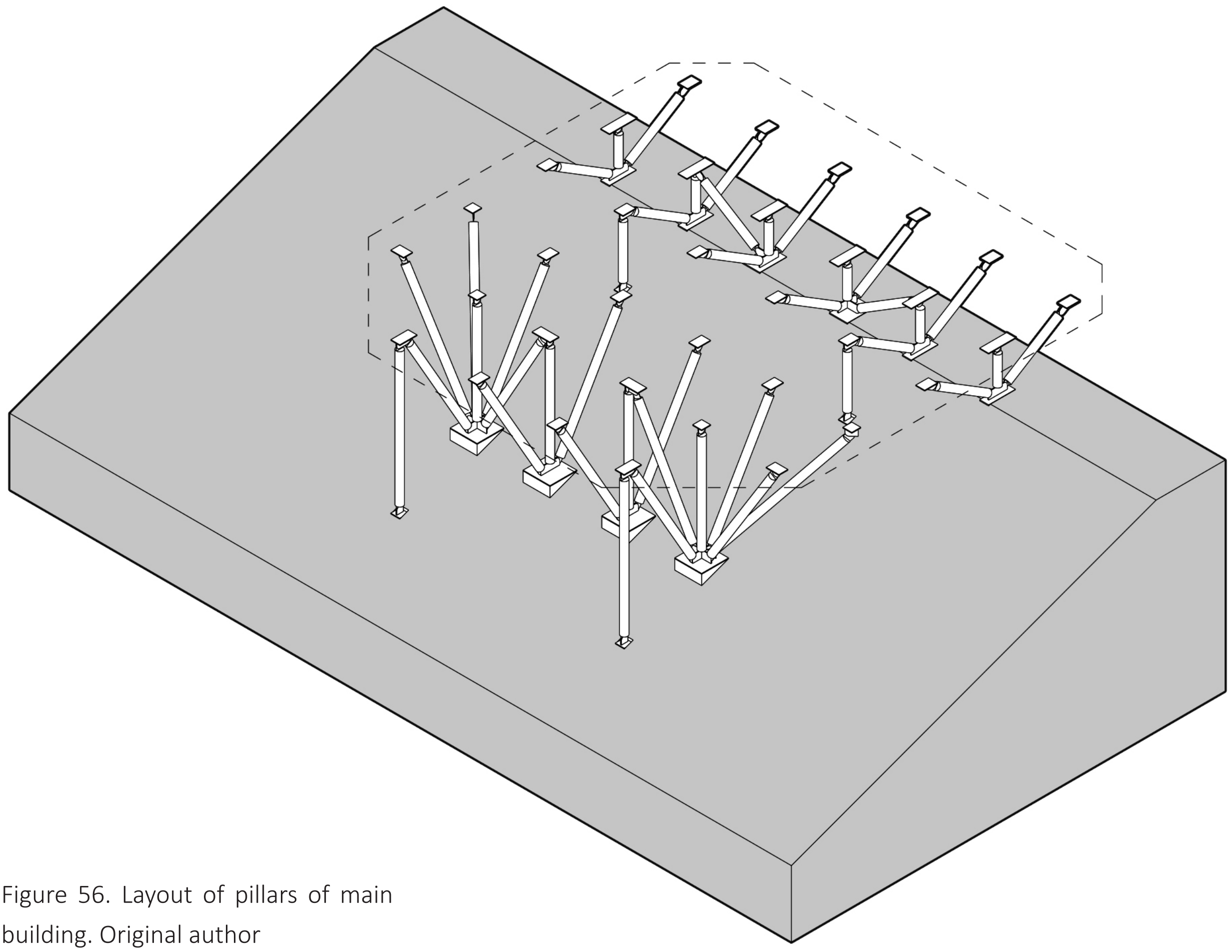


Figure 56. Layout of pillars of main building. Original author

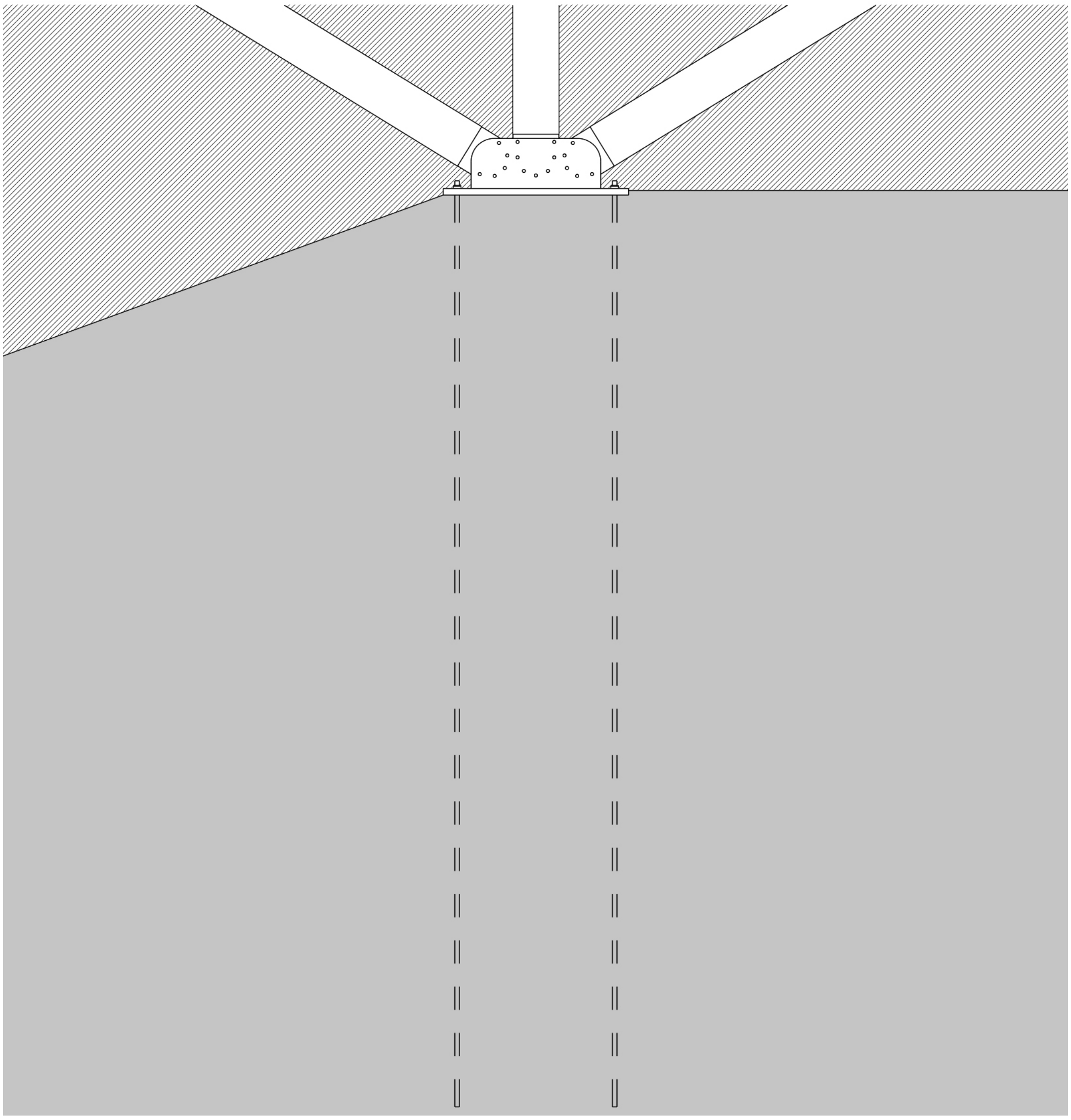


Figure 57. Drilling 6m deep holes in granite to install piles in preparation for steel pillars. Original author

Figure 58 (Lower left). Drilling 6 metre deep hole in granite for pillars. Photo attributed to Nighat F.D. Amin. Source: Princess Elisabeth Antarctica and zero emission quest

Figure 59 (Lower Right). Backfilled the hole with resin. Photo attributed to Nighat F.D. Amin. Source: Princess Elisabeth Antarctica and zero emission quest

Structure

When the steel pillars of the station were erected, this was the most critical moment. It will become clear if the preparations are done with sufficient precision to align the steel pillars with the connection points of the wooden frame on the station. The building team then reinforced the structure to accommodate the supporting structure of the building.

The station was conceived as a column and beam structure. When the steel pillars were anchored in place, various wooden columns and beams were framed on top of the metal structure. The building team built a temporary wooden platform between the steel pillars to install the wood frame on the steel pillars. Then use the prefabricated wooden frame to form the skeleton of the entire station. The modular wall can be installed on the wooden frame when the shell of the entire station is completed.

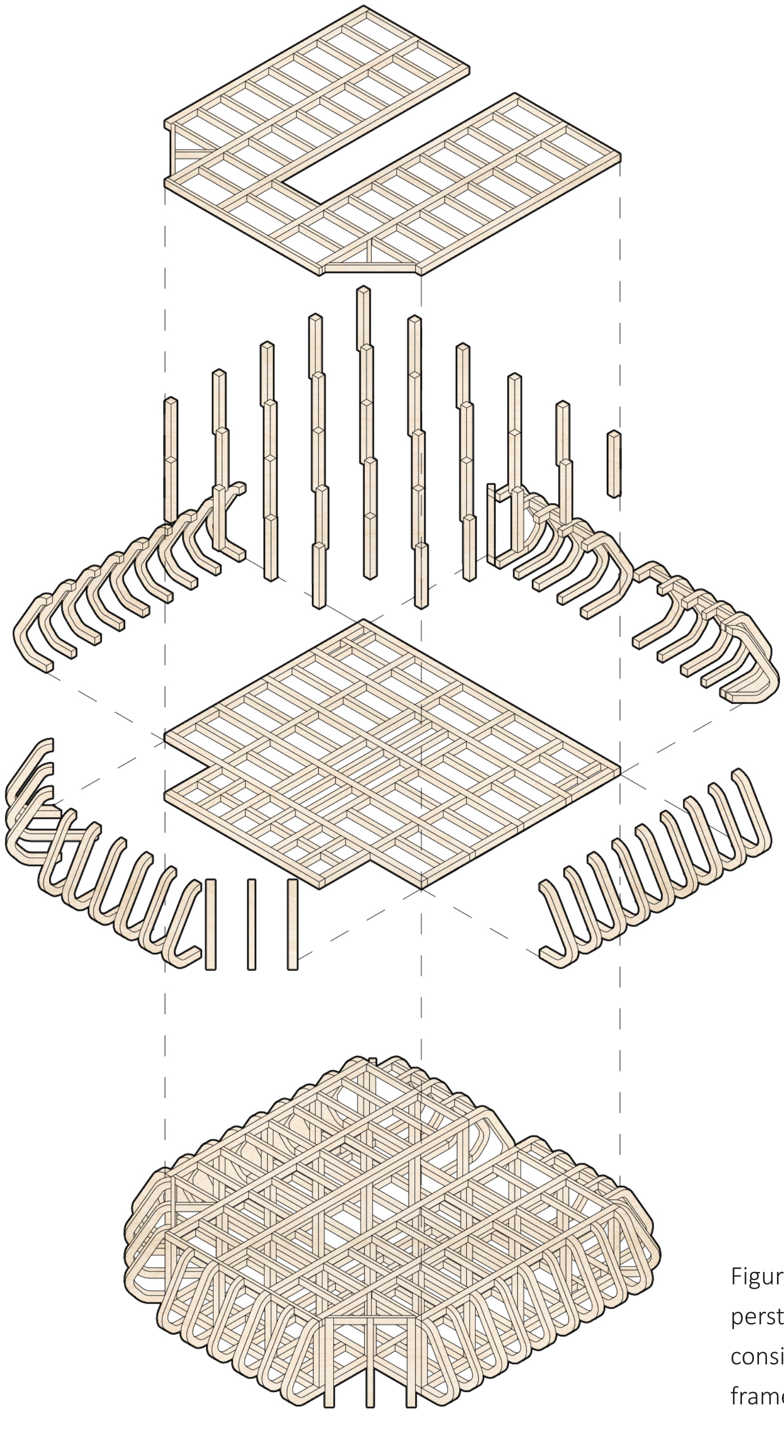
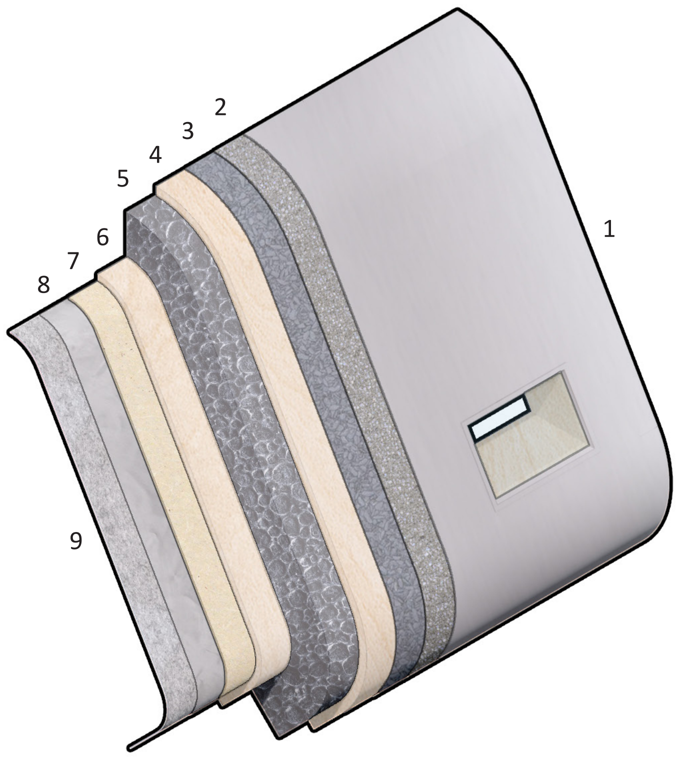


Figure 60. The structure of superstructure of the main building consists of wooden beams and frames. Original author

Exterior Wall and Insulation

The exterior wall of the entire station is composed of modules (Figure 61). The wall is about 53 cm thick and consists of a wooden frame structure and nine layers of materials. A thermal barrier is provided in the middle of the walls to keep the temperature inside the station warm. The walls can withstand winds of 300 km/h while absorbing shock and preventing wear. It is not easy for cold air to penetrate the walls of the station to get inside because these walls provide a high level of insulation and all joints are sealed to prevent air passing through gaps.



1. A layer of 1.5 mm thick stainless steel plate
2. A layer of 5mm thick closed cell foam
3. A 3mm thick resistive layer also acts as a waterproof layer on the wood to prevent any outside moisture from entering
4. A layer of 80mm thick laminated pine wood and glued
5. As the main insulation of the walls there is a 400mm thick graphite layer and coated with low density polystyrene.
6. A layer of 60mm thick laminated pine wood and glued
7. Kraft paper made from Abaca which is a species of banana tree
8. An aluminium foil water vapour surface to prevent any internal moisture from entering the wood
9. Woollen felt and inner wall

Figure 61. Wall detail of Princess Elisabeth Antarctica. Original author. Source: International Polar Foundation

5.1.5. Operation of Station

Energy

The Princess Elisabeth Station is mainly powered by renewable energy. Although there is no sunset in Antarctica for half the year, it is the opposite in winter, so the station needs to be equipped with a second energy source that can be used. The station uses a combination of power sources, which include wind turbines and solar panels, to generate electricity to reduce fossil fuel consumption. Although the station has a reliable renewable energy system, two diesel-powered generators have been installed for safety and backup in the harsh conditions of Antarctica. Fossil fuels will not be used unless necessary because the station needs to reduce its effect on the environment. Each wind turbine can withstand Antarctica's vicious storms. There are nine wind turbines that were built along the ridge of the station to make up for the inability of the solar panels to operate in winter. Each turbine consists of three blades with a direct drive generator and a self-regulating rotor that rotates with the wind. The solar panels at the station are applied thermal and photovoltaic solar panels. The thermal solar panels on the roof are for melting snow and heating bathrooms, water and heating in the kitchen. The photovoltaic panels are installed on most surfaces and roofs of the station to convert solar energy into electricity for the entire station. These panels are the station's smart grid, and any excess production is stored in batteries.

Water Treatment

The lack of flowing water in Antarctica makes the vast snow to be the main source of water for the research station. This melted snow is filled with fresh snow automatically and manually by hydraulic pumping and piping systems. The water is directed to two different locations after the snow has melted in the snow melter. Cold water is stored in the cold water tank and hot water is stored in the hot water tank after being heated by thermal solar panels for a longer circuit.

Wastewater Disposal

The station was equipped with an advanced water treatment system capable of treating 100% black and grey water. Approximately 60% of the water can be reused and the rest will be processed. The system uses bioreactors, filters, UV radiation, and activated carbon in several stages to recycle waste and reuse it.

Waste Disposal

The station sets strict rules and management for waste disposal. It classifies and prescribes treatment methods for various types of waste. Organic waste and waste fuels are stored in containers and sealed before being transported to Cape Town for disposal. All waste containing hazardous chemicals is sorted and stored in dedicated containers and shipped out of Antarctica for disposal.

5.2. Case Study: Halley VI British Antarctic Research Station

The Halley VI Research Station is located on the 130 metre thick Brunt Ice Shelf in Antarctica. The station is owned by the British Antarctic Survey (BAS) and the Natural Environment Research Council (NERC). Even in the summer, temperatures in the area around the Halley Research Station are usually around-10 °C, and the area rarely rises above 0 °C. Halley Bay has a particular problem with approximately 1.2 metres of snowfall per year. In the winter, temperatures can drop to-50 °C, and the lowest temperature ever recorded is-55 °C. Therefore, the snow never melts, but it will be blown away by strong winds. Snow can accumulate on buildings and other obstacles. The design of Halley V solves this problem by placing the station on outriggers that must be jacked up every year. However, this is a time-consuming operation involving all summer staff at the station. BAS and RIBA released an architectural competition for the station in 2004, and the design of the project was awarded to AECOM and Hugh Broughton Architects. The project was officially completed and started operation in 2013 after four summers.

5.2.1. Station Design Principles

The station was asked for a variety of design requirements, such as the station's being able to relocate to another site, build, and operate until decommission. The station can be relocated to a new site when there is a risk of an iceberg at the current site collapsing. The entire station is designed to keep the environmental impact to a minimum at all stages of its lifespan and to minimise the use of fossil fuels while maximising the use of renewable energy. In addition, the station has to provide a safe, comfortable, and stimulating working and living environment for the residents.

Figure 62. Halley VI station side elevation. Photo attributed to Ruth Slavid. Source: Ice Station the creation of Halley VI Britain's Pioneering Antarctic Research Station

5.2.2. Station Layout

The station modules are positioned linearly on the ice shelf against prevailing winds to minimise snow management. The floor area of the entire station occupies 2,000 m2. The modules are divided into two types of colour and connected to form two platforms. The northern platform provides sleeping areas (modules B1 and B2), an office area (module C), an energy centre (module E1), and a two-story social centre (module A) located in the middle of the entire station for living, dining, and entertainment. The southern platform provides laboratories (modules H1 and H2) and an energy centre (module E2). In the event of the malfunction of one platform or energy module, the two platforms can be separated to provide shelter. The location north of the station will provide garages, technology, waste management, and summer accommodation facilities. In addition, the station interiors provide a delightful environment for the crew to spend the polar night and help to combat the debilitating effects of seasonal affective disorder.

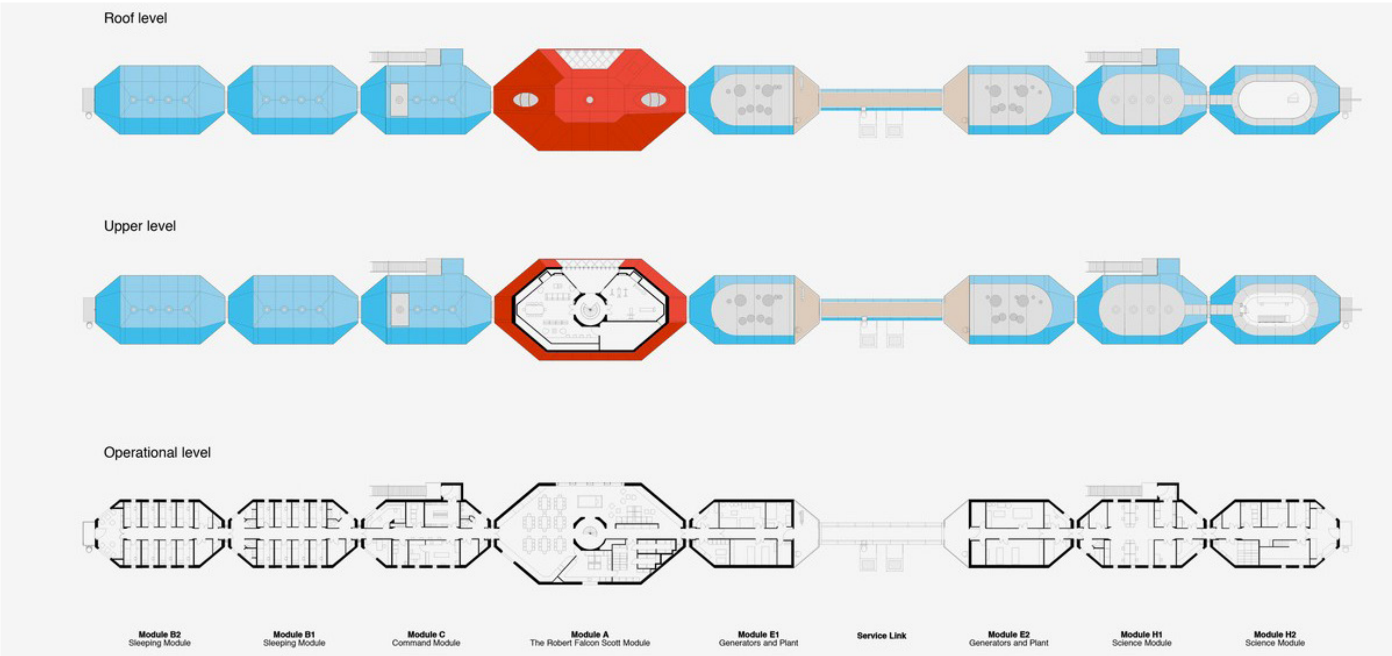


Figure 63. Halley VI Plan. Photo attributed to Ruth Slavid. Source: Ice Station the creation of Halley VI Britain’s Pioneering Antarctic Research Station

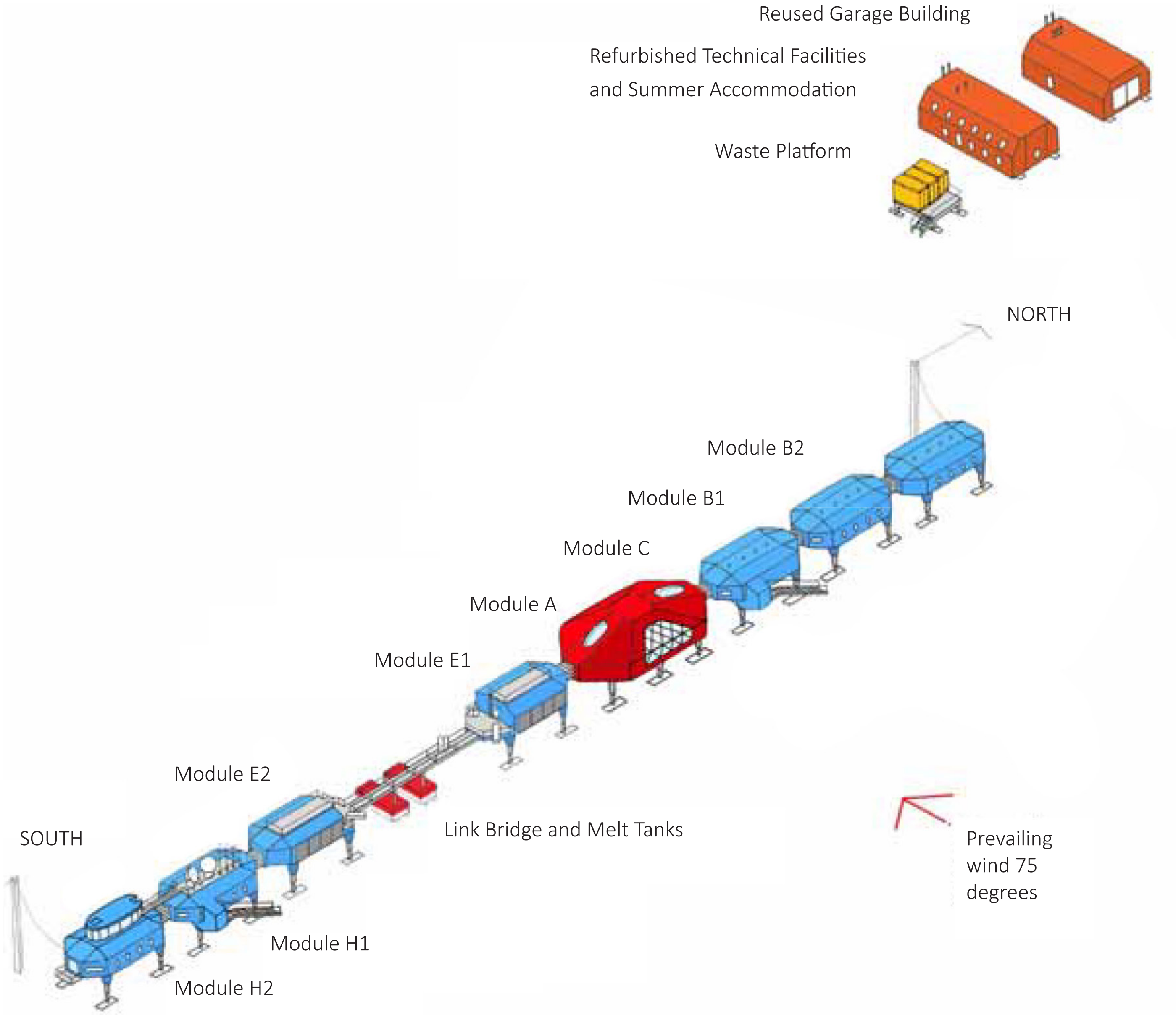


Figure 64. Scheme of Halley VI station. Photo attributed to British Antarctic Survey. Source: Proposed Construction and Operation of Halley VI Research Station, and Demolition and Removal of Halley V Research Station, Brunt Ice Shelf, Antarctica

5.2.3. Construction Method

Foundation

The foundation of the Halley VI station is different from other stations. Since it is located on an ice shelf and was required to be designed to be movable, the modules are supported by massive steel skis and hydraulically powered legs that allow the station to be raised on accumulated snow every year and designed to be relocated to deal with the movement of snow and ice shelves (Figure 65). Each leg is mounted on a massive steel ski so that the module can be towed to another site by tracked vehicle. Skis are designed to be manually operable and interchangeable for future flexibility and mobility. Each ski is held with a dagger board that passes through the ski into the ice to prevent the module from sliding when in place.

Pros: The ability to minimise the impact on the surrounding geographical environment and be able to relocate according to the environmental changes of the location to increase the lifespan of the station.

Cons: The foundation that does not pile or anchor is obviously not stable enough. It is likely to overturn in strong winds or other natural disasters. In addition, the cost of hydraulically powered legs will be higher than normal foundation construction.

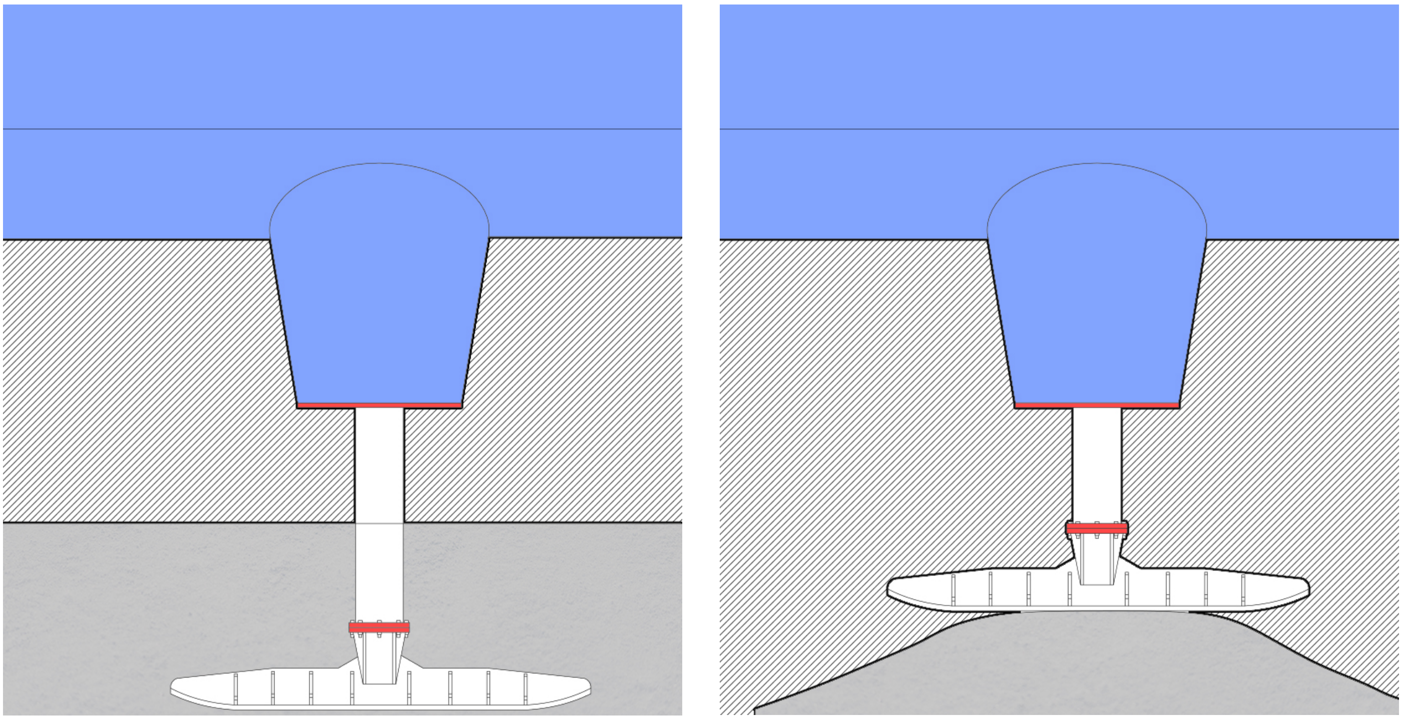


Figure 65. Hydraulically powered legs can be lifted from accumulated snow every year. Original author

Structure

Preparation is essential in the construction of Halley VI. As much of the station structure as possible is prefabricated. The prefabricated components are primarily assembled in the UK and South Africa for testing. Then everything has to be loaded, calculated, and then unloaded on site to ensure each item can be positioned as required. All modules in the station use steel framing as the main material. When the bottom frame of the module arrives on site, it is placed on shipping containers (Figure 66) and then the hydraulic legs and skis are installed in the bottom frame to form the main support of the module (Figure 67). After the prefabricated timber floor is laid on the bottom frame (Figure 68), then the superstructure will be installed on the bottom frame (Figure 69) and wait for cladding to be installed.

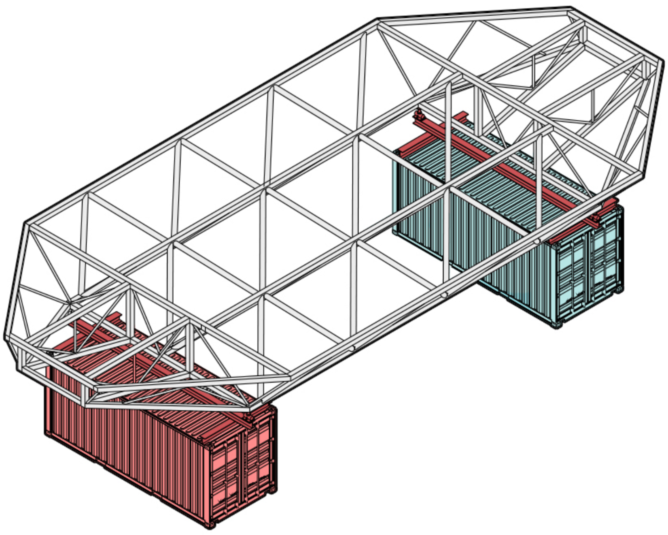


Figure 66. Module of structure construction - stage 1 The module raised on containers to allow hydraulic legs and skis to be installed. Original author

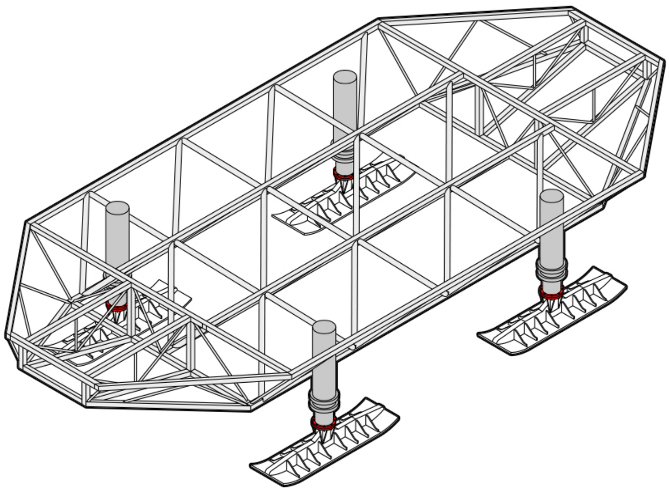


Figure 67. Module of structure construction - stage 2 Hydraulic legs and skis installed. Original author

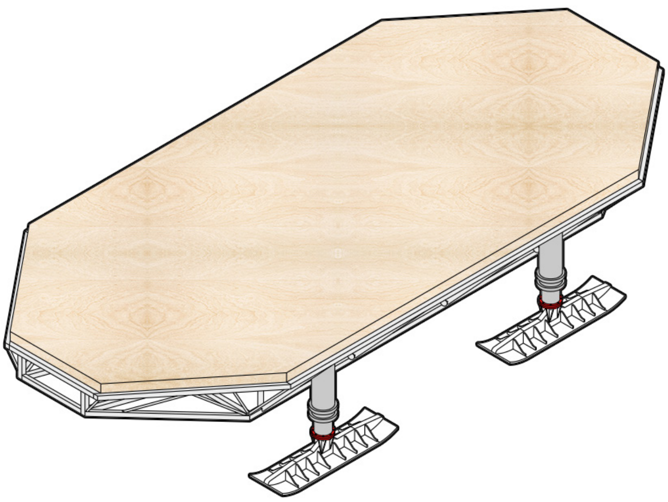


Figure 68. Module of structure construction- stage 3 Prefabricated timber floor being installed onto frame. Original author

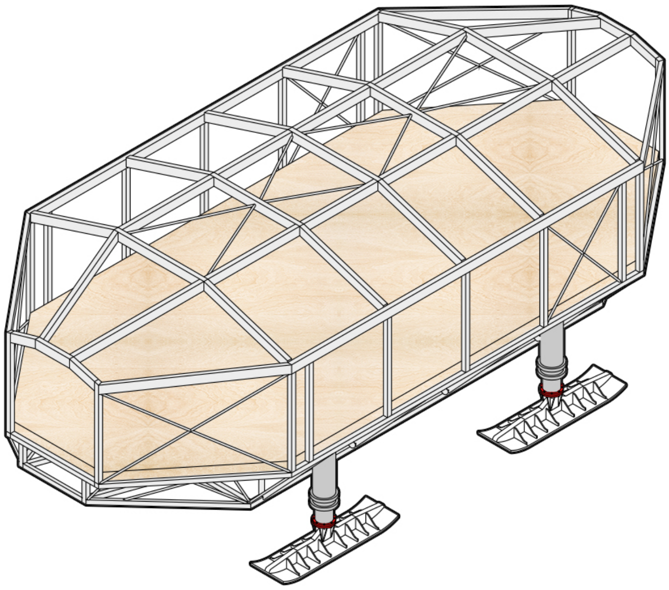


Figure 69. Module of structure construction - stage 4 steel Superstructure was installed on bottom frame. Original author

Exterior Wall and Insulation

When the superstructure is installed, prefabricated wall panels will be installed on the steel frame. These prefabricated wall panels consist of highly insulating composite glass-reinforced plastic. These panels are fastened to the structure and attached to silicone rubber gaskets. The panels consist of closed cell polyisocyanurate foam insulation encapsulated within GRP and finished with a layer designed to minimise discolouration, resist UV and the abrasive effects of wind, snow and ice.

Pros: 1. GRP is a lightweight material that is strong and can bear heavy loads. Due to the lightness of the material, it can be easily transported and installed.

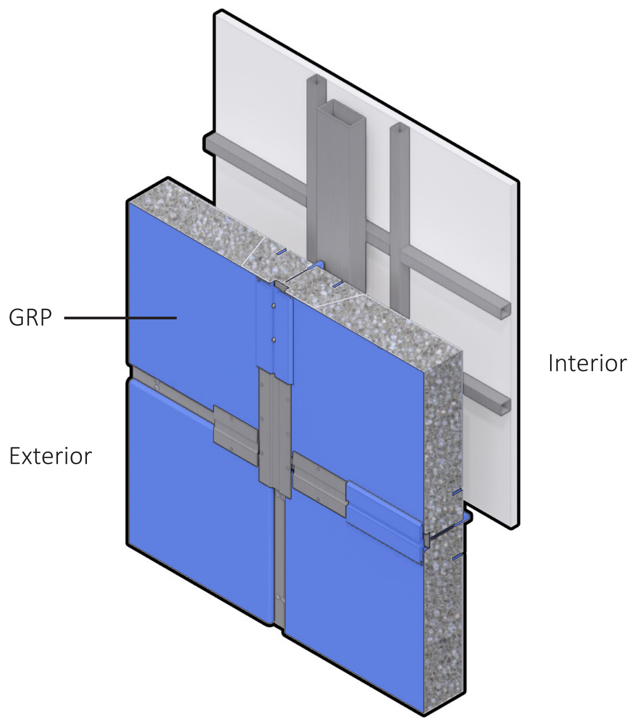
2. Low maintenance.

3. It can withstand any kind of wear, pressure, or damage, making it durable.

4. Not damaged and affected by the environment even in harsh climates.

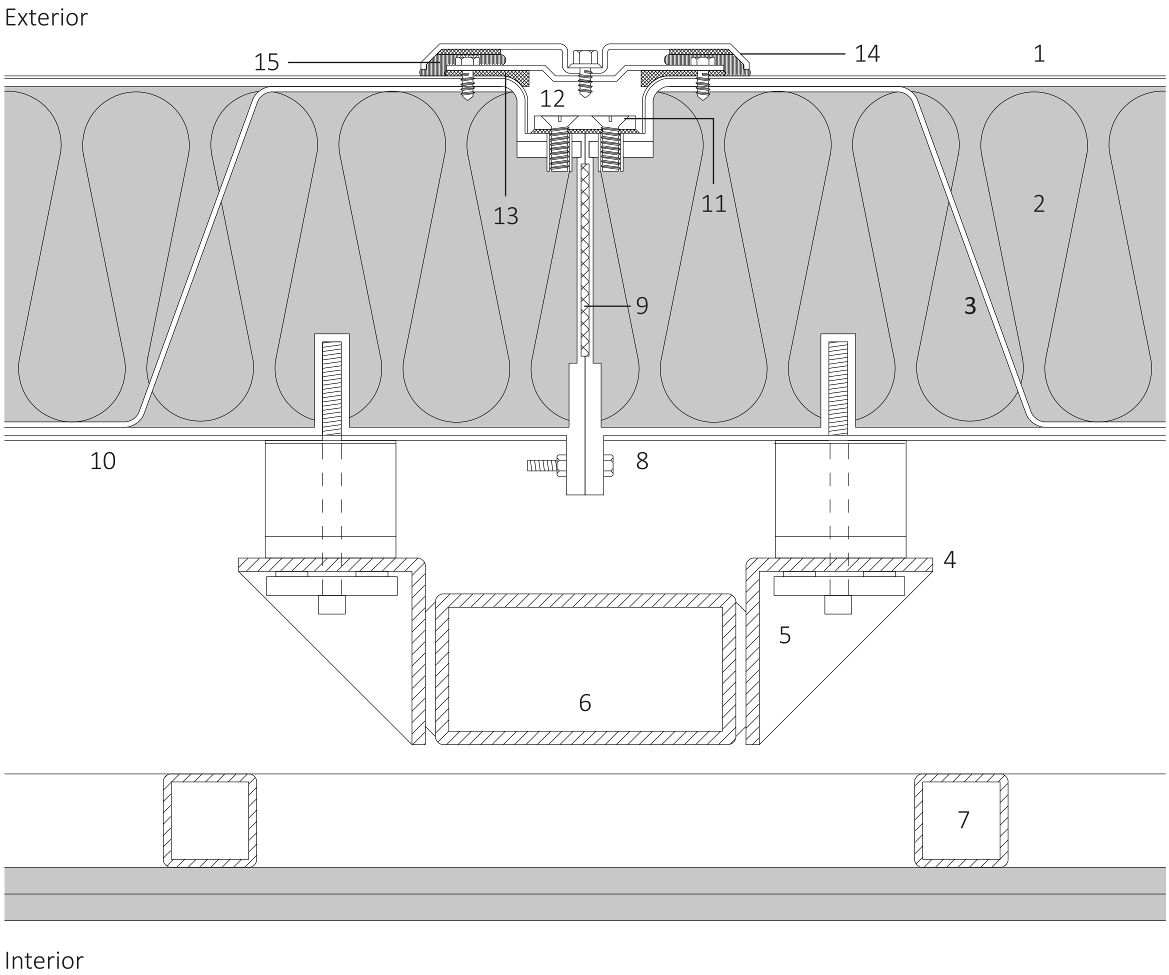
5. It provides grip and stability even in wet conditions.

Cons: GRP can be expensive, depending on complexity and scale.



Detail refer to figure 71

Figure 70. Exterior wall of Halley VI. Original author. Source: Ice Station the creation of Halley VI Britain's Pioneering Antarctic Research Station



Legend:

1. GRP outer skin to panels finished with gel coat and oversprayed with polyurethane acrylic automotive paint to ensure UV stability. Filled polyester resin used to achieve 30-minute fire resistance

2. 190mm polyisocyanurate (PIR) closed-cell foam insulation to achieve U-value of 0.113Wm^{2}K

3. Resin-infused cross-fibres prevent delamination under wind load

4.Flexible elastic-silicone cladding mounting screwed into GRP 'hard points' cast into panels

5. Steel cladding brackets welded to primary steel superstructure

6.Steel superstructure finished in intumescent coating to achieve one-hour fire resistance. Steel grade selected for performance at extremely low temperatures

7. Steel structure to prefabricated room pods. Pods lined in Fermacell board selected for rigidity and acoustic performance

8. Panels bolted together through GRP flanges using stainless-steel fixings

9. Continuous compressible neoprene insulation maintains thermal performance at joints, finished with PTEE to refuce friction during installation

10. GRP inner skin to panels finished with intumescent paint to achieve Cs3d2(Class 0) surface spread of flame characteristics

11. Panels jointed with GRP jointing strip fixed with countersunk M10 stainless-steel cap screws through compressed foam neoprene gasket

12. Extruded aluminum internal cover mounting strip

13. Aluminium mounting strip fixed with coach screws. Foamed EPDM compressed gasket seal between mounting strip and panel.

14. Extruded aluminium external cover strip finished with polyurethane acrylic automotive paint to match panel finish, fixed to internal aluminium mounting strip with self-drilling stainless-steel fasteners

15. Junction cover gasket formed in foamed EPDM

Figure 71. Exterior wall detail. Original author. Source: Ice Station the creation of Halley VI Britain's Pioneering Antarctic Research Station

5.2.4. Operation of Station

Energy

The base of each module has its own energy centre for self-sustaining in an emergency. Bridge connections allow sharing of electricity, drainage and water. The station's applied combined heat and power (CHP) system provides electricity and heat to the station in the most efficient way to minimise energy waste and reduce fossil fuel consumption. The generation system is located in modules E1 and E2. Each module has two generators and two diesel engines. All facilities outside the station will be connected to the CHP system.

The station's design can be compatible with future renewable energy sources such as photovoltaic panels and wind turbines. The design of the power distribution system allows for renewable equipment. It can install a range of different types of photovoltaic panels. Both energy modules (E1 and E2) will be able to install solar thermal panels to supplement waste heat collected from the CHP generator engine for water heating.

Water Treatment

The station's applied melting tank will convert snow into water and will be used for all drinking functions. In addition, the station's water treatment is designed to minimise water requirements and uses an extensive water recirculation system. It minimises water use through various facilities such as providing low-flow showers, spray and aerated taps, vacuum drainage and the use of water-efficient laundry and dishwasher machinery. Less water usage means less energy input to melt snow and less pump power to circulate water.

Waste Disposal

All waste at the station is disposed of in accordance with the BAS Waste Management Manual. To prevent them from being buried by snow, they are stored on raised mounds, platforms, or shipping containers. They are secured to prevent being blown away by the wind. During the summer, they are transported to a relief site near the ice and then loaded on a supply vessel to Cape Town, where they are transferred to a licenced waste contractor for disposal. The station will carry out maximum recycling, whether it is the station's own construction materials or other recyclable materials.

Wastewater Disposal

With the exception of grey water in kitchens and workshops, all grey water for all purposes passes through a vacuum and filtration device into grey water storage tanks, and pressurised grey water will be used for toilet flushing and other non-potable uses. Kitchen waste goes through a grease eliminator to remove grease for further processing before entering the black water system. The Biodisc Water Treatment Device treats black water from toilets and sinks. The grey water treated by the Biodisc device is returned to the used water storage and distribution system for recirculation for toilet flushing and low-level flushing operations.

5.3. Case Study: Jang Bogo Station

Jang Bogo Station is the second base of the South Korean Antarctic expedition after the Antarctic King Sejong Station. It is located on the small cape of Cape Möbius in Terra Nova Bay, Ross Territory, Antarctica, and it is approximately 1.2 km from Germany's Gondwana Station. The area is connected to the vast Ross Ice Shelf. The Ross Sea in this area is full of evolved animals that, over millions of years, have also developed adaptations that allow them to survive in the harshest climates on Earth. Construction of the station by Hyundai engineering is planned to begin in December 2012 and last two years during the Antarctic summer season. The station was completed and started operations in early 2014. The total building area of the station is 4411.46m2 and its facilities include the main building, scientific research facilities, and maintenance and operation facilities. The station is expected to have a lifespan of not less than 25 years. The station can accommodate up to 60 people in the summer and 15 people in the winter.

Figure 72. Jang Bogo Station. Photographer unknown. Photo attributed to EPA. Source: https://www.bbc.co.uk/news/magazine-38574003

5.3.1. Station Design Principles

The station has been required to be designed to be energy efficient and able to withstand the extreme weather conditions of the site so that it can operate safely year round. In order to meet the above requirements, the designer adopted a dynamic triple-arm structure to resist strong winds from all directions. The centralised radial positioning of the facilities around the main building is designed to reduce the overall area usage of the station, thereby minimising any possible intrusion into the surrounding environment. Each section of the station is clearly divided according to its function to reduce the interference between different internal procedures and improve the functionality and efficiency of maintenance and management.

5.3.2. Station Layout

The primary layout within the station is designed to provide the functionality, safety, and efficiency required for station operations. Each section of the station is positioned with consideration for interconnectivity, minimal functional disturbance, and optimal routing so related facilities are grouped together. The entire station is based on the main building as a hub. All similar facilities and spaces will be located on the triple-arm structure within the same arm of the structure. The station is radially arranged around the main building of the triple-arm structure. The main facilities include power plants, research facilities, storage, maintenance buildings, waste treatment facilities, communication antennas, and an observatory. Most maintenance facilities are located in the southern part of the station, separate from the main building and research facilities to minimise noise disturbance. Geophysical research and atmospheric science research facilities are located to the northwest and northeast to ensure a safe distance from the main building and to reduce facility interference with equipment in other facilities.

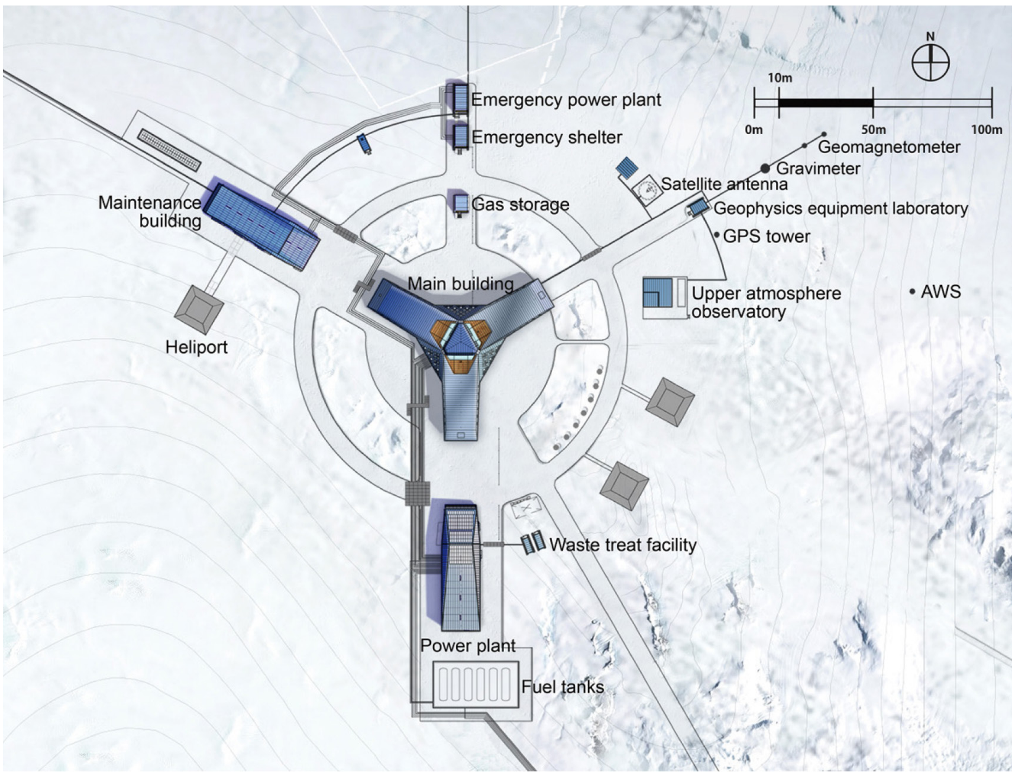


Figure 73. Layout of the Jang Bogo Station. Photo attributed to Korea Polar Research Institute & Korea Environment Institute. Source: Final comprehensive environmental evaluation, construction and operation of Jang Bogo Antarctic Research Station, Terra Nova Bay, Antarctica

5.3.3. Shape of Station

In order to deal with the problems caused by snow and strong winds, the station developed the best building layout plan and performed computational fluid dynamics (CFD) on building shape to find the design with the least impact on the building by wind and snow. The design team conducted simulation testing under strong winds for the linear I-type design, divided E-type design, and triple arm design (Figure 74). The final result is that the triple-arm structure is the most capable of withstanding the impact of snowdrifts.

The weight of snowdrifts can distort the structure, so the station incorporates an elevated slanting structure to reduce environmental impact and withstand snowdrifts. The exterior wall surfaces of the dimple effect can help to minimise snowdrift damage. An elevated slanting structure allows the wind to pass between the structure and the ground, reducing the heat generated by the building and melting the permafrost.

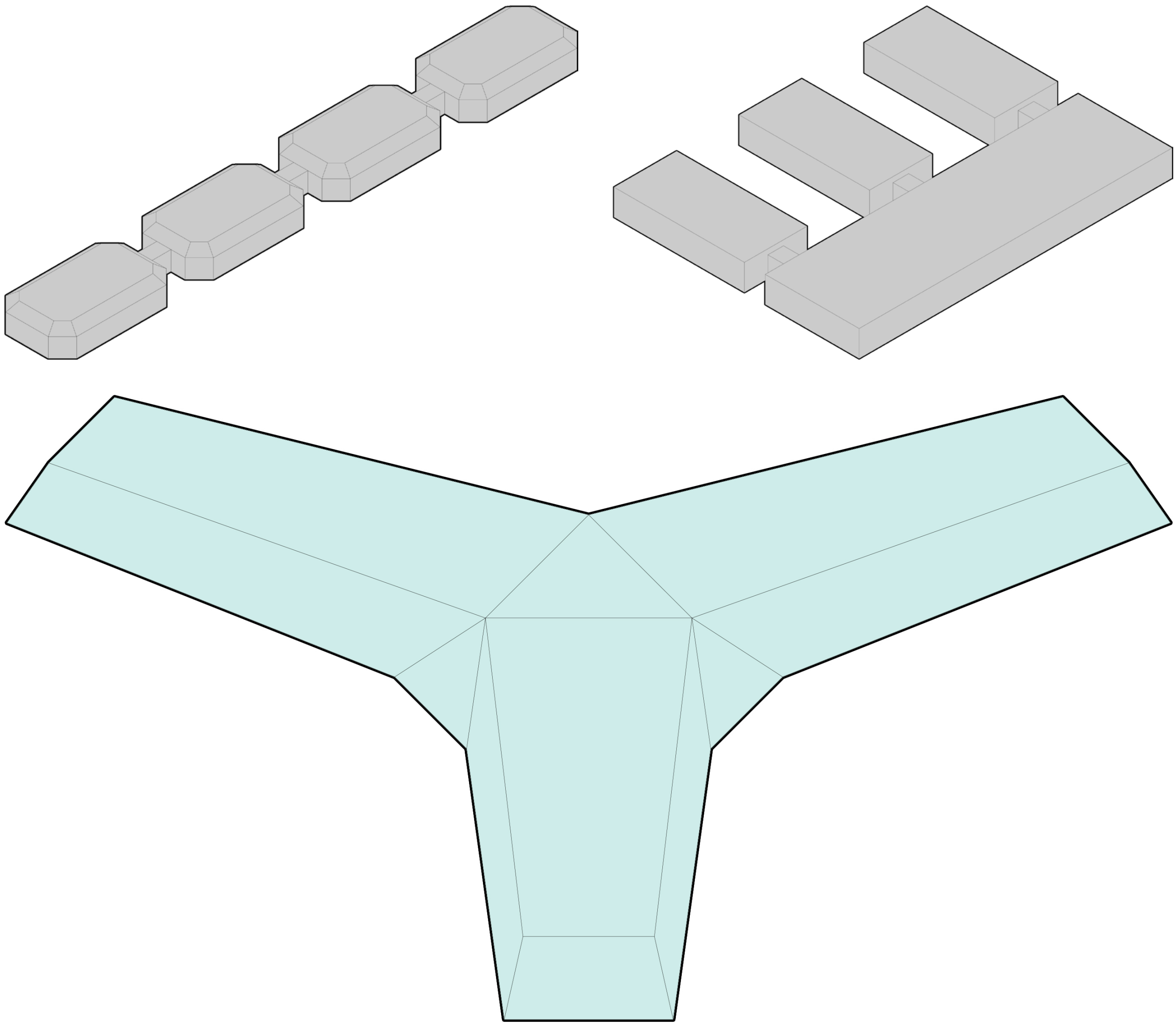


Figure 74. Linear I-type (Upper left), divided E-type (Upper right), triple arm type (Bottom). Original author. Source: Final comprehensive environmental evaluation, construction and operation of Jang Bogo Antarctic Research Station, Terra Nova Bay, Antarctica

5.3.4. Construction Method

Foundation

The construction of the station is divided into two phases. The first phase is to carry out the foundation work first. Pre-cast concrete is used for the foundation of the main building and surrounding facilities. All pre-cast concrete blocks are placed directly on the surface and then refilled with soil to cover all concrete blocks (Figure 75). Reserve the part of the starter bars for connecting steel pillars. Site work and construction time are reduced since pre-cast concrete blocks do not require piles or anchors (Figure 76) to be driven into the ground. All pre-cast concrete is manufactured in Korea and shipped from Korea to the site.

Pros: 1. All concrete blocks are manufactured off-site and transported to the site and foundation without piles or anchors to minimise the impact on the geographical environment.

2. Shallow foundation to avoid affecting permafrost.

3. Shallow foundation can be built in a short time to help reduce labour and costs.

4. Simple construction procedure due to shallow depth of foundation placement

Cons: 1. The site is close to the sea, and the foundation may be scoured.

2. If the site's soil bearing capacity is small, there is a chance of settlement.

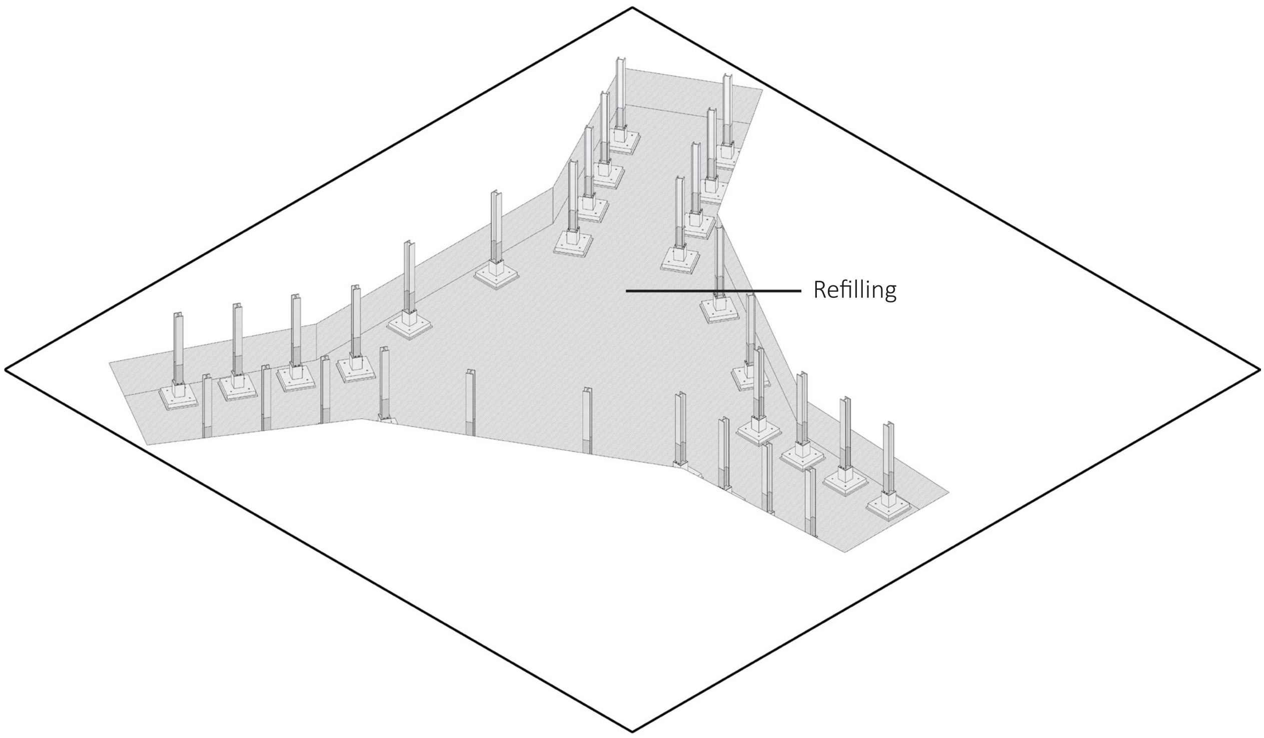


Figure 75. Foundation layout. Shallow foundation is applied to the station. Original author

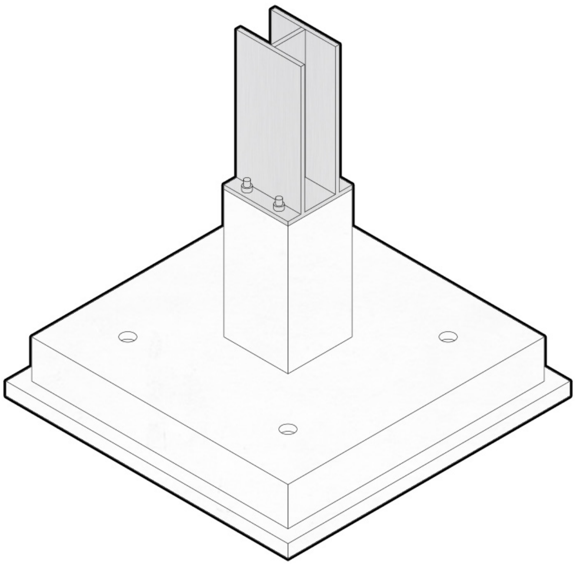
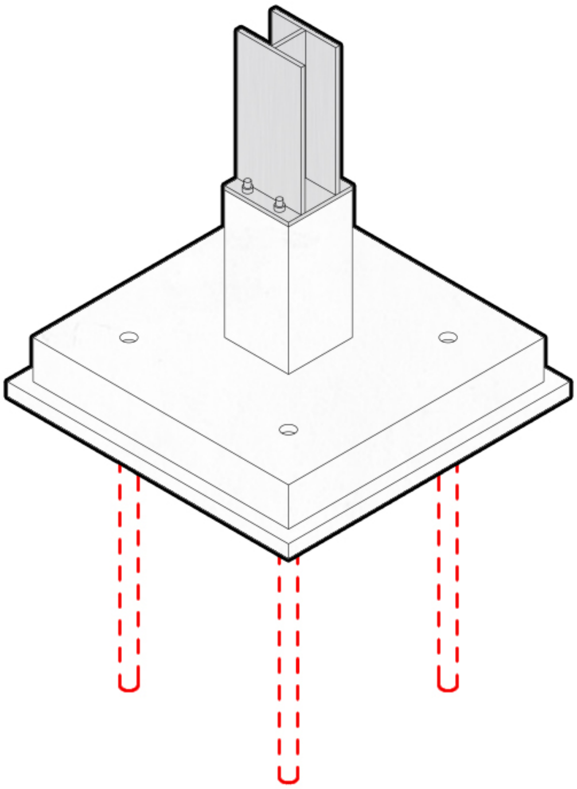


Figure 76. Steel pillars will be installed on prefabricated concrete blocks without anchors and piles and buried under the surface. Original author



Structure

The structure of the station consists of steel frames and steel pillars, which are pre-manufactured in Korea and shipped to the site for assembly. When the pillars are fastened to the started start bar of concrete blocks, they form the base of the station platform. The construction team then installed steel frames on the pillars to form the platform of the station. They then installed the rest of the steel frames on the platform to form the shell of the entire station.

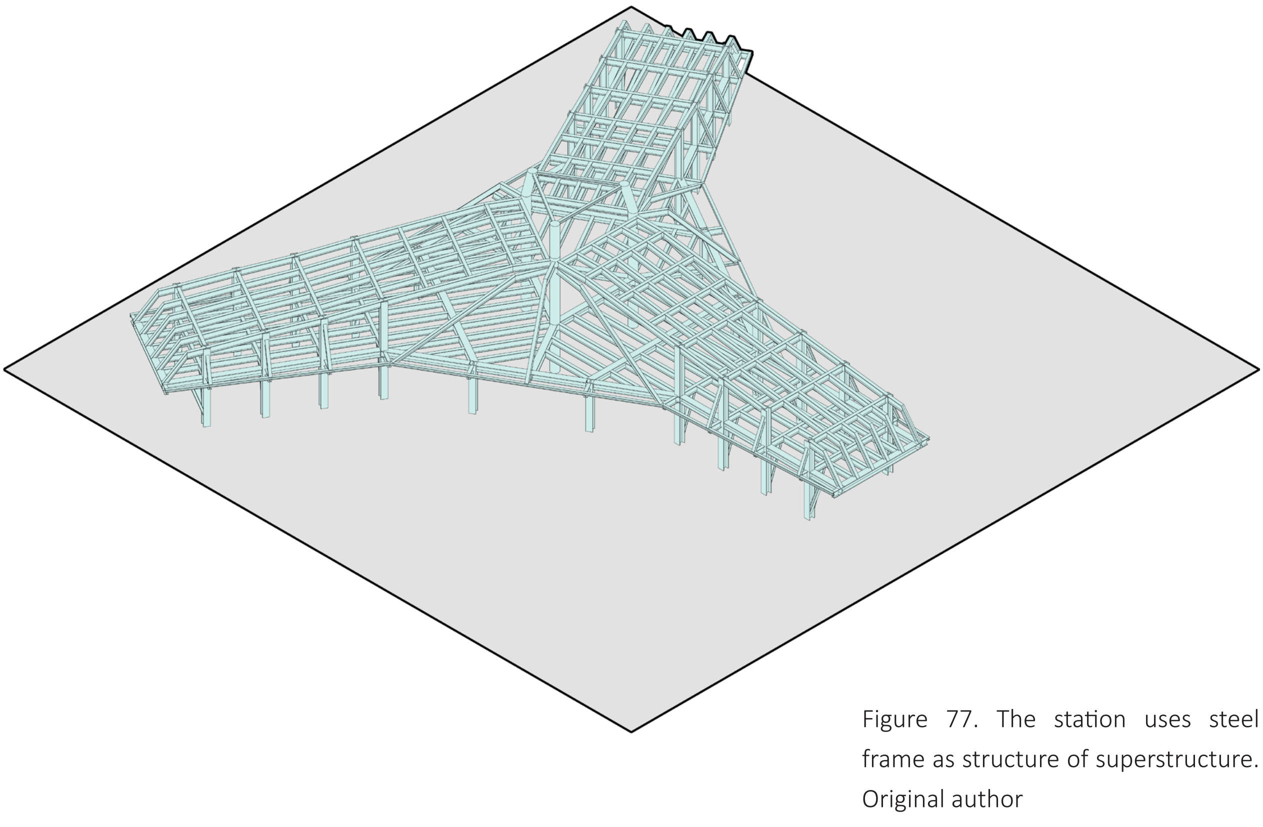


Figure 77. The station uses steel frame as structure of superstructure. Original author

Interior Installation of Station

The interior of the station uses a modular construction system. Prefabricated room modules are installed on the platform before the beams used to support the roof are installed. The modules are designed for easy transport, installation, and minimum waste. The module system is designed to reduce construction time, and they are assembled in Korea and then shipped to Antarctica.

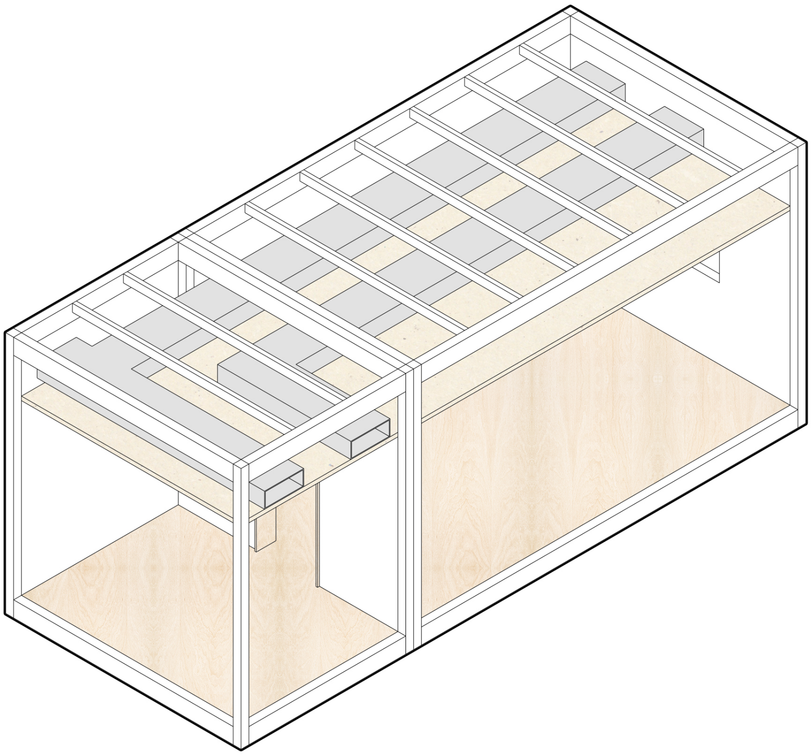


Figure 78. Prefabricated modules for main building. Original author

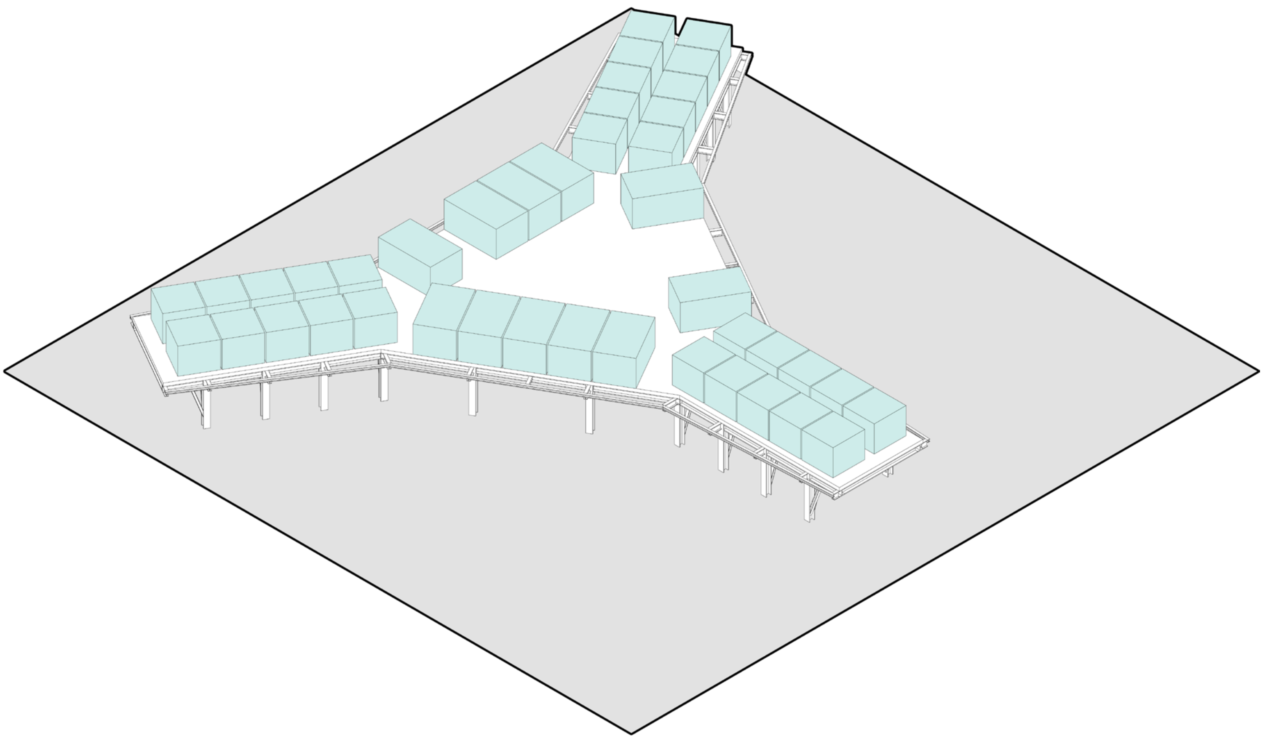


Figure 79. These modules are pre-manufactured in Korea and placed on the platform before the roof structure is installed. Original author

5.3.5. Operation of Station

Energy

The station's energy strategy is to minimise energy losses and increase energy efficiency. It uses a combined heat and power system (CHP) to provide electricity and heat to the station to reduce energy waste and fossil fuel consumption. In addition, it uses solar and wind renewable energy to minimise carbon dioxide emissions.

Three CHP systems are installed at the station, two of which are alternately used as regular generators and the other as backup generators. The system of generators uses diesel as the main fuel. For emergency fuel supplies, nine 100-ton fuel tanks have been installed at the station to store fuel for at least two years. In addition, a separate generator is installed at the emergency power plant to provide energy in an emergency. Renewable energy from solar and wind power accounts for 30% of the total power capacity generated by the entire station. It can be used to provide emergency power to the main facility in case all four generators fail.

Water Generation

The station applied a desalination device as a source of water supply. A snow melting device is used in winter depending on the freezing of the sea water. A seawater storage tank is installed near the shore, connecting the desalination device and a fresh water tank. The water pipes are built on the ground more than 1 metre high with heating wire and insulating material to prevent freezing.

Seawater is transported from the intake pump to a seawater tank where it is temporarily stored and then pumped into the power plant's desalination device. The desalinated water is stored in two tanks and then treated and distributed to the station. The snow melting device will use the waste heat of the CHP system to melt snow and store it in a seawater tank for processing.

Waste Disposal

The waste generated from this station will be handled and stored according to the Jang Bogo Station Waste Management Manual. The waste will be divided into more than six categories to minimise environmental impact while maximising recycling and eventually being shipped outside the Antarctic region for disposal. The station has also installed a waste compressor and hydraulic extractor to reduce the volume of waste.

Wastewater Disposal

The station applied a comprehensive treatment system to dispose of the wastewater to reduce any impact on the environment. Wastewater from the station is processed by internal circulation through a sequential batch reactor (IC-SBR). The principle of IC-SBR is to reuse and discharge relatively clean water through high-level treatment. Treated wastewater is passed through a discharge point located at an active sea current location away from the entry point near the dock facility.

5.4. Conclusion

After the above case study of the current station, the main factors for building a station in an extremely cold environment are the climate of the site, whether the station is designed to withstand strong winds and accumulating snow, how the station was built, material application, the way of operation, and comfortable living space. including enough privacy and work space, energy, and logistics. Every element must be taken into consideration in the design process, otherwise it may affect the psychological and physical health of the station personnel. In brief, the design and operation of the station are the most critical factors.

Each station construction method has its own advantages and disadvantages depending on its location, geography, climate change and biological habitat. In terms of foundation, their construction methods are not interchangeable because they are limited by their geographic environment. In the case of Halley station, its hydraulic legs cannot be used in stations other than ice shelves because its skis are only suitable for smooth ice surfaces and cannot be towed on soil, rocky terrain, or high altitudes. In other words, the Jang Bogo station and Princess Elisabeth Antarctica station foundations cannot be applied to the ice shelf because the ice properties do not provide sufficient bearing capacity for the structure. Each method is unique and depends on various factors on the site, so there is no specific method that will be considered the best way to build in Antarctica. On the contrary, the material application and cladding design can be interchanged on different stations. There are a variety of materials that can be used on the Antarctic continent, but their characteristics must be able to withstand extreme weather, light, durable, easy to transport, and require low maintenance. Materials that meet the above characteristics are the most suitable for Antarctic stations. In the design of the cladding, Jang Bogo Station has added a dimple effect to each panel to reduce snowdrifts. This extra design is more effective at withstanding wind and snow than smooth surfaces. Further development of the station requires devoting more resources to details of cladding so that the station can withstand extreme weather in all aspects.

In terms of operation, stations operate very differently than urban buildings, and they are limited by the extreme climate and the Antarctic treaty. Within the city, there is a stable grid supplying electricity to buildings, but the Antarctic station relies on independent generators and regular supplies of fossil fuel. It became a reliance on the station every year, but it was necessary to ensure that supply vessels could successfully enter the Antarctic continent during the summer, and there was no risk of icebergs collapsing when unloading supplies. Therefore, renewable energy sources must be used instead of fossil fuels for future stations to reduce their reliance on supply and reduce their environmental impact.

Chapter IV- Conclusion

6.0. Conclusion

6.1. How a Recently Constructed Research Station Responds to the Environment to Improve Human Habitation

The research found that safety and withstanding extreme weather are the first priorities for current research stations. Snowfall in the Antarctic region in winter is generally a few meters, and strong winds can blow this snow away in a short period. Building directly on the surface or burying it under the surface would cause the station to be buried by snow, causing the structure to lose its effectiveness and be constantly crushed. Therefore, stations located on the Antarctic continent are now built on steel pillars to prevent them from being buried by snow. This approach has various benefits, such as reducing snow management, increasing the lifespan of the station, better ventilation and exhaust systems, reducing environmental impact and reducing psychological effects of station personnel like winter-over syndrome and claustrophobia.

Building on steel pillars not only benefits the overall safety of the station and increases its lifespan, but also minimises its impact on the environment. Most of the foundations of the station are built with the least amount of excavation in accordance with the principle of not destroying the geographical environment of the Antarctic. In the case of the Halley VI, it was built with hydraulic legs instead of steel pillars, so there was no need to excavate the surface to maximise the environmental impact. For the elevated station located in a permafrost site, it is intended to prevent its own heat from melting the permafrost below the surface. Secondly, a buffer zone can be established between the station and the surface to reduce the damage to the soil. As far as these extreme climates are concerned, stations built on steel pillars are currently the most effective and cheapest construction method to withstand wind and snow.

In terms of construction, prefabricated components and composite materials are commonly used in the construction of recently constructed stations. Prefabricated components are the ideal method for the construction of current and future stations. Its effectiveness can be found in every station. It can build stations in the shortest period of time without large construction equipment. The properties of composite materials are very effective in adapting to extreme climates, and they are lighter materials. It shows that it is suitable for the Antarctic region both in terms of transportation and durability.

In response to the impact of humans on Antarctic psychology. The general living and working environment of the current station has changed greatly compared with the past station. The sense of space of the station is wider than the past station and no longer feels pressured. Clear space planning and entertainment facilities make personnel feel satisfied. Most stations will have an expansive social centre to provide people with living, dining, and entertainment options. Their planning is no longer limited by space and only provides limited entertainment facilities like the past stations. The privacy of stations is also improved so that each person has their own private space as much as possible. In addition, a variety of materials and colours are used in the interior to create an appropriate atmosphere in the space.

6.2. Further Development of Research Stations

As station designs continue to mature, how to withstand extreme climates is no longer a big issue. However, extending these designs will necessitate addressing the issue of station operation. The future development of stations is generally most limited by energy and supply issues. Most stations still rely on fossil fuels to generate electricity for station operation. For the people living in the station, energy can symbolise their survival. The biggest disadvantages of fossil fuels are the problem of limited supply and the impact on the environment. The supply vessel every summer is the only supply method, so further development of the station must be minimised to reduce reliance on annual fuel replenishment. Future stations must use new energy sources to replace current fossil fuels. Although some environmentally friendly biofuels, such as algae biofuel, are the most suitable alternatives to fossil fuels, they are not suitable for use in stations unless they can solve the problem of replenishment or produce these energy sources in the station. For the time being, renewable energy is the only solution to the above problems. Although some stations have applied renewable energy in order to continue to reduce their dependence on fossil fuels, it has not been fully popularized. The Halley VI is an example of why renewable energy has not been fully adopted. It is equipped with a generator that is compatible with renewable energy, but its effectiveness is unknown. Unless renewable energy is used as the main source of power generation in newly built stations in the future, it is difficult for its development to extend further afield.

Cultivation is also an important key factor for the further development of the station. NASA has established greenhouses in Antarctica since 2018 to study food production in deserts and cold regions and to explore the possibility of growing fresh food in harsh conditions on the Moon or Mars. Cultivation in extremely remote and cold regions is not easy. Most of the Antarctic region is covered with permanent ice and snow, and there is extreme cold and no sunlight for half the year, so most plants are not suitable for natural cultivation. Therefore, artificial planting methods must be applied to carry out cultivation on this vast white land. Research found that the soil provided to the station by the Falkland Islands for planting was low in acidity, and hydroponics was the best way for plants to grow in harsh environments. For the future development of the station, it is necessary to expand the scope of planting so that the supply of food is no longer dependent on a regular supply, which can be beneficial to future development.

In the days to come, the development of the stations in terms of construction and operation will be more advanced. They are currently serving as outposts in extreme climatic regions for humans to continuously experiment in order to overcome harsh environments and provide high-quality habitats. If the development of stations can solve the above problems, it will allow humans to reach further afield.

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Appendix

Vegetation experiment

As early as the last century, Antarctic expedition crews began to transport plants and their supporting facilities to Antarctica for planting experiments. These experiments not only bring fresh food and a stable food supply to the station but can also be used for biological regeneration of life support systems because their supplementary station capacity can be provided for air and water regeneration. Antarctic planting experiments can also contribute to the development of preparations for future space journeys.

In 1962, Jack Hill of Radio Operator did an experiment to grow vegetables at Halley I Station. The experiment was not officially a scientific project. He experimented with the possibility of growing a limited supply of fresh vegetables under the existing conditions of the Antarctic. A soil-less cultivation system called hydroponics was used in this experiment, which was carried out under artificial and natural light. Some crops are grown to maturity under fully artificial conditions, like only using artificial light and hydroponics in a station, while some crops are grown to maturity under hydroponics and natural light in a greenhouse. The conditions required for plant growth are influenced by light, food materials, moisture, warmth, and air, each of which interacts with each other. Photosynthesis plays an important role in the growth of plants. In this reaction, carbon dioxide and water combine with the help of light energy to form plant foods consisting of starches and sugars. There are a few problems in normal plant growth when all these requirements are met. However, it is extremely difficult to meet the above requirements under Antarctic conditions. Therefore, it is necessary to provide a suitable environment for plant growth at the research station. Several British Antarctic Survey stations on the Antarctic Peninsula have greenhouses. Most of the stations import soil from Stanley in the Falkland Islands using normal cultivation methods. One of the problems with using this soil is that it quickly becomes soured because of its low pH. While this problem can be corrected with the addition of artificial fertilizers, it still does not provide a satisfactory growing medium. The method of soil cultivation is not suitable for the environment of Halley Bay. Therefore, hydroponics is used as a substitute for soil cultivation. The technology is to grow plants without using soil and only use water to supply the nutrients needed for plant growth or use materials that support plant roots such as perlite, gravel, wood fibre, sand and foam. The second major consideration is whether there is sufficient light. The Antarctic has insufficient light for two-thirds of the year and more than enough for the remaining one-third. This means that the actual growing season is very limited and artificial light (fluorescent tubes) must be used for plant growth. In mid-May 1962, a rack was installed in a corner of the radio office. The upper rack is for the lighting unit and its controls, and the lower rack is for the growing trays. Humidity is low due to the existing radio equipment in the office, but no kind of ventilation is provided. A blower motor was installed to improve the circulation around the plants. It draws air from near the grow tray and blows it to the workshop next door. Shallow trays of water placed between grow trays help increase the level of humidity.

As summer approaching he plans to build a small greenhouse outside but there are following problems to overcome:

1. Drifting snow buried the entire station, causing a drift to form covering the entrance, chimney, and ventilator.
2. To maintain optimal temperature within the structure, most of its surface must be glass, and there is also temperature loss due to opening a door to access.
3. Temperature control makes indoor ventilation problem.

The outdoor greenhouse was built with timber frames on the roof of the station. The outer layer was cladded with 6 mm thick marine plywood, and the inner layer was cladded with 3 mm thick hardboard, and there is 3.8 cm of thick fibreglass insulation between the two layers. The top and front panels were rebated to the glass, which was held in place by wood strips. These parts are 2.5mm thick double glazing with air space between the glass. The parts are then taken out through the entrance hatchway and assembled in another small hatchway. This hatchway provides access to the greenhouse so that individuals can stand on the ladder with their heads and shoulders inside doing any work. With the greenhouse completed, he moved the artificially grown plants from the radio office to the greenhouse for natural daylight testing. There were no serious problems, except for ventilation issues caused by drifting snow and humidity control during windy periods. The fibreglass filled between panels and double glazing maintains the right temperature inside and still lets plenty of light in. Regarding the ventilation problem, he solved it by using shutters on the opposite vents and a drift-tight inner door. Since the daylight is constant during this period, it is necessary to install shutters on the glass at certain times to give the plants a night time. Overall, experiments have proved that plants can grow in extremely cold environments and with insufficient sunlight under artificial cultivation methods.

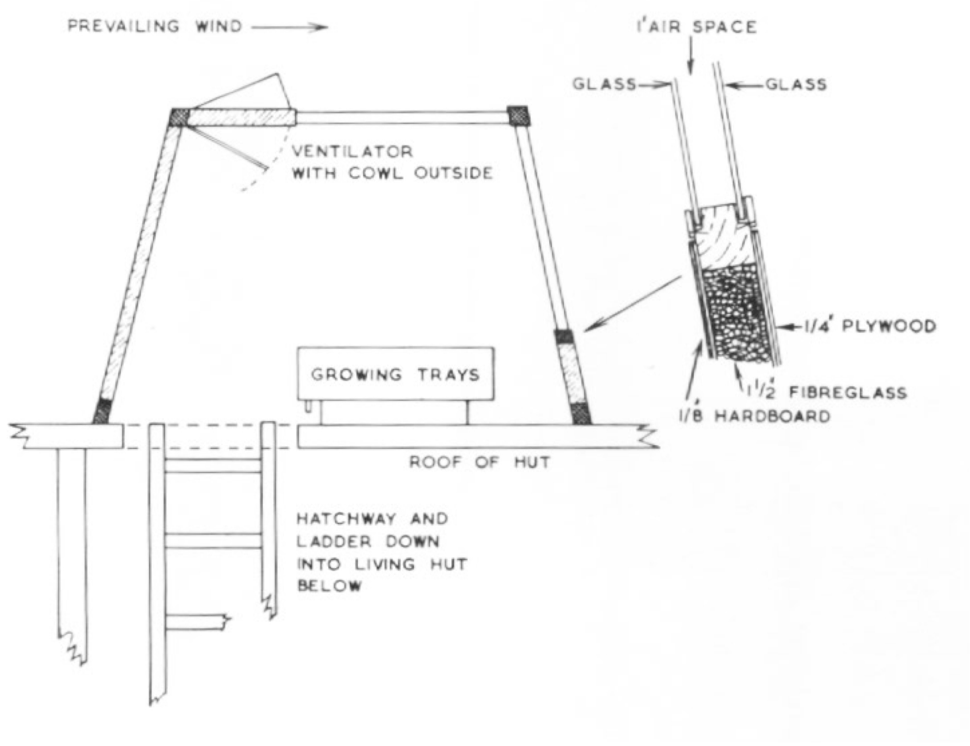

Figure 80. Construction detail of the outside greenhouse at Halley I. Photo attributed to Jack Hill. Source: https://core.ac.uk/download/pdf/31017763.pdf

Winter-over Syndrome

Several studies have confirmed that the Winter-Over Syndrome can affect the mental health of people in Antarctica. This not only affects their daily lives and work, but they can even lose their lives. The Antarctic environment, such as extreme weather, long-term darkness, and isolation, puts them under tremendous stress, leading to symptoms of seasonal depression such as insomnia, depression, and manic depression. Current measures to deal with these symptoms are primarily the establishment of synchronised group sleep schedules, regular sleep and wake times, and artificial lighting to improve mood. In addition, it is imperative that people maintain regular social activities and regular exercise. These measures not only help to improve group morale but also to maintain mental health.

Antarctica is the most extreme and remote region on Earth. Many countries have established multi-generational research stations on this driest, coldest, high-altitude, and windiest continent. The most complete cure for the Winter-Over Syndrome problem currently in Antarctica is to leave the Antarctic, but this is extremely difficult for those working on the station. In order to effectively solve this problem without leaving Antarctica, in addition to the above measures, the environment and facilities of the station can also be improved to reduce the risk of Winter-Over Syndrome. Stable communication facilities are provided in the station so that people do not feel isolated. It is important for station personnel to be able to communicate with distant relatives and friends so that they can get information from the outside and reduce the feeling of being isolated. In addition, providing people with a stunning environment and facilities, even in Antarctica, will allow them to live a normal daily life without getting bored. In this remote part of the world, it is necessary to create a familiar environment in the station so that people can feel at ease and reduce the risk of suffering from Winter-Over Syndrome.

One of the purposes of the further development of Antarctic stations is to serve as an outpost for interstellar travel. However, the environmental and psychological effects of space are worse than in the Antarctic, so the Winter-Over Syndrome must be overcome. The environment during the interstellar journey is like the Antarctic in winter as it has long-term darkness and is the coldest. Various experiments for interstellar travel have been carried out at stations in Antarctica. These experiments simulate the effects of long-term isolation and confinement on human psychology during interstellar journeys. Although the environment cannot replicate the effects of weightlessness and radiation in space, its harsh environment can contribute to the factors to be considered in interstellar journeys. In the future, the development of the station to overcome the Winter-Over Syndrome must be a crucial research project.