# **Pursuing Prefabrication:**
An Exploration of Building at McMurdo Station

by

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# Contents

# Abstract

While experimentation during the early 20th century pushed prefabrication by challenging off-site and on-site practices, it still struggles to establishes itself beyond novelty in contemporary building. The qualities of prefabricated building assemblies are governed by the relationships between factory, site, transportation and loading gauge. These qualities are responsible for both the benefits and limitations of this building method. However, by examining strategies and emerging trends within prefabrication we can see how negotiating and leveraging these factors can enable us to provide both a variety of programmatic needs while accommodating the complexities of modern building.

Due to its extreme climate and remoteness, McMurdo Station in Antarctica is a promising location for the study of prefabrication. Building there is complicated by an annual cycle of operations which overlays the most favourable construction season onto the most intense period of research. By erecting a factory at the station, itself prefabricated, the building capabilities of McMurdo Station would be greatly enlarged.

# Acknowledgements

To my supervisor Emanuel Jannasch and advisor Michael Putman, thank you for your continued support and insight throughout this long and arduous process.

I also wish to thank my family for their love and support over the past several years, especially during these most recent difficult and uncertain times.

# Chapter 1: Introduction

Prefabrication strives not only to challenge off-site and on-site practices but also to negotiate the problems and inconstant nature of the building site, to navigate the avenues of transportation, and to maximize the potential offered by factories and off-site facilities. Limitation and restriction of activities pertaining to on-site and off-site practices characterized much of the early prefabrication in the 19th century. Industrial processes were only possible in factories that could accommodate the machinery and materials needed for building production. Concepts of factory-based production would expand greatly in the early 20th century as the scope and scale of manufacturing capabilities dramatically increased. While computer-aided manufacturing may have enabled shifts in on-site and off-site practices, the physical reality of size, mass, fragility, and so on addressed by twentieth-century contemporary prefabrication is still governed by manufacturing. This has led to for a variety of practices and methods to emerge. These include the standardization of building materials, various assembly theories, and more recently, container architecture.

To realize these approaches, prefabrication must negotiate issues and possibilities such as non-sequential production and building methods, the flexibility of open and closed systems, project permanence, and end of life strategies. One factor prefabricated construction has to navigate is transportation between factory and site. A fundamental bottle neck is the loading gauge, the maximum allowable cross section of cargo that will fit between and under obstructions along a given transport corridor. Loading gauge varies from route to route, but for international shipping it is defined by the 8' width and 9'-6" height of the standard high-cube container.

McMurdo Station, a research station located in Antarctica, provides a remote testing site with a unique annual cycle of operations and site considerations. As the largest year round station in the region, McMurdo boasts the world's southernmost harbor, acting as a logistical gateway for the USAP (United States Antarctica program). In order to support McMurdo Station's mission of scientific inquiry, the station has developed a unique annual cycle of operation and resupply (NSF n.d.).

By increasing time available for construction in the annual schedule and enlarging the loading gauge, it would be possible to dramatically increase the building capacity of McMurdo. This thesis proposes a two-stage process, the first will take advantage of established prefabrication methods to construct a production facility at McMurdo Station. In the second stage, the factory will expand the construction period into the season where research has slowed down, but which until now has been too cold for building. Materials and small assemblies will be shipped to the factory within the loading gauge of the container, and here they will be pre-assembled into larger units better meeting many of the programmatic needs of the station. These assemblies would have a lower specific value, or value density, compared to densely-packed construction material but would save time in final assembly. This will enable the creation of a Habitat, a complex that will be used to test the newly-designed prefabrication assemblies and methods, enriching the architecture of McMurdo Station and expanding the building possibilities in the region. Through this hypothetical testing we can hope to learn more about loading gauge and specific value as considerations in of off-site construction.

# Chapter 2: Influences on Early Prefabrication

## 2.1. Early 19th Century Off-site and On-site Practices

There are two problems with site work. The first is weather, and the second is the limiting of equipment to what can be set up on a rough and exposed site. Building components that are compact enough and robust enough to be shipped safely and cheaply, for example wood and steel trusses, cabinets, and windows are therefore made off-site. As Herbert states:

> "During the nineteenth century, for the first time in the long history of "man the builder," serious and sustained attempts were made to devise systems whereby most of the component parts of a building could be fabricated in a builder's yard or workshop prior to their assembly on the actual building site." (Herbert 1978, 1).

Established sawmills and brickyards had been operating for a long time, were now joined by foundries, sash and window mills, steel fabricators, and other fabricators. Attempts were also made to make 2-dimensional panels and volumetric modules, but these are harder to transport. The development of these industrialized processes resulted in the standardization of construction materials and resources that are relied upon today (Herbert 1978, 186). This sets up the factory to be the cornerstone for the prefabrication process, whose advancement into the 20th century would inspire innovations that still only represent a small portion of the building industry but that are gradually becoming more viable.

## 2.2. 20$^{th}$ Century Established Modern Manufacturing Processes in the Factory

Several architects of the 20th century such as Jean Prouvé, Konrad Wachsmann, and Walter Gropius, shared the hope that factory-based methods would lead to a significant amounts of prefabrication (Herbert 1986, 186). However, ideas such as the factory-made house, the general panel, and large scale geodesic domes were not widely used or implemented beyond initial conception and testing (Herbert 1986, 6). The viability of panels and modules is still limited by the realities of transportation, but the success of the factory in producing more portable goods continues to inspire investment and innovations in the factory production of larger building components (Kieran and Timberlake 2004, 105).

## 2.3. The Factory Environment

The factory setting provides an environment for building and assembly with some advantages and some disadvantages. On one hand, it creates a stable sheltered environment for workers and equipment (Smith, 2011, 67). Limiting exposure to the elements eliminates variability providing consistency in production (Smith, 2011, 95). Unlike certain on-site practices that require sequential task management to complete the intended structure, factory-produced prefabricated assemblies can be manufactured in parallel. This enables simultaneous production of numerous assemblies ready for site transport and erection (Smith, 2011, 96). This illustrates that prefabrication is a forward-heavy process, with the manufactured assemblies requiring greater production time and warehousing costs prior to transportation to site. Also, the factory is removed from the building site making large modules expensive to transport. The location of prefabrication plants is always a compromise. First, land costs, servicing, noise, and so on keep prefabricators out of the urban core. Second, the power of the factory lies in centralization and the economy of scale, which suggests locating prefabrication plants between population centres and thus at a greater distance from more destinations.. The specialized nature of these facilities could result in an increased shipping range for prefabricated assemblies by hundreds of kilometers from their point of origin. The challenge taken on by this thesis is to locate a factory so as to capitalize on the inherent advantages of off-site production while minimizing the drawback of the loading gauge.

# Chapter 3: Current Prefabrication Practices' Modest Role in Building

## 3.1. The Spectrum of Prefabrication

The characteristics of prefabrication are not only derived from the separation between site and off-site practices but also in the logic of their building processes. As the building industry tries to develop a language to describe prefabrication, it can instead by understood as a series of discrete and condensed building "chunks" delivered to site whole. The lay term "chunks" include the more specialized terms like module, cassette, component, assembly, sub-assembly, and so on. Some of the most important distinctions are made in the visual lexicon (Figure 3). These "chunks" can be organized by level of completeness or spectrum of prefabrication indicating the overall complexity and function of their intended whole. At one end of the prefabricated spectrum, these assemblies would include all the necessary functions of a building, including utilities, envelope and even the foundation. One of the most successful examples of this is the mobile home or trailer, with Kieran and Timberlake writing "In quality, off-site fabrication has come to be associated with products in trailer parks"(Kieran and Timberlake 2004, 107). As we move away from this prefabricated extreme, we see more conventional modules, panels, and components of prefabrication. While some panels may contain greater complexity in the form of integrated utilities (referred to as cartridges or cassettes) a lesser specific value of an assembly does allow for greater flexibility in a design (Kieran and Timberlake 2008, 82) However, to push the possibilities of prefabrication at a location such as McMurdo Station a single prefabricated methodology is insufficient. Kieran and Timberlake write

> Needed here to sustain the dream of an accessible architecture is a commitment to a pluralist process. Rather than the imposition of architectural vision on contemporary modes of construction, the process must be a broadly-based fusion of all possibilities and capacities across the entire spectrum of those who make architecture. (Kieran and Timberlake 2004, 107)

## 3.2. Sequential Vs. Non-Sequential Building

Typical construction methods take raw or standardized building materials with a higher specific value. Whether on-site or in the factory, the process of construction expands the volume occupied by materials. So even as value as added, the value-per volume or specific value is diminished. This enables construction managers to put a more exact price on the lay person's worries about "shipping air" (Jannasch 2012, 2). These materials are assembled in a particular sequence building upon each in order. This clear order of operations equates typical construction to a layered process or taller method of project delivery, with each step dependent on the completion of the one prior. In contrast, prefabricated assemblies or building "chunks" have a lower specific value. They are assembled and erected on-site, sometimes requiring little or training. However, greater planning and preparation is required before the prefabricated assemblies can be shipped to site. That a factory centralizes waste-production does suggest a small weight-savings in shipping any kind of "chunk" in spite of the massive cost in increased volume. However, construction planners also need to factor in the cost of packaging and handling that large "chunks" may entail. But unlike typical construction, manufacturing of these prefabricated assemblies can be performed in parallel prior to site delivery. Collection of these prefabricated chunks or assemblies can then be transported to site simultaneously. Kieran and Timberlake state “Framing is the old way of making in architecture, in which hierarchical parts are sequentially aggregated into a whole. Quilting is the new way of making in architecture, in which integrated assemblies are elements that can be made in various locations by various makers and integrated seamlessly with the other assemblies to form the whole” (Kieran and Timberlake, 2004, 57).

### 3.3. Open and Closed Systems

Prefabrication is often expressed as a system of producing kinds of parts and assemblies whose diversity and useability define the flexibility of that system. These prefabricated systems are usually referred to as “open” or “closed”. Open building strategies “have the aim of achieving flexibility in internal planning and servicing both in the initial design and in future changes of use. (Ogden, Lawson, Goodier, 2014. 71) These open systems often include the capacity to interface with a variety of other prefabricated or standardized systems giving the design a greater flexibility to address different challenges (Smith 2011, 124). More kinds of panels, modules, cassettes and cartridges can be positioned and used throughout the design. These construction methods can often respect the dimensional modules of standardized construction materials. This efficient prefabricated strategy would enable the same panel or module to be repeated, with only minimal modification required to repurpose it as needed. Closed building systems are often the product of designs with a high degree of prefabrication. They do not readily interface with other building systems unless they have been specifically designed to do so. Smith states “closed class buildings are proprietary and the range design options can be too limiting given a specific location context of the site" (Smith 2011, 124). A prefabricated living pod or trailer is an example of an entirely self-sufficient prefabricated assembly which includes all the required functions before it is shipped to site. Computer-control of factory equipment and the principle of mass customization suggest that such modules can respond to particular needs and tastes..

## 3.4. Grids and Alignment

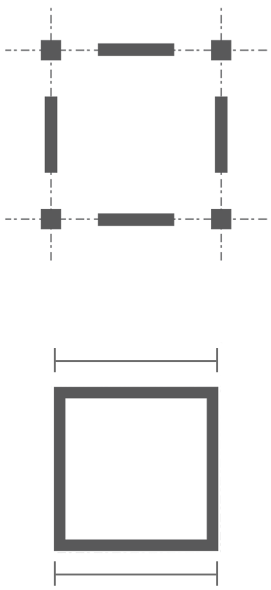

Figure 1: Axial grid (top), modular grid (bottom).

When bringing together a series of prefabricated assemblies, careful consideration must be payed to their organization, alignment, connection, and joinery. Two methods of alignment and organization are common: axial and modular grids (Smith 2011, 125). Axial grids organize building elements along grid lines and nodal intersections. Structural steel systems which rely upon a series of linear members and components are often organized in this manner. While assemblies may be placed at consistent and regular intervals, consideration must be payed to the differences in spacing between nodal intersections as the varying sizes of assemblies would change. This can be seen in the forementioned example as the size and proportion of the linear structural members may change in response to loading conditions within the building.

Modular grids position assemblies either adjacent to or within grid lines, taking into consideration the real-world dimensions of assemblies and tolerances. This often results in connections between sub-assemblies and assemblies occurring along seams and edges rather than on corners or nodes. Hence this method is often used when similarly-sized prefabricated assemblies are positioned one after another. Sequential panel assemblies and large-scale modular construction use these methods of organization. Ultimately, given the complexity of modern building and prefabrication, its is likely that both systems could be used within a given project. This negotiation of organizational systems necessitates the keen cooperation and oversight necessary for prefabrication to succeed as a building method.

# Chapter 4: Navigating Site and Factory

## 4.1. Loading Gauge

The loading gauge is the primary bottleneck in the transportation of prefabricated assemblies between factory and site. Loading gauge is the cross sectional shape that prefabricated assemblies must conform to allow unimpeded movement along a particular transportation network. While this is not the only limiting factor in the transportation of prefabricated assemblies it is the most immediate. Loading gauge limits the scale and proportion that prefabricated assemblies can reach. This restriction of physical dimensions is not the only constraint on transportation. The lifting capacities of cranes and gantries are limited to a an allowable mass as well as sizes and shapes (Jannasch 2012, 2). To be loaded or off-loaded these assemblies would need to conform to capabilities of handling equipment on and off site. Rooms and other chunks of buildings are designed to function in place. Making a module robust enough to survive acceleration and deceleration due to shipping and handling adds to the expense. So does engineering it to be handled at the support points offered by the equipment involved. So does padding things against the inevitabilities of transit. So does protecting incomplete parts of a building against the weather. Examining the transportation methods available to McMurdo Station, we see that materials sent to site must conform to either transportation by plane or by container vessel.

## 4.2. Unique Qualities of Container Architecture

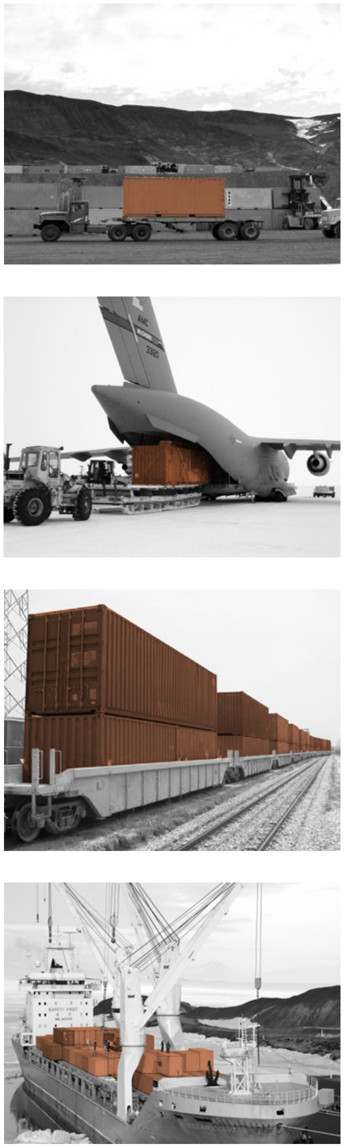

Figure 2: The variety of methods to transport freight containers includes; road (top), air (top middle), rail (bottom middle), Sea (bottom).

The use of ISBU shipping and freight containers revolutionized the transportation of goods and materials during the 20th century. The ISBU containers are so common that "freight containers can be found all over the world – from Antarctica to the tropical rain forest" (Slawik 2010, 8). The use of either standard or modified freight containers in building has become an increasing trend within prefabricated architecture. Both the abundance of ISBU containers and their structural properties make them a readily adaptable starting point for both small and large-scale projects incorporating modular design. Given that the current global shipping industries are now specifically designed to handle freight containers, ISBU containers are uniquely suited to fit within the loading gauge of most available transportation avenues by land, sea, and even air (Jannasch 2012, 2). The limitation of containers is that programmatic demands on a place so often exceed a width of 8'.

When examining McMurdo Station, freight containers are as easily recognized on the landscape as the ice and snow that surrounds them. The capacity for transportation and handling of freight containers at McMurdo Station is already well established and could be a key asset in developing a strategy that will expand the building potential of the site.

## 4.3. Prefabrication Lexicon

One thing hampering the rationalization of building processes is the sheer confusion of terminology. One term might mean different things, to different people, and the same group might use several names for the same object or idea. Ryan E. Smith writes:

> Elements of prefabrication refer to the form or configuration of the output. Components, panels, and modules are general categories in which buildings are fabricated or manufactured off site and assembled. These categories are not industry standard names, as no hard, fast rules exist to categorize prefabrication. (Smith 2011, 127)

For Wachsmann, “module” was not a volumetric or room-based component building component, but a dimensional increment (Wachsmann 1961, 54). It is this realization that led to the development of the prefabrication lexicon. This lexicon not only helps to clarify of the terminology that prefabrication presents but hopes to inform others how to navigate prefabrication as a building method as well. The quote alludes to the benefits that prefabrication can enable within a project such as faster on-site assembly, quality control, and parallel manufacturing. It may also suggest some of the drawbacks or limitations of prefabrication.

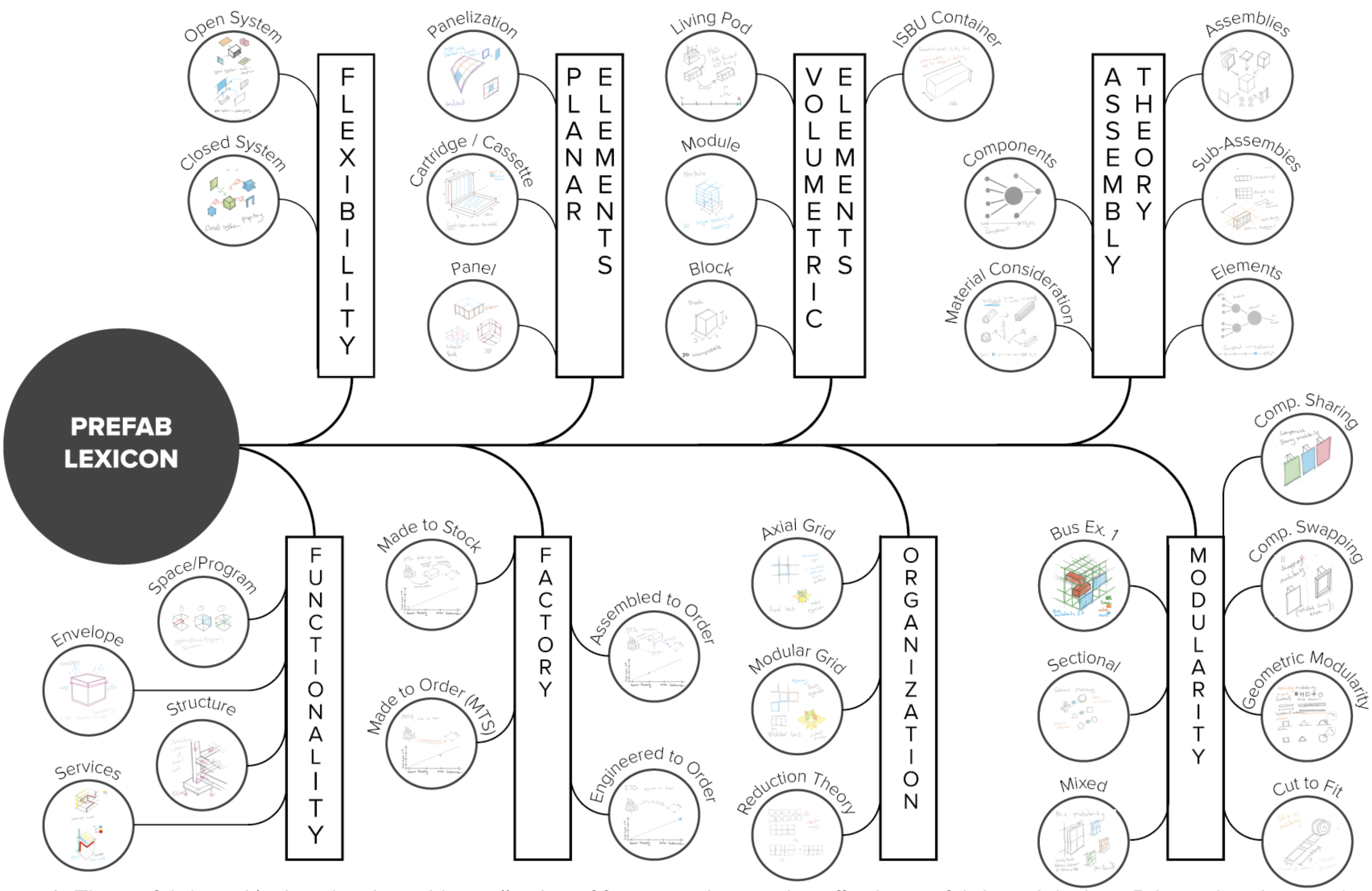


Figure 3: The prefabricated lexicon is a branching collection of factors and strategies effecting prefabricated design. Primary headers are broken down into related concepts and definitions.

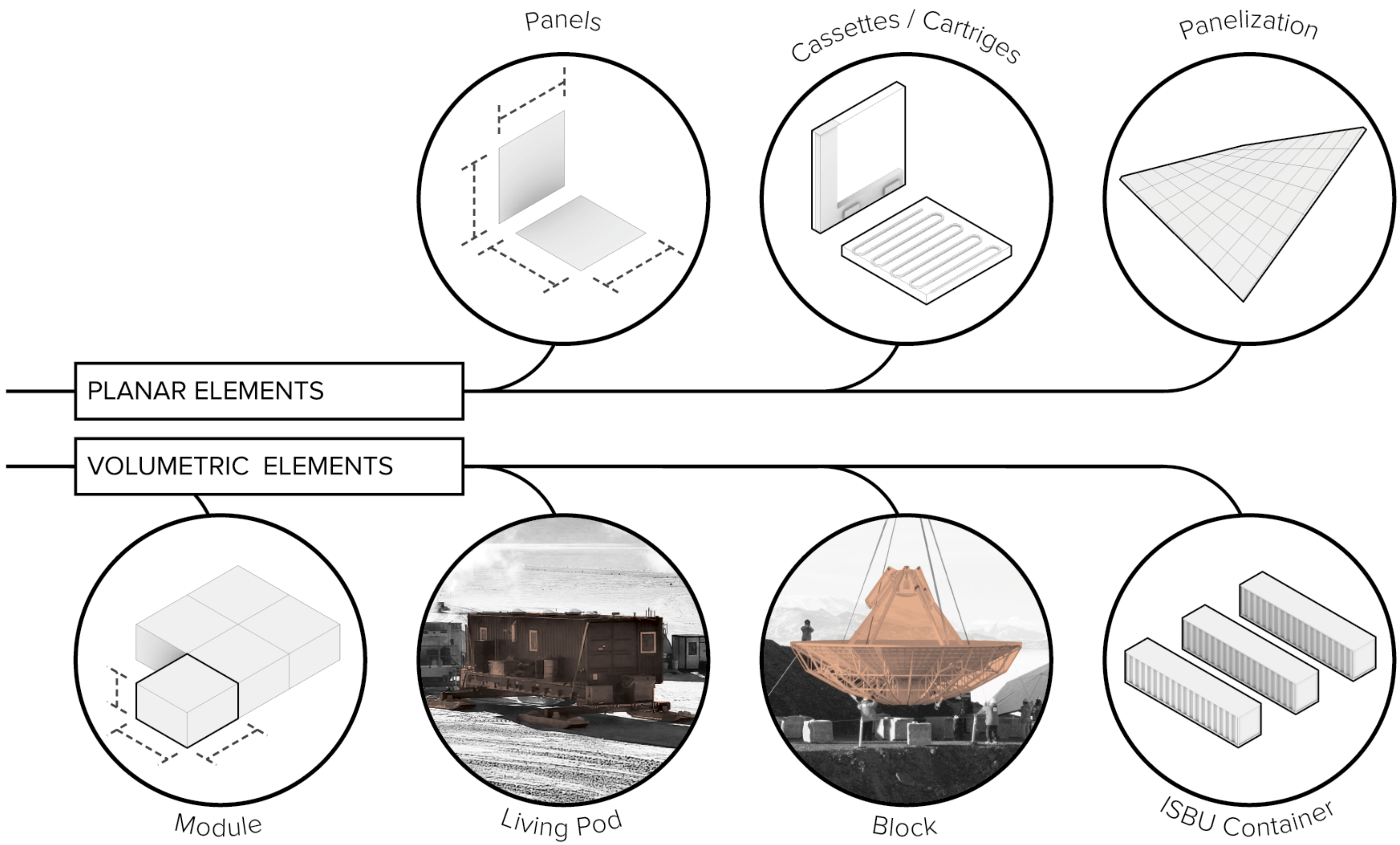


Figure 4: Prefabrication is readily associated with panels and modules: however, these terms include a variety of building strategies and avenues for prefabrication. South Pole Traversal Living Pod 2020; original photograph by Gabriel Nerf (USAP, n.d.). New radar dish shipped to site as an incompressible assembly or “block” 2010; original photograph by Kevin McCarthy (USAP, n.d.).

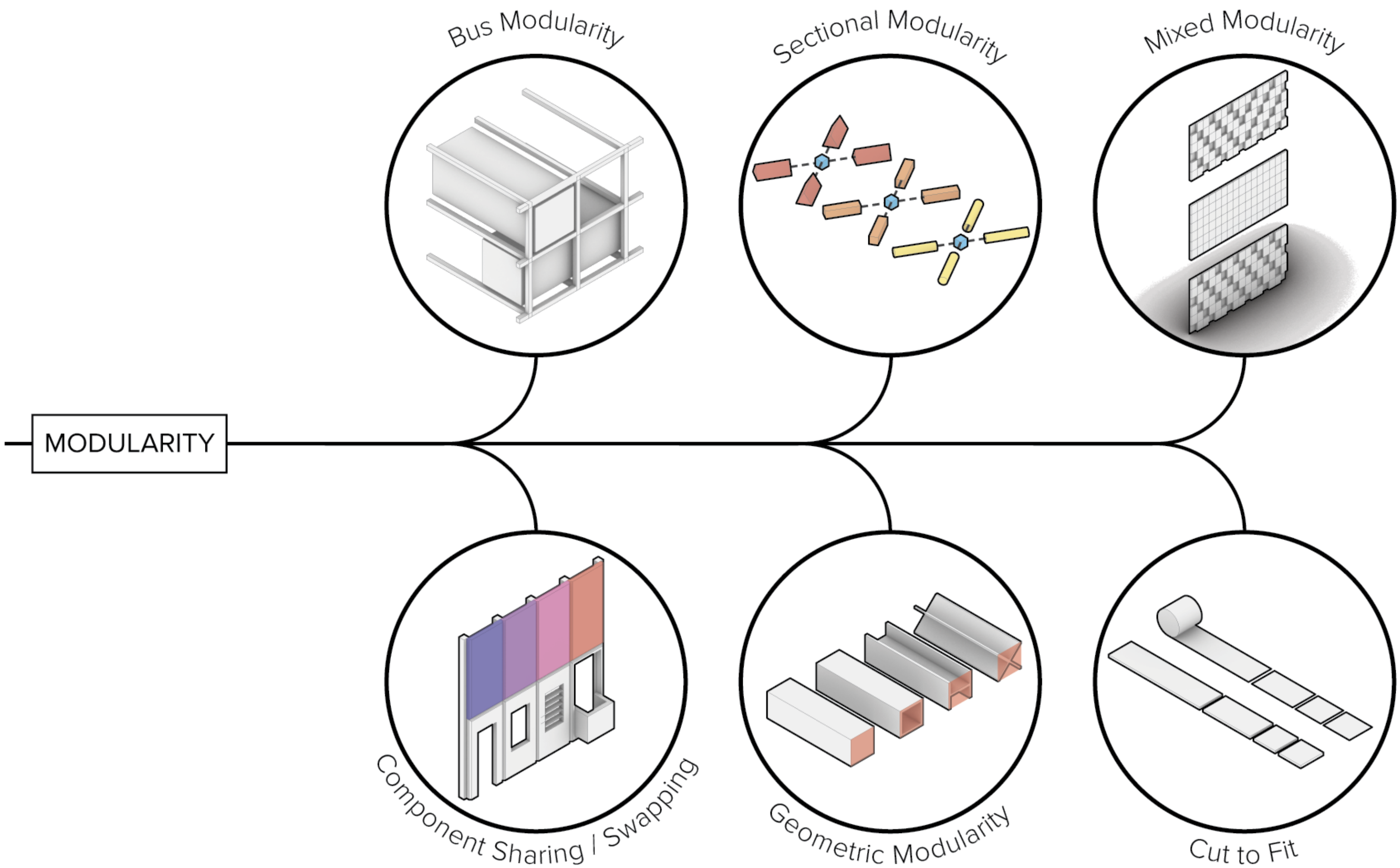


Figure 5: Modularity exists beyond limitation of size and proportion and extends to strategies and method.  It the case of geometric and cut to fit, it even determines how the manipulation of specific materials can create diversity within a particular strategy.

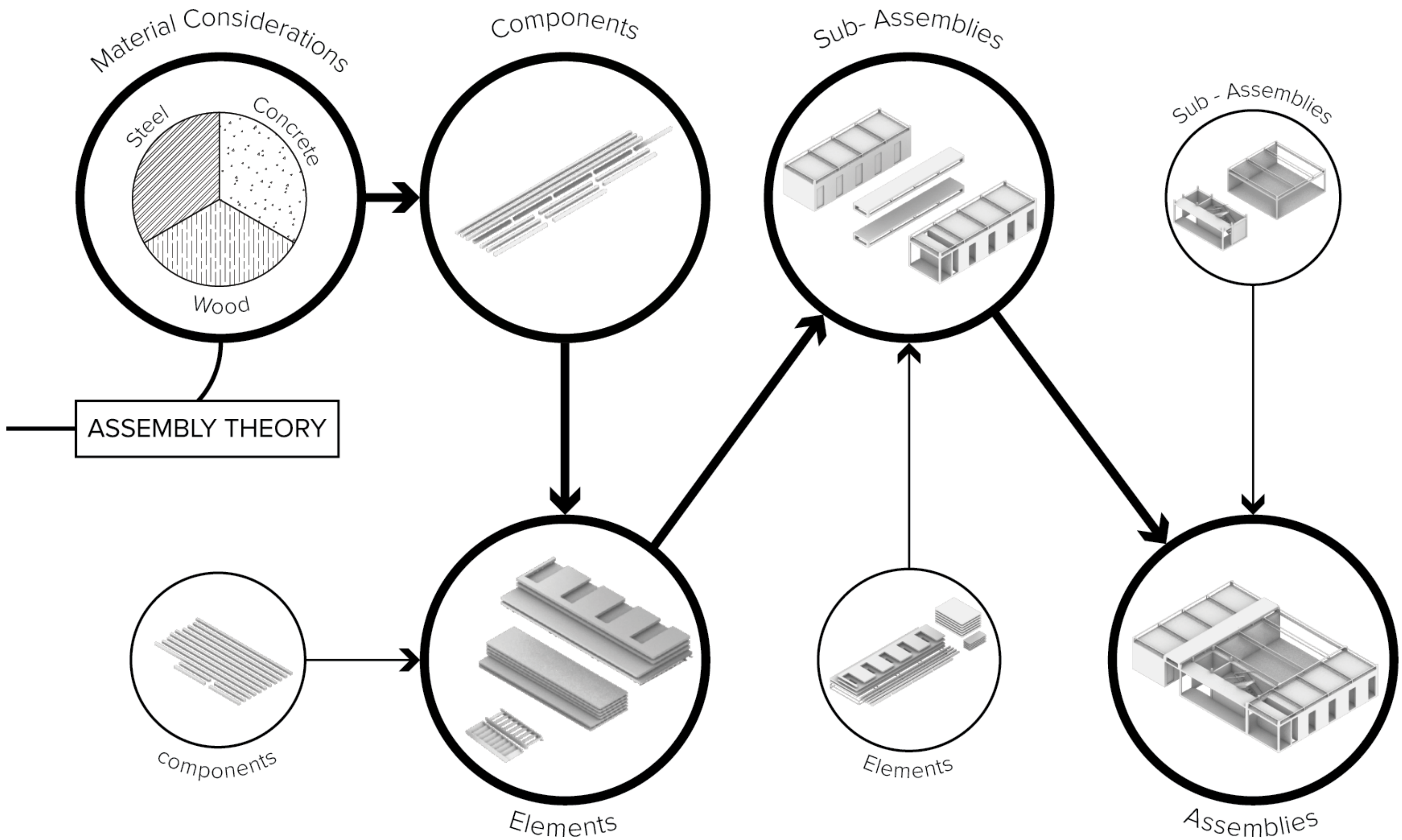


Figure 6: Assembly theory seeks to establish prefabrication in terms of collection and hierarchies. Each level is composed of collections of prefabricated “chunks” from the level below it. While modern manufacturing may result in many points of origin for these various components, elements, and sub-assemblies, their culmination on site produces the final assemblies needed to erect the finished structure.

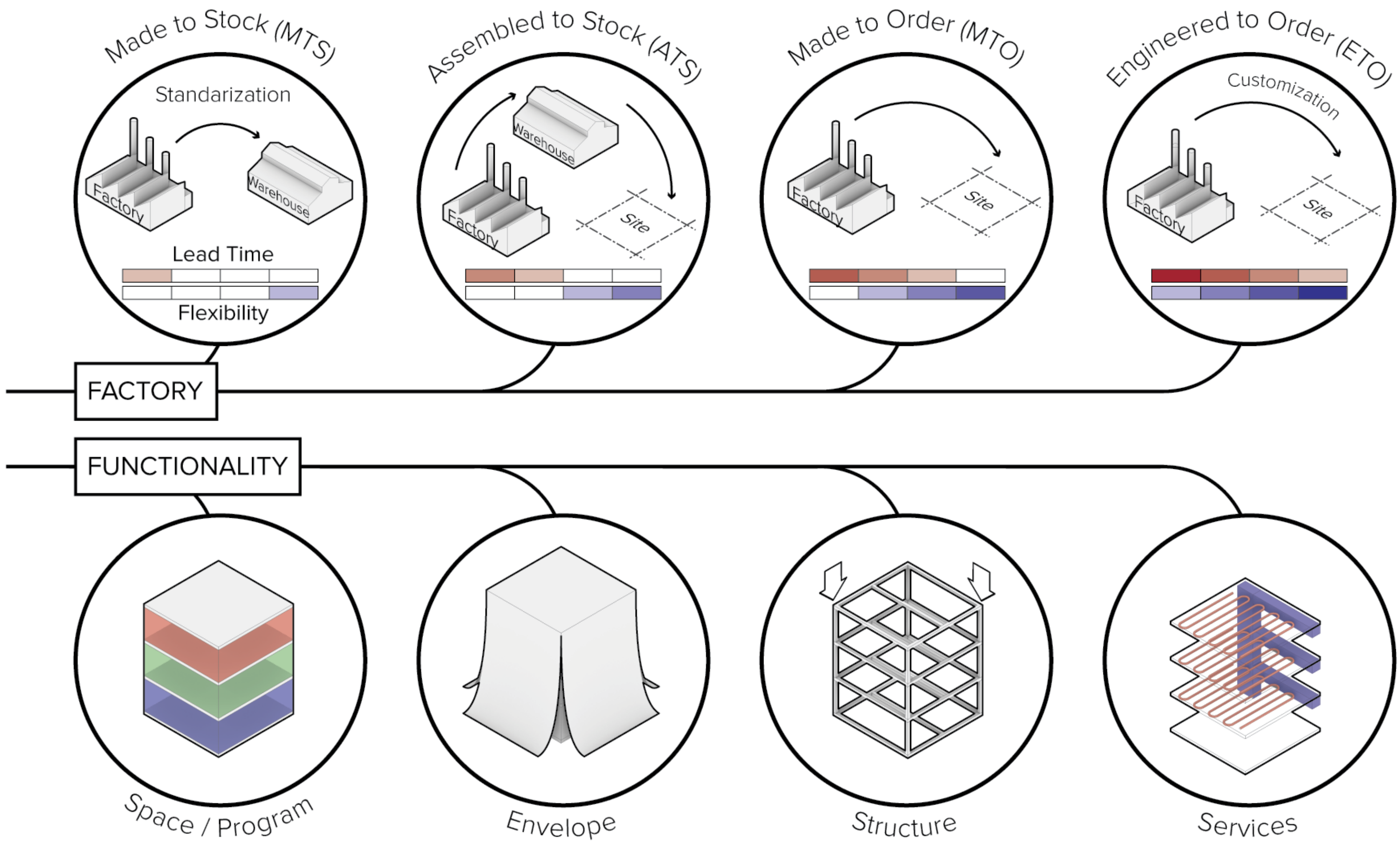


Figure 7: The factory is capable of producing a variety of prefabricated assemblies not only limited to utilizing standardized building components but extending to highly specialized and customized assemblies as well. These prefabricated assemblies often include multiple functions which contribute to the performance of the final structure.

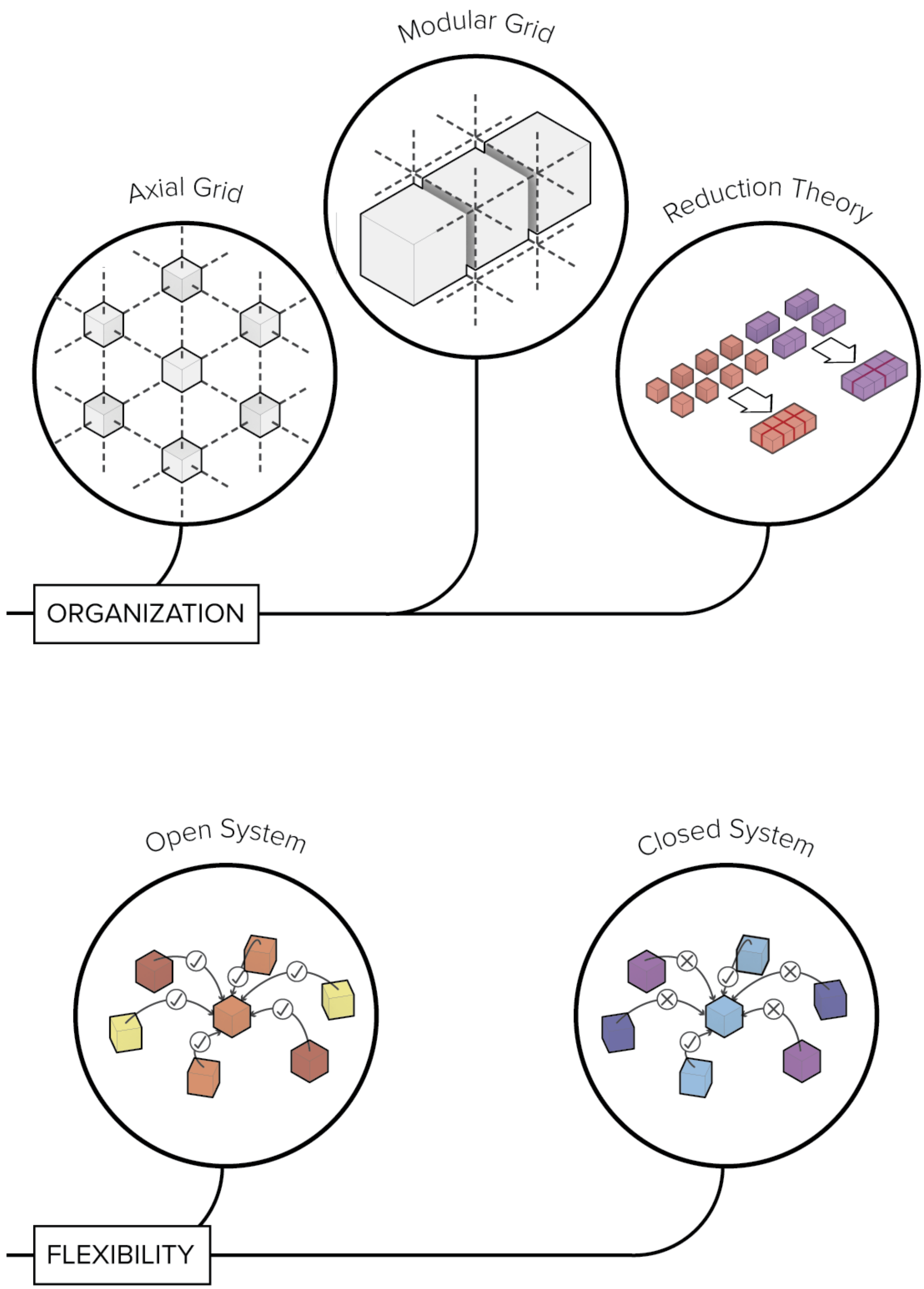


Figure 8: Organization determines the types of connections and joints between prefabricated assemblies, while flexibility illustrates the accessibility of proprietary or non-proprietary prefabricated systems.

# Chapter 5: The Environmental and Logistical Hurdles of McMurdo Station

## 5.1. Environmental Condition in Antarctica

Not only is Antarctica one of the most isolated regions on earth, but it exhibits an extremely harsh climate as well. The mean temperature experienced at McMurdo Station is -18 $^{o}$C, with temperatures reaching as low as -50$^{o}$C during the winter (ASA 1997, 118). These effects of these temperatures can be dramatically worsened by wind chill and blowing snow, with gusts approaching speeds of 185 km/h (ASA 1997, 119). Because of these harsh conditions, McMurdo Station operates on an annual cycle consisting of four major periods: summer operations, annual resupply, winter operations, and summer preparations.

## 5.2. Exploring the Limitations and Opportunities of McMurdo Seasonal Cycles

By examining the annual operational cycle of McMurdo Station, how time and resources are spent during a particular season can be better understood.

### 5.2.1. Summer; Height of Productivity

The summer operational period from approximately mid September to early January is the most active period for McMurdo Station. This is the station's busiest and most crucial time as most of the scientific inquiry and investigation occurs during this time. As a result, this is the peak of the station's population, which can reach as high as 1200 people (Figure 18) (Carroll 2016, 65). This population is made up of a combination of researchers, scientist, workers, and trades

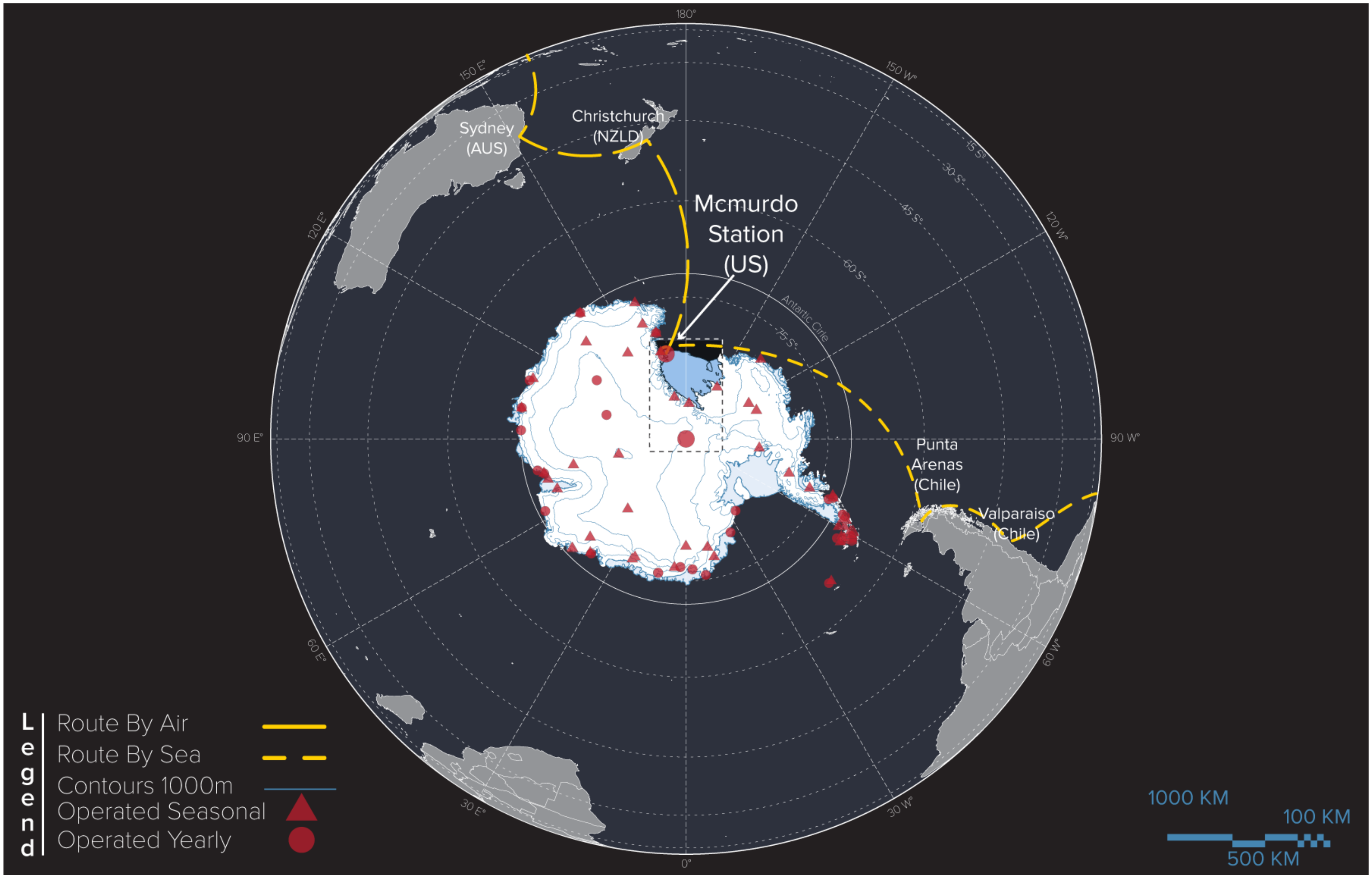

Figure 9: Southern hemisphere map with transportation avenues & research stations. GIS data from Quantarctica datasets (Matsuoka et al. 2018)

persons. It is at this time that the station will also experience 24 hours of complete daylight (Figure 16). This results in a split 24 hour working day, maximizing the working potential per season. As temperatures and weather conditions are milder during the summer operational period (Figure 15), it is the main acceptable period for new construction and building maintenance on site. Everything at McMurdo Station is done in the service of research, and construction cannot disrupt research efforts. As a result, the growth of McMurdo Station is limited, resulting in incremental growth and project delivery accomplished over several seasons.

### 5.2.2. Resupply, Organization, Preparation, and Winterization

Figure 10: Container ship Ocean Giant, moored at the ice pier at McMurdo Station, 2015; photograph by Peter Rejcek (USAP n.d.)

Following the summer operations and prior to the harsh winter is the resupply and winterization period. During this time, icebreakers make McMurdo accessible to container ships and tankers (Figure 17). This resupply is a fundamental necessity not only for McMurdo but all USAP operations in the region (Carroll 2016, 65). This is the only time that large volumes of materials and resources can be shipped to site as only one resupply occurs each year. Any significant quantity of building materials would need to be sent to site at this time. Incoming cargo is limited to the loading gauge of containers, though lengths can exceed the standard 40’.

### 5.2.3. Winter, Standby and Idle

Figure 11: McMurdo Station in complete darkness during the winter operational Season, 2012 ; photograph by Deven Stross (USAP n.d.)

The winter season sees the lowest annual population of the station ranging from 150 – 200 people (Figure 18) (Carroll 2016, 65). This is the least active and therefore least productive season of the annual cycle. From early February till late July, temperatures far below freezing and months of complete darkness envelop the station (Figure 15) (Figure 16). The site is rendered inaccessible to the outside world during this time, with exception only under dire or extreme circumstances (Figure 17). Given that winter is the longest season of the annual cycle, it is possible to leverage this time of year to increase the building potential at McMurdo Station. Due to the extreme weather conditions during this time, normal building practices are almost impossible. Creating a factory environment would enable better preparation for the summer season. Larger assemblies prepared in a nearby factory space would require less time to erect on-site, increasing the building potential of a single season. There is little point in making preassemblies larger than the streets of McMurdo can accommodate. Utility lines would need to be raised and rerouted and other obstructions removed over time, to enlarge the effective loading gauge within McMurdo.

### 5.2.4. Pseudo Spring, De-Winterizing and Summer Preparation

Figure 12: Light Returning to McMurdo Station after the Long Winter, 2014; photograph by Elizabeth Mockbee (USAP n.d.)

In preparation for the summer season, a transitional pseudo spring occurs. This is the time when it is safe again to access McMurdo Station by air and begin the de-winterization procedures (Figure 17). These preparations will enable the station to support the hundreds of inhabitants that will occupy the site over the summer. Any major supplies and equipment needed during this time would have been delivered to site prior to the winter. Therefore, organization and logistical planning are key for McMurdo Station to thrive and operate efficiently year to year. Any prefabricated assemblies that would be delivered to site would arrive the year prior during the annual resupply.

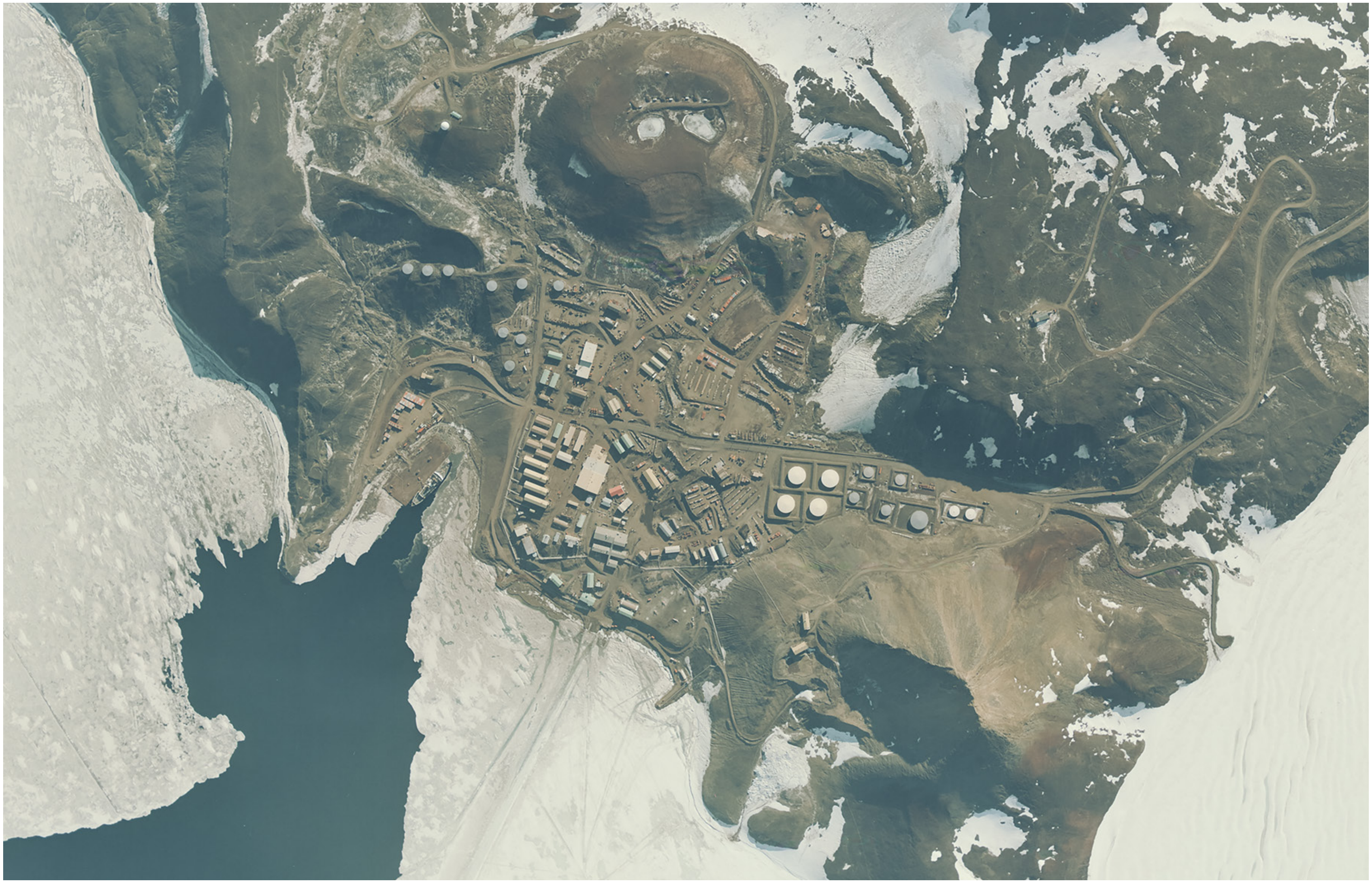

Figure 13: Aerial photo of McMurdo Station, 2000; aerial photo by the U.S. Navy (University of Minnesota 2020).

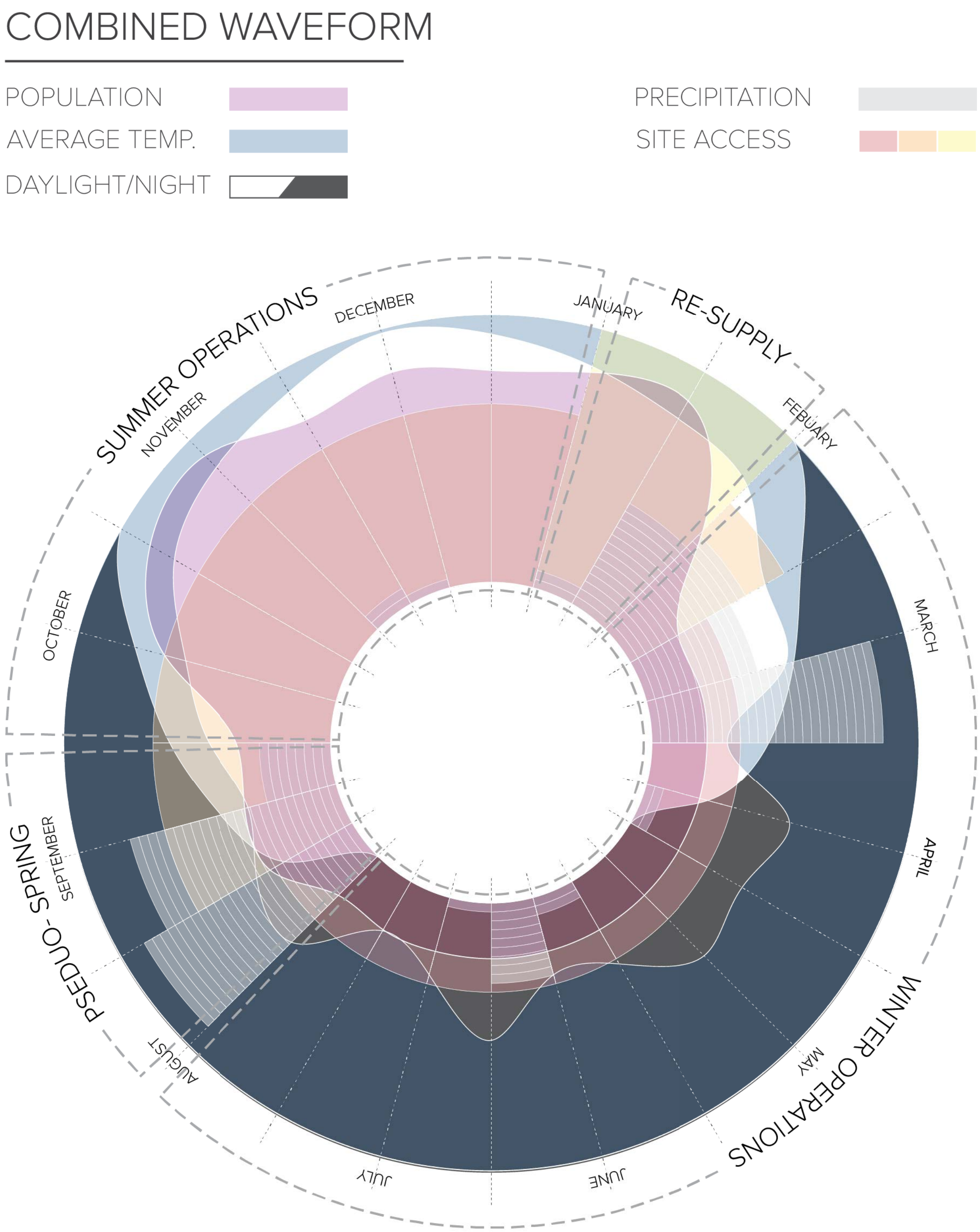


Figure 14: Compiled annual site Information for McMurdo Station including precipitation, hours of daylight, population, average temperature, and site accessibility.

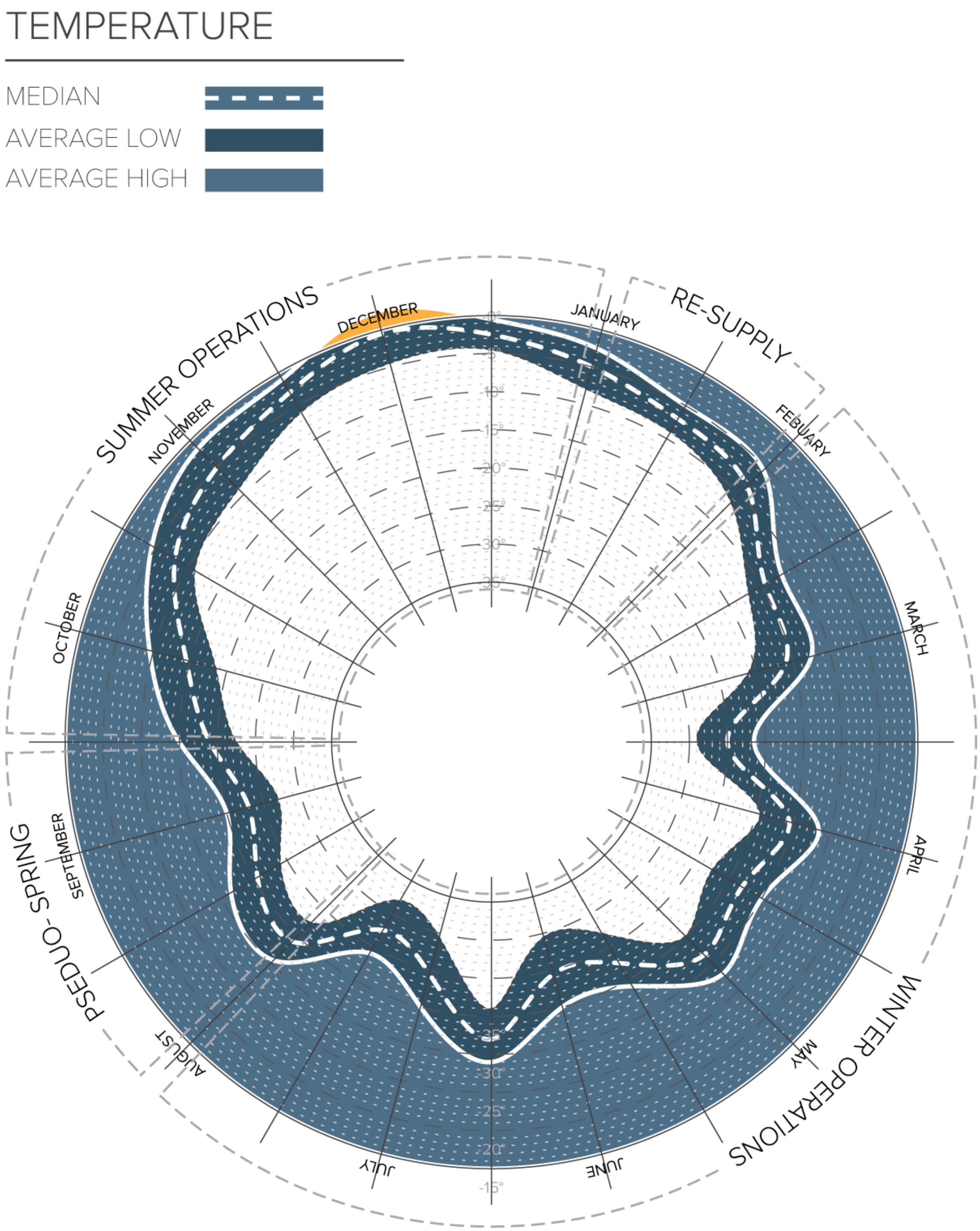


Figure 15: Annual temperature variations at McMurdo Station, 2019; data from Meteoclimat meteorological database (Meteoclimate n.d.)

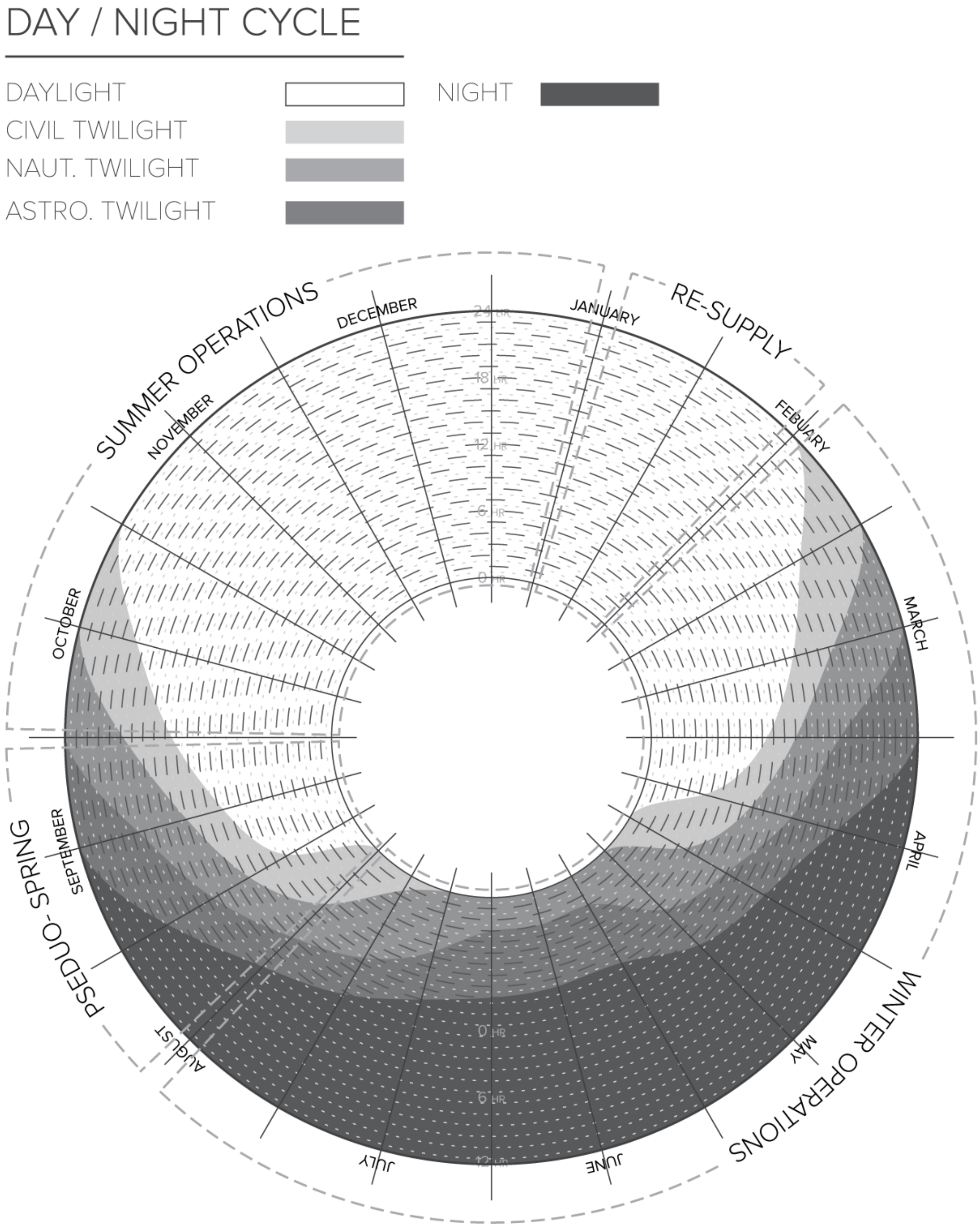


Figure 16: Total hours of day and night experienced at McMurdo Station including their transitional periods, 2019, data from Time and Date AS (Thorsen n.d.)

# SITE ACCESSIBILITY

LIMITED ACCESS
AERIAL ACCESS
OCEAN ACCESS

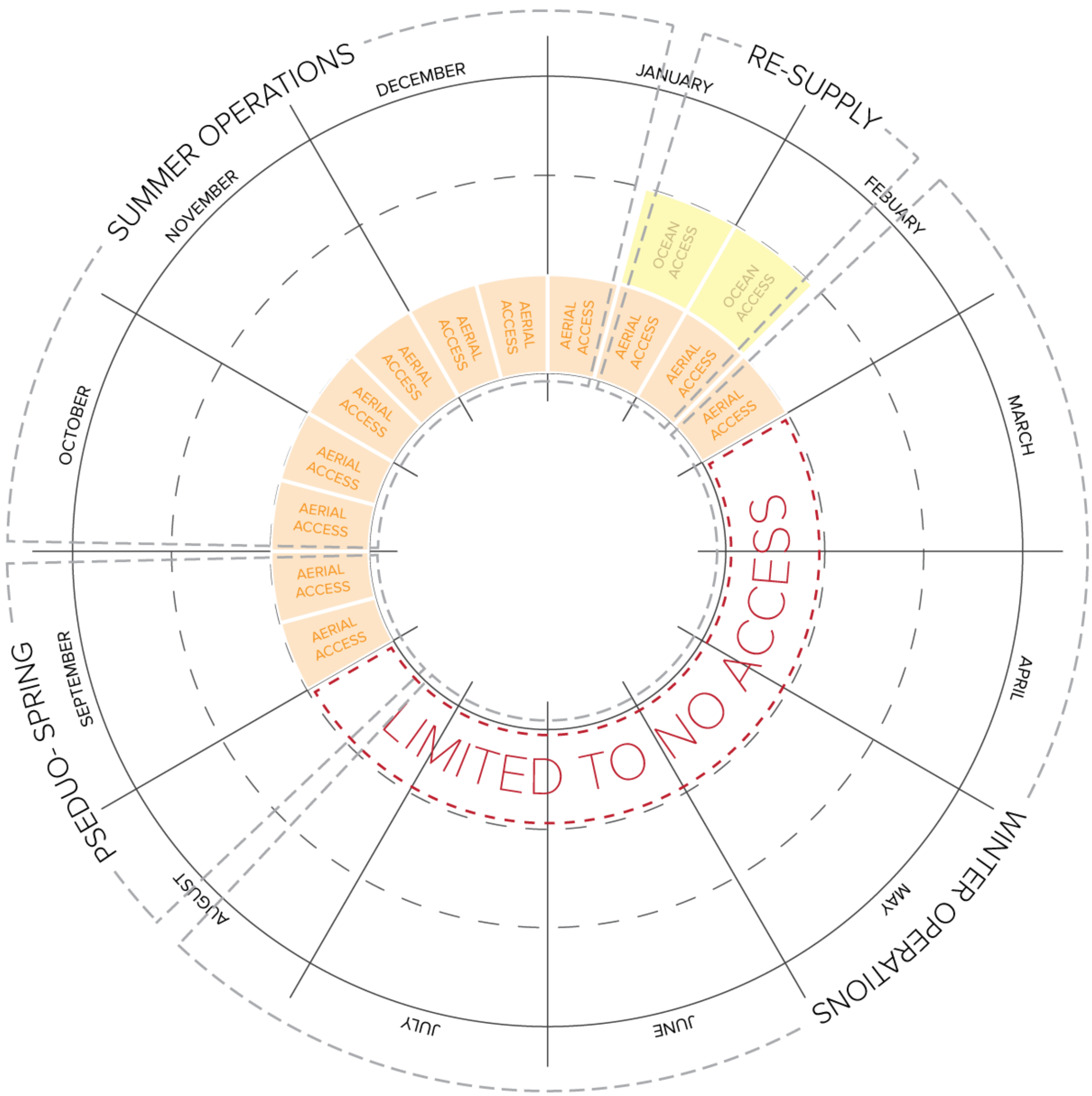


Figure 17: Annual site accessibility to McMurdo Station 2016, information retrieved from United States Antarctic Program: Participant Guide (Carroll 2016)

# POPULATION


Figure 18: Annual population fluctuation at McMurdo Station 1997, data retrieved from The United States in Antarctica: Report of the U.S. Antarctic Program External Panel (NSF 1997)

# PRECIPITATION

AVERAGE PRECIPITATION

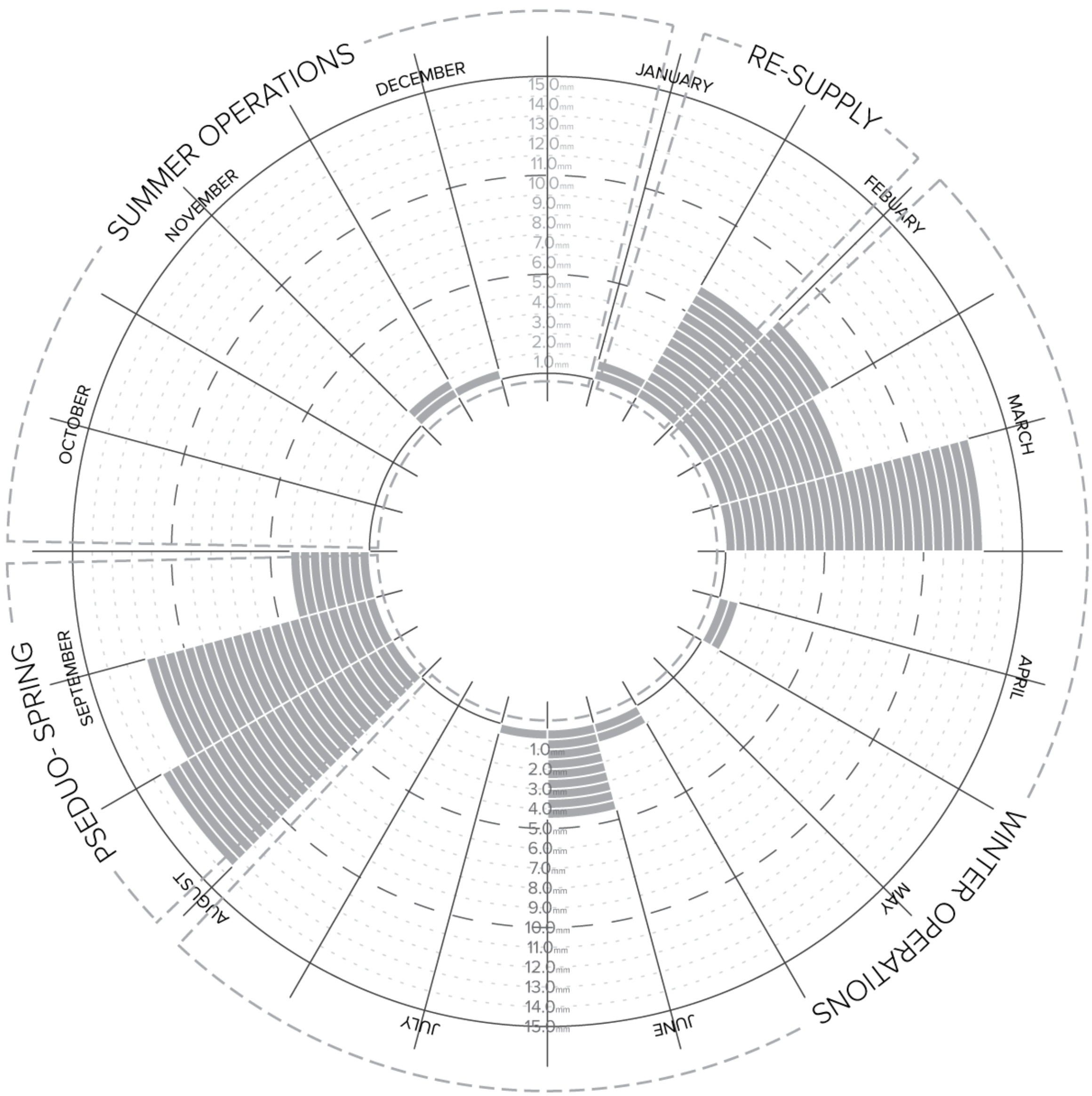


Figure 19: Annual precipitation accumulation at McMurdo Station, 2019; data from Meteoclimat meteorological database (Meteoclimate n.d.)

# Chapter 6: Expanding Building Potential Through Leveraging On-site Condition

## 6.1. McMurdo Station, the Logistical Gateway to Antarctica

McMurdo Station is uniquely situated in Antarctica, acting as the major logistical gateway for all the United States Antarctic Programs (USAP) activities in the region. The site is accessible by air and sea, but the station has limited access depending on the time of year. Throughout the pseudo spring, summer, and resupply seasons the station is accessible by specially-designed aircraft that land on the adjacent ice shelf (Figure 22). At the end of the summer season the site is made accessible by sea (Figure 17). Large container vessels and fuel vessels deliver the necessary supplies to operate and maintain not only McMurdo but other research station throughout the region (Figure 20). Without a logistical beachhead like McMurdo Station, other stations, most notably the year-round Amunsden-Scott South Pole Station, would not be able to exist.

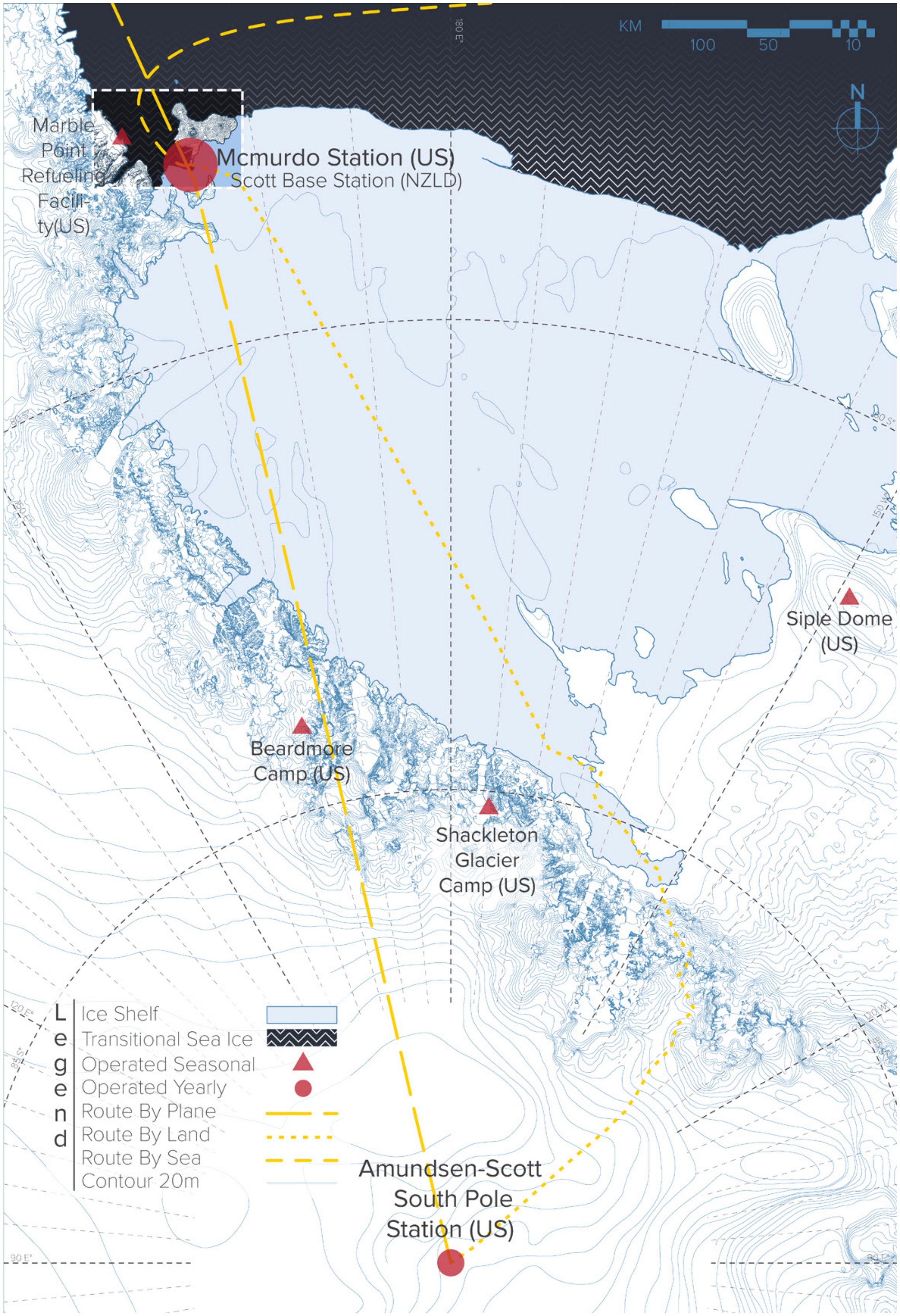


Figure 20: McMurdo Station is the logistical nexus for the USAP operations in Antarctica, GIS data from quantarctica geographical datasets (Matsuoka et al. 2018)

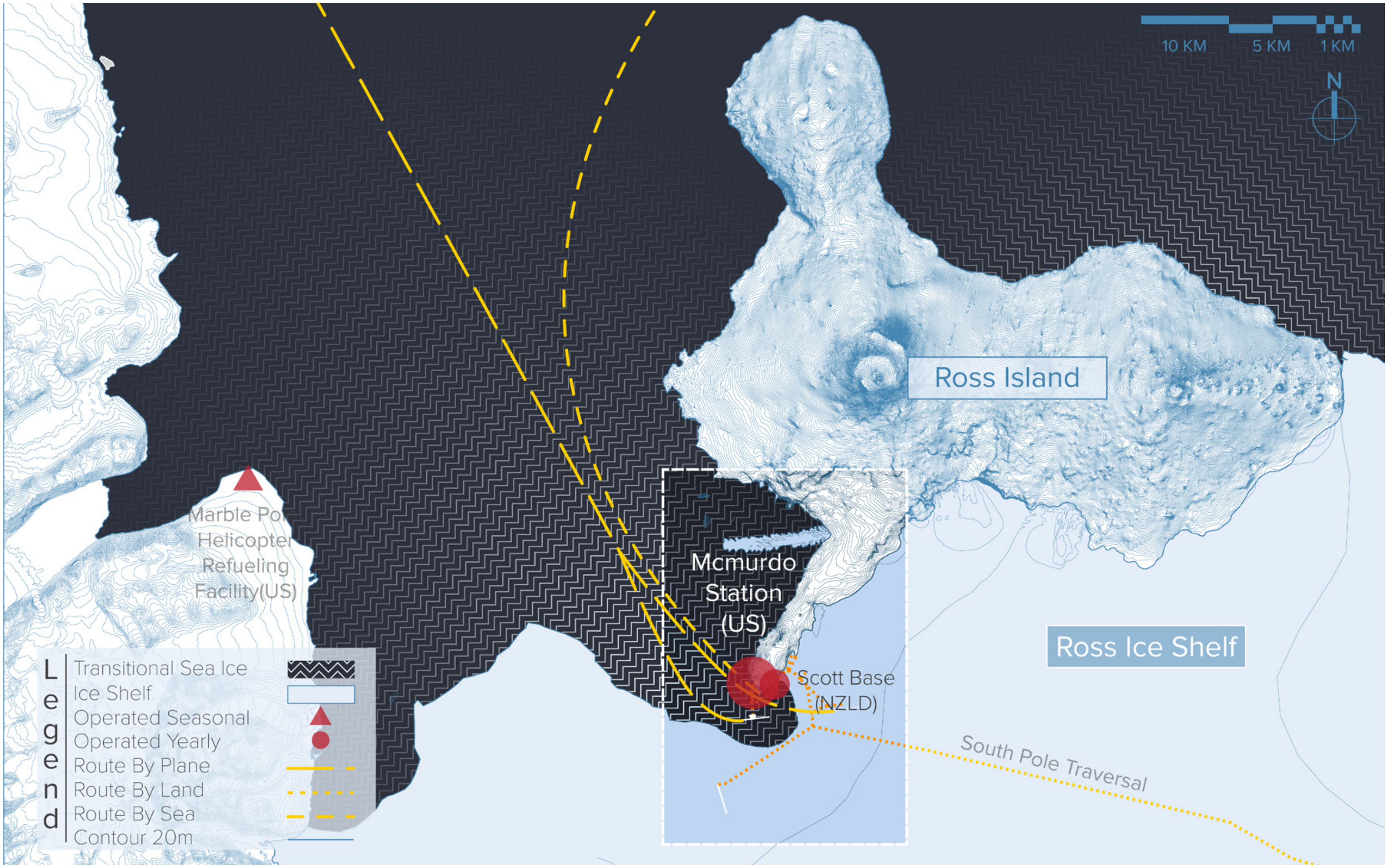


Figure 21: McMurdo Station position on Ross Island and adjacent ice shelf, GIS data from quantarctica geographical datasets (Matsuoka et al. 2018)

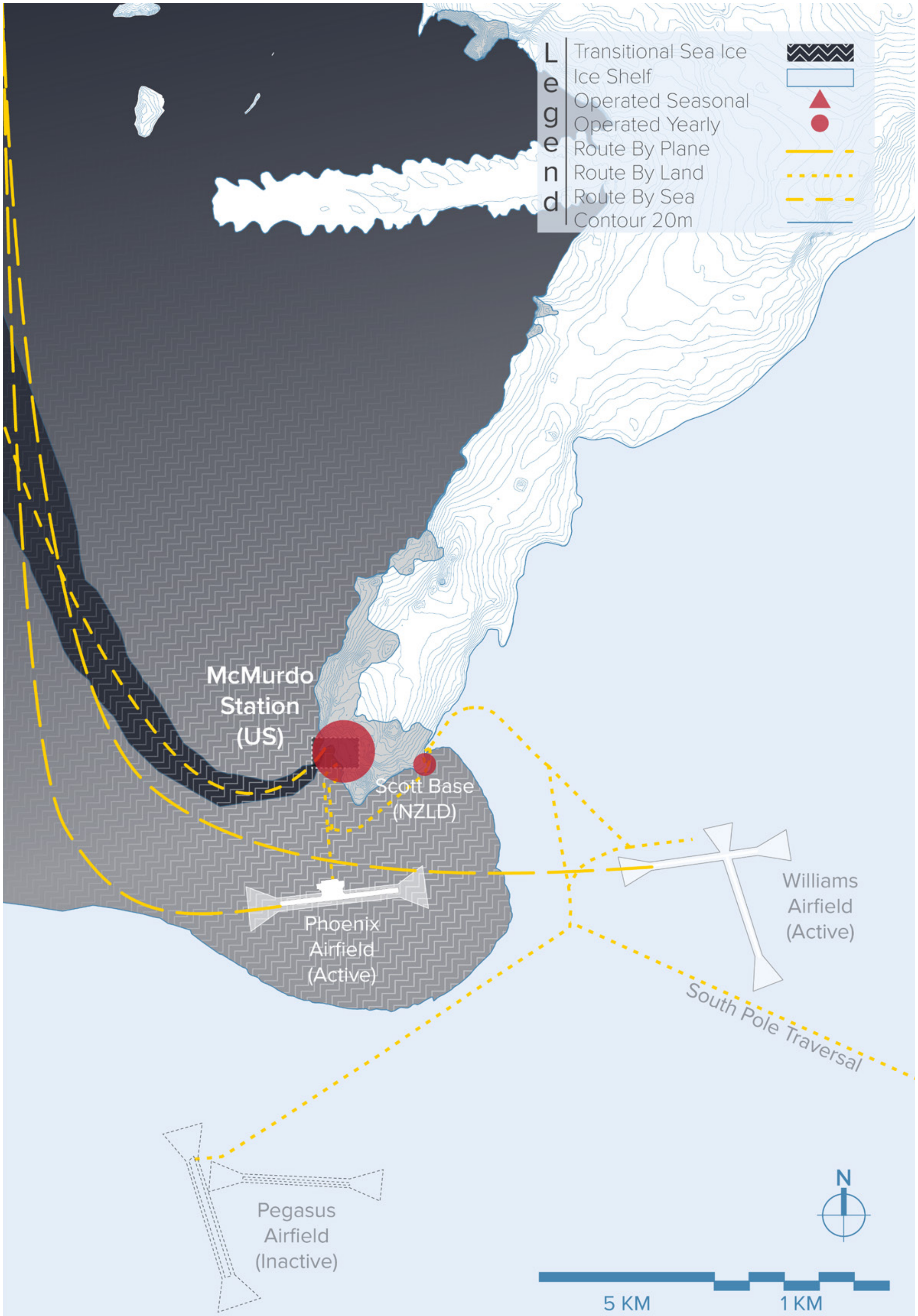


Figure 22: Airfields just outside McMurdo Station, GIS data from quantarctica geographical datasets (Matsuoka et al. 2018)

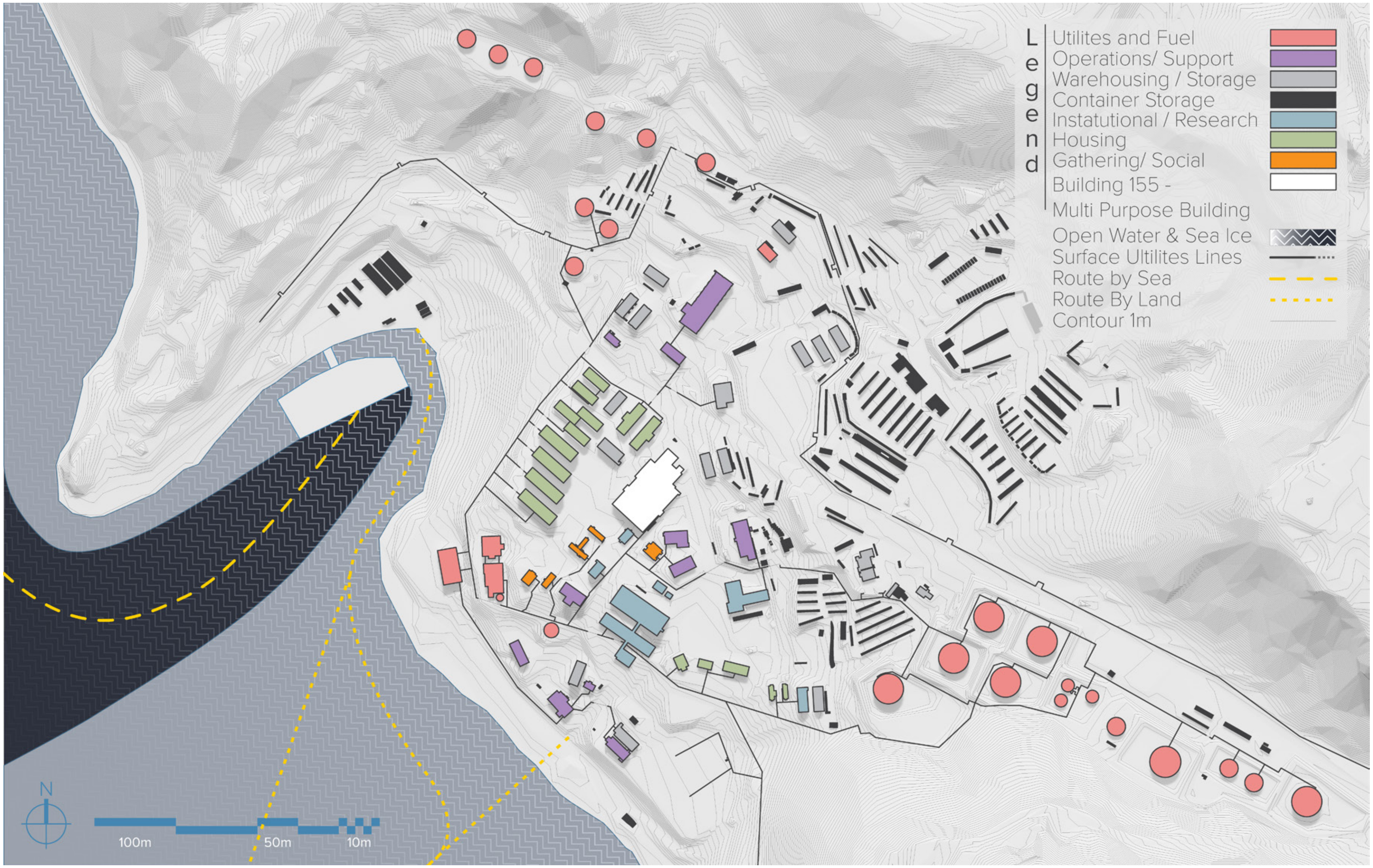

Figure 23: McMurdo Station site plan with breakdown of major programmatic spaces, map data from Lidar imaging of the McMurdo Valley, Antarctica (Fountain et al. 2017).

## 6.2. Providing Site Rejuvenation Through On-site Factory and Building Sub-Assemblies

For McMurdo Station to function efficiently throughout its peak operations period during the summer season, any construction that occurs on-site cannot disrupt the ongoing activities of the station (Davis 2017, 180). This limits the scope of building during each annual cycle.

Summer can't be lengthened, so the building season has to be moved or extended into other parts of the year. The benefit of prefabricated assemblies is the reduced erection time on site. However the time saved is offset by the extra time needed to plan the project and prepare the pre-assemblies. A factory on location would enable larger assemblies than can be shipped along container routes, and this would be done during the less productive winter season. By creating assemblies beyond the scope of the international loading gauge, larger and more varied assemblies could be produced bringing programs and spaces that were previously unavailable to the site.

Transforming the production of buildings at McMurdo would be a two-stage process. First the construction of an on-site factory would use a combination of conventional prefabricated methods and assemblies that conform to the loading gauge of container transport (Figure 24). Second, the capacities of the factory would enable larger and more varied modules than could be shipped to McMurdo (Figure 25). The size and variety of these components would allow better use of the summer and would create a richer inhabited environment.

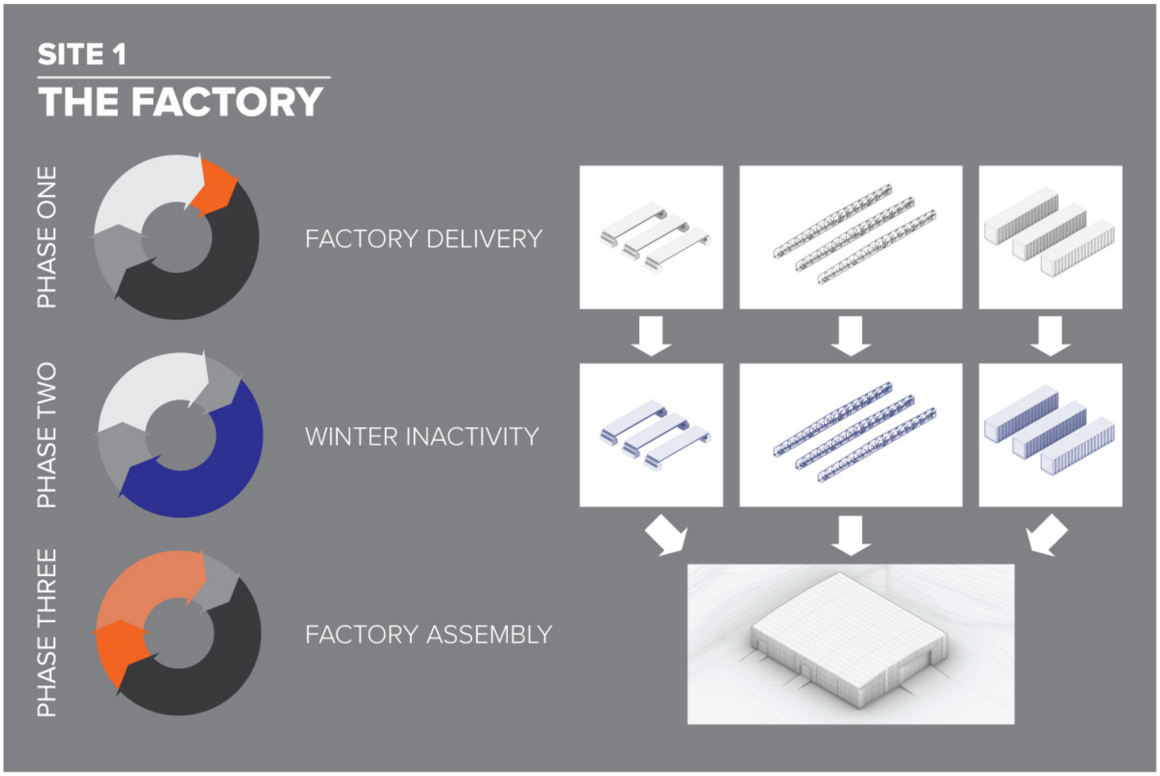


Figure 24: Due to the harsh conditions of the winter season, the prefabricated assemblies that arrived during the resupply cannot be utilized until the following summer season.

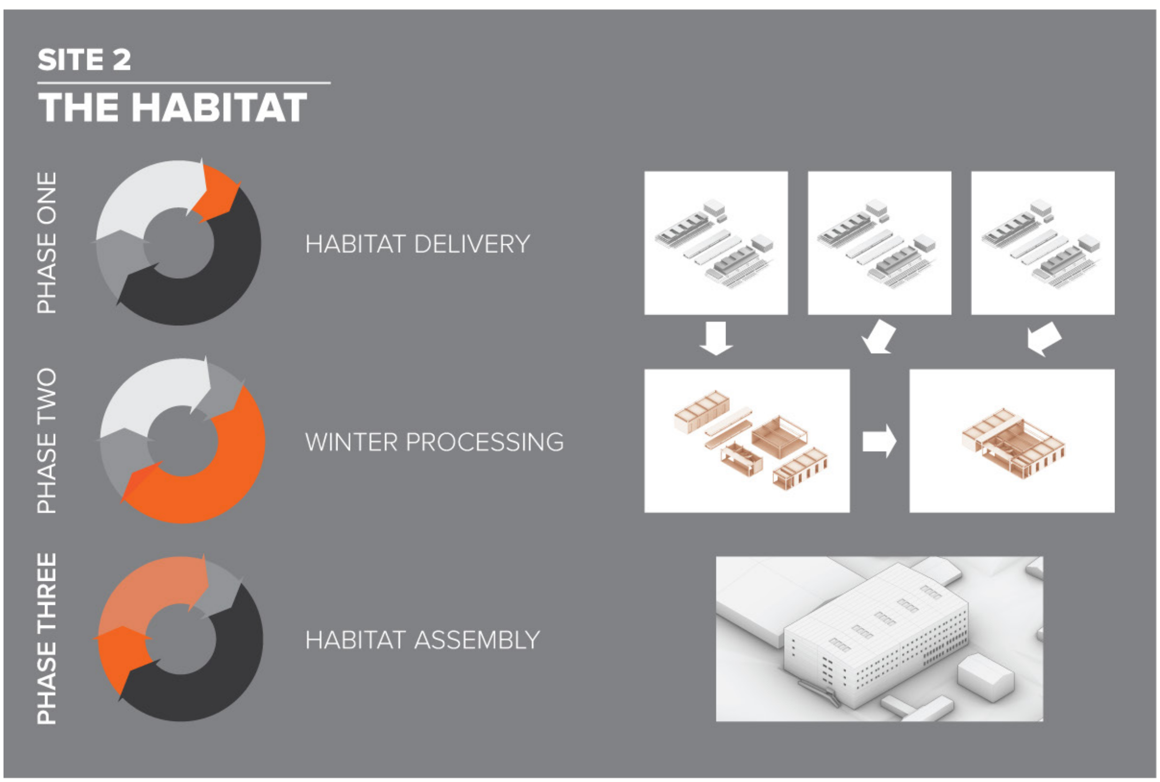


Figure 25: The time reclaimed during winter season enables far greater production of prefabricated assemblies outside the established loading gauge, which in turn increases the building capacity of the summer season.

## 6.3. Site Selection and Building Schedule

When selecting suitable sites in McMurdo Station for these interventions certain criteria must be taken into consideration. While McMurdo has expanded over the years, there are fears that further expansion beyond the current boundaries of the station could be irreversible, contaminating the surrounding area (Davis 2017, 179). Fears of contamination limit intervention sites to the existing extent of the station.

The factory will be located close to the harbor at the station. A convenient location will make the factory readily accessible to materials that would be off-loaded and staged on-site (Figure 26). Since this area is already used for cargo storage and staging, little site preparation will be required.

The test habitat would be located in a more centralized location in McMurdo Station (Figure 37). Being centrally located will enable greater access to established services and utilities on site. This location will also test the loading gauge of the existing settlement. There is no point building a factory whose output is larger than what can be moved around the station. Most utilities such as water and power are distributed to the buildings on-site through a series of above ground service conduits. Given the test site will incorporate several programs within a single enclosure, easy access to heavy servicing will be crucial. The test habitat will be located near the centre of the station, adjacent to the building 155. The few buildings on this site are either secondary or auxiliary, and their functions can be met, if need be, by the new building.

## 6.4. The Factory: Maximizing Existing Processes

The factory will be built of components that meet the loading gauge of containers, though some of them may be of longer than standard length. Shipping containers will compose the perimeter of the factory and separate the primary functional areas. These containers will be modified to incorporate insulation, structural reinforcement, and other features as demanded by their position in the finished building. Due to the annual cycle at the station, these containers would arrive on site almost a full year prior to assembly. There would be insufficient time to assemble the factory prior to winter season. However, these modified containers can also be used for the transportation and storage of other goods and materials in the meantime.

### 6.4.1. Factory Assembly

The door of the factory will have to be high and wide enough to allow passage of the largest anticipated module. The effective height and width of the bay will have to accommodate the equipment and workers building the module. The length of the factory will need to accommodate however many modules need to be sheltered before taking them to site in the outdoor building season. Remote ports like McMurdo Station are supplied by container vessels like the Ocean Giant, with their own on-board cranes. These cranes allows the Ocean Giant to load and unload cargo longer than standard containers, although, because it typically arrives at the port of origin by road or rail, needs to fit the usual 8’ by 9’-6” loading gauge. The paired and serviced trusses shown are designed to exploit this dimensional envelope as fully as possible (Figure 27). McMurdo Station

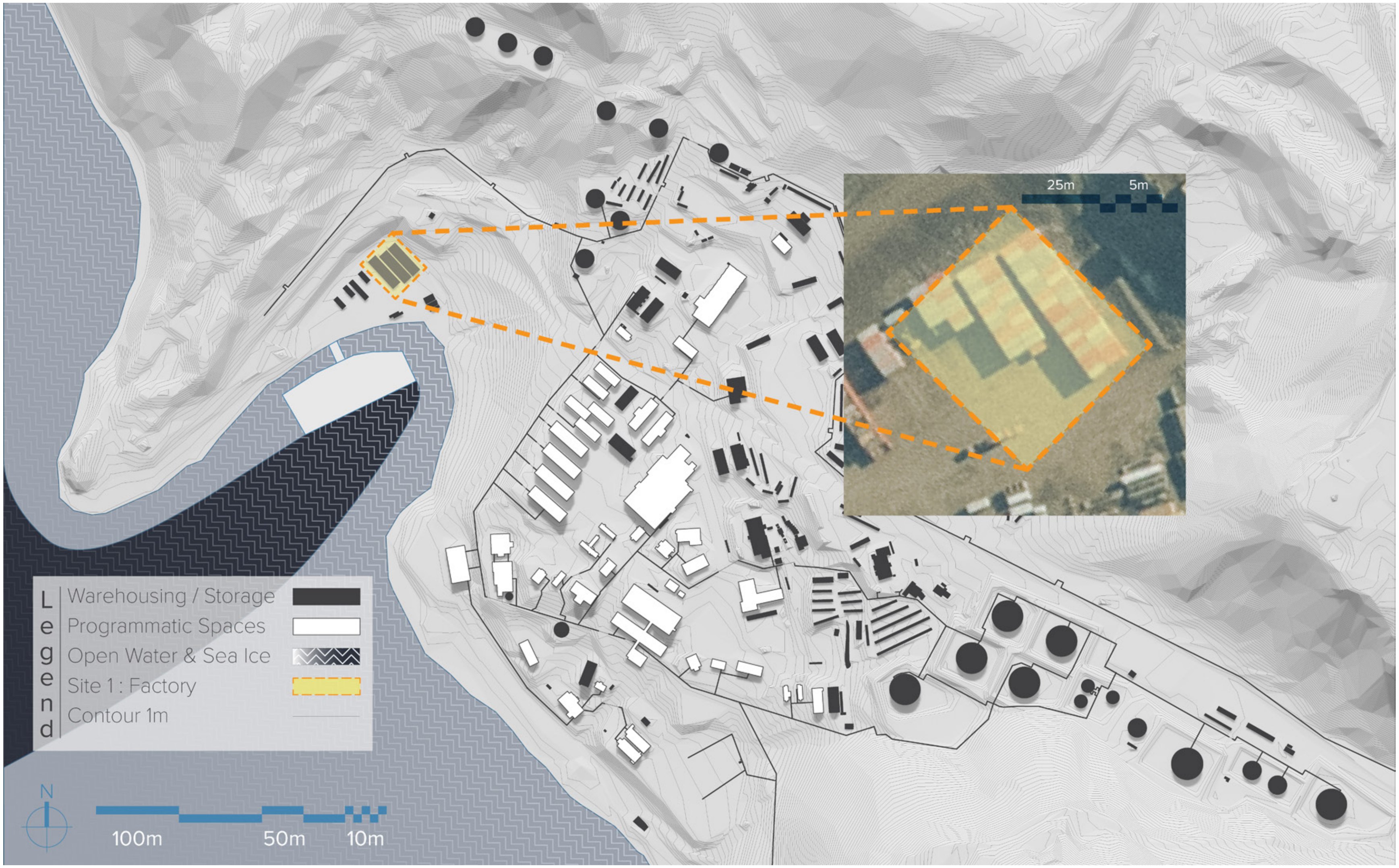


Figure 26: McMurdo Station site plan indicating the proposed site of the on-site factory, map data from lidar imaging of the McMurdo Valley, Antarctica (Fountain et al. 2017).

has the necessary equipment on-site to maneuver such components into place once offloaded. Shipping these structural trusses whole will both reduce the erection time of the factory and incorporate additional functionality and utility routing prior to transportation to site. The remainder of the roof will be assembled with a series of structurally insulated panels. It is important that the roof be sloped to prevent the accumulation of blowing snow, which has been known to overwhelm structures erected in Antarctica very quickly. The factory will rest on a foundation made from precast concrete footings and insulated panels. The use of precast concrete pads, columns, and footings can be seen in use in many of the other buildings at McMurdo Station. The size and scope of the floor panels will be limited to the maximum

Figure 27: Unloading large prefabricated trusses for factory assembly area. Original photograph by J.F.Alexander (Burford 2013)

panel size capable of surviving the journey aboard ships similar to the Ocean Giant.

The factory will be assembled progressively (Figure 28). Subsequent sections of the building will be erected after the completion of the prior section. The sequential assembly process aims to accelerate the speed of the assembly in a way that maintains the safety for on-site workers. While some final detailing may be required after the initial building erection, each assembly already contains the necessary components to perform its various required functions.

### 6.4.2. Factory Functionality and Program

The factory will consist of three main spaces; a large assembly area, a warehouse-type storage area, and a fabrication workshop (Figure 30). The primary space, the assembly area, is where the larger test assemblies will be fabricated from the smaller container constricted sub-assemblies shipped to site. The moving of sub-assemblies and assemblies within the space will be assisted by overhead crane (Figure 32). The warehouse style storage area will contain any auxiliary construction materials needed to facilitate the fabrication of the assemblies. Finally, the fabrication workshop will contain a variety of tools and equipment. This space will also supplement other shops at McMurdo. By having these spaces all under a common roof, the workers can limit their exposure to the harsh external environment. This sheltered environment enables pre-assembly to take place throughout the year. By leveraging the downtime during the limited winter operational season, larger and more varied assemblies are produced then are currently possible at McMurdo Station. Finally, while the factory may function primarily as an assembly space, it could also support recycling.  Decommissioned buildings and structures at McMurdo Station could be processed, salvaging construction materials for future reuse.  Recycling obsolete buildings would reduce the amount both of materials that would be sent off site as waste and of materials that would be shipped in for future projects.

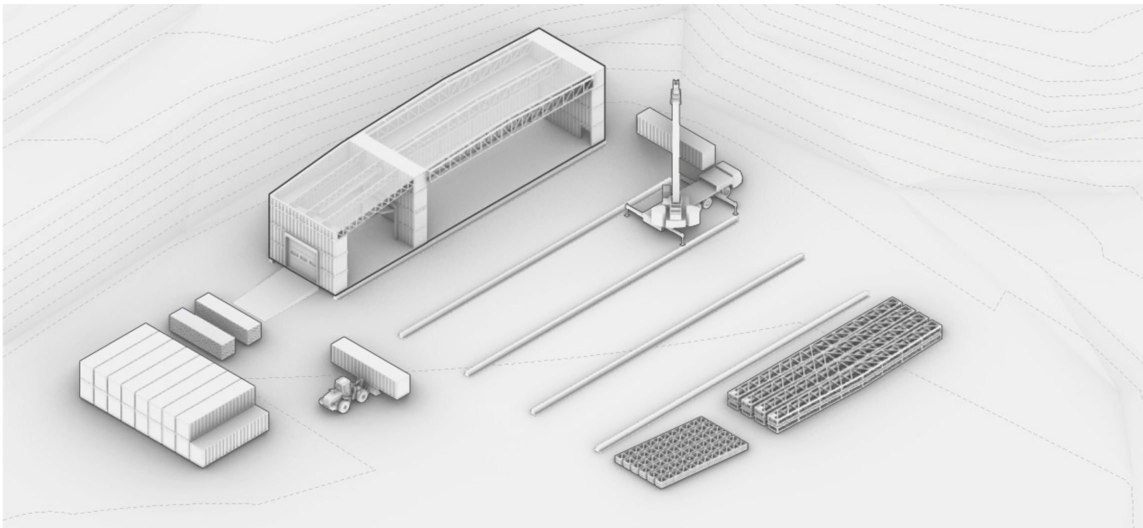

Figure 28: The Factory will be assembled in a series of sections on prefab concrete foundations.

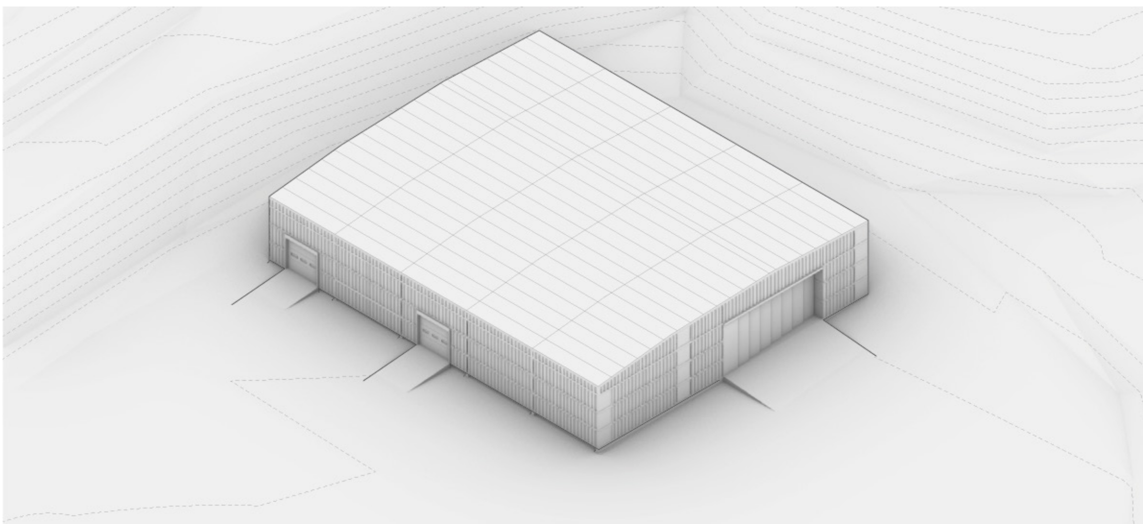

Figure 29: The factory is made of a variety of prefabricated elements and assemblies.

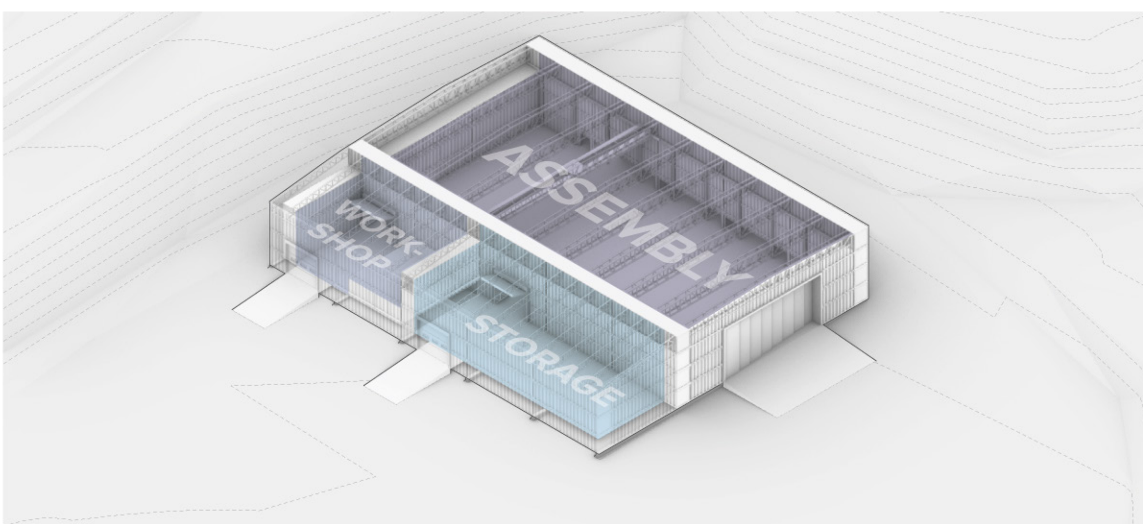


Figure 30: The factory will consist of a large assembly area, workshop, and material storage.

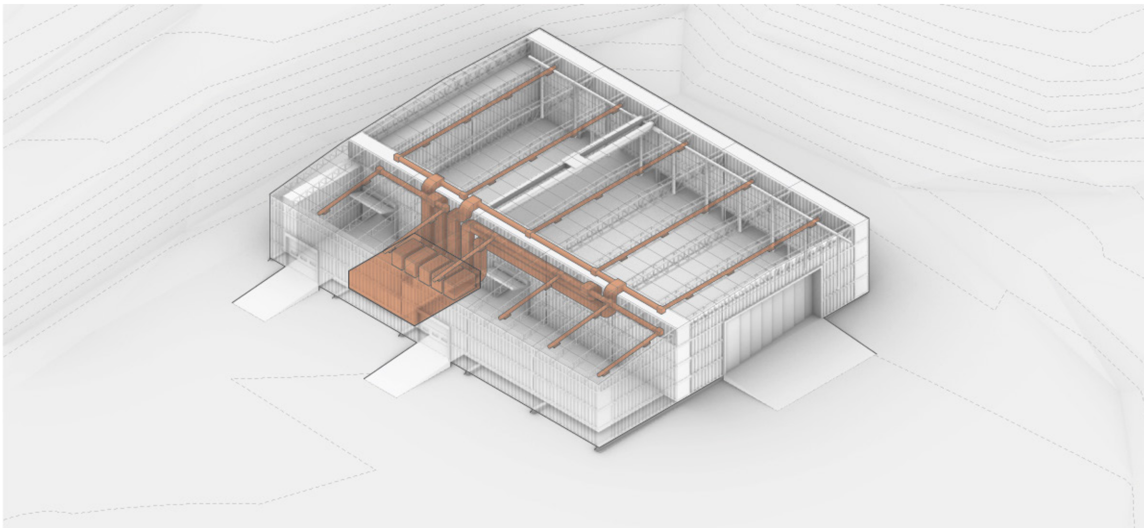

Figure 31: The mechanical system within the factory will be connected to pre-installed services contained within the prefabricated trusses delivered to site.

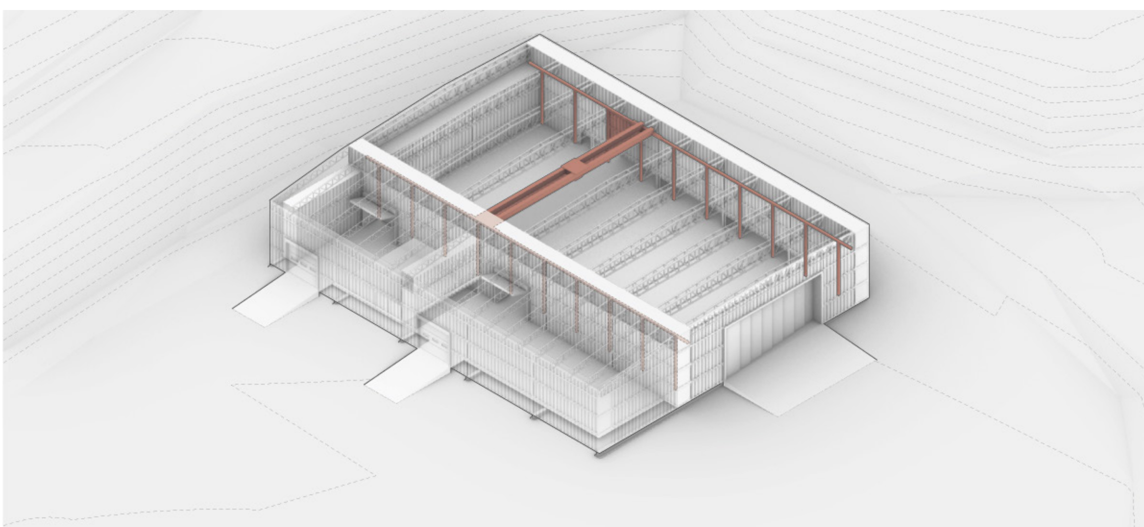

Figure 32: Work during the winter season will be assisted by a large gantry crane located within the main assembly area.

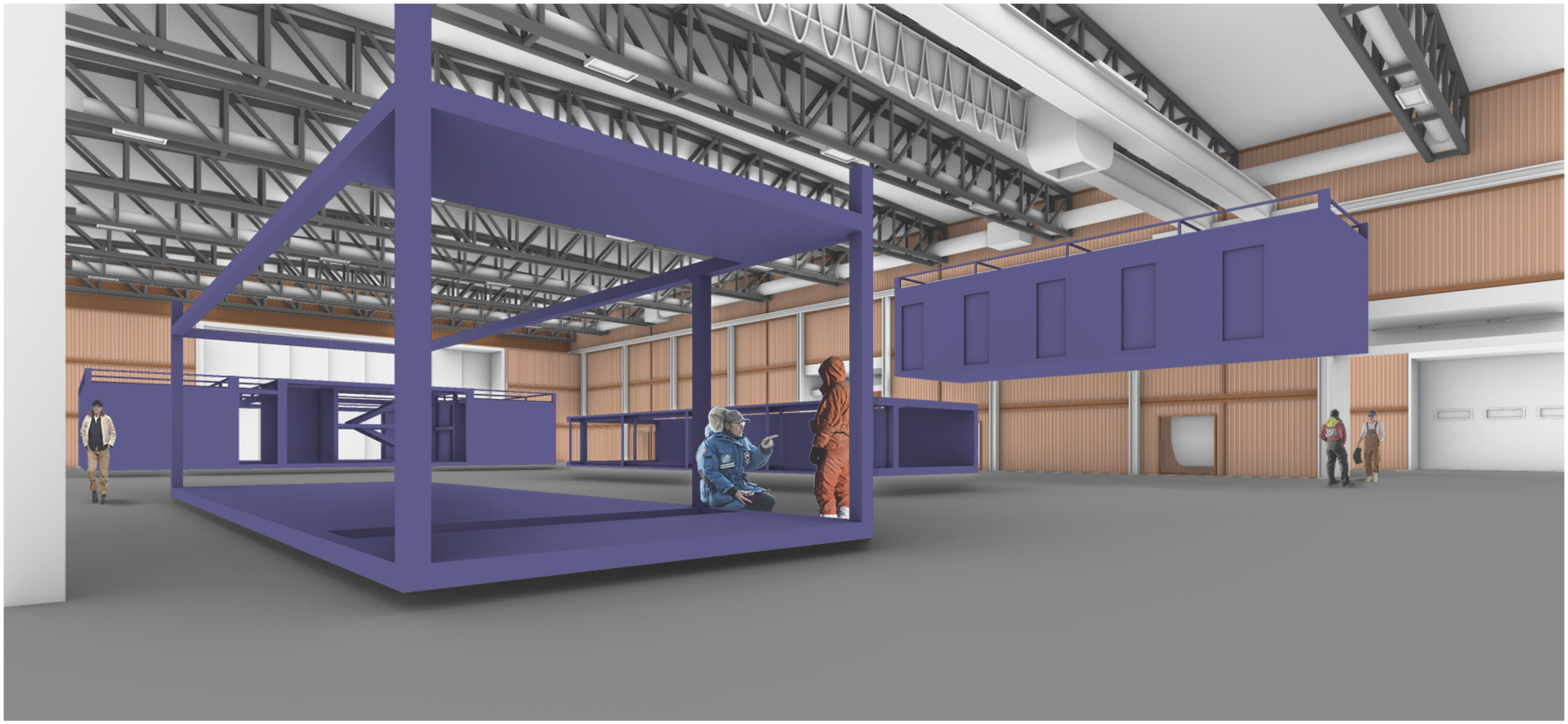

Figure 33: Both the large interior volume and large bay doors enable the fabrication of large prefabricated assemblies which now dramatically exceed the current loading gauge available to McMurdo Station.

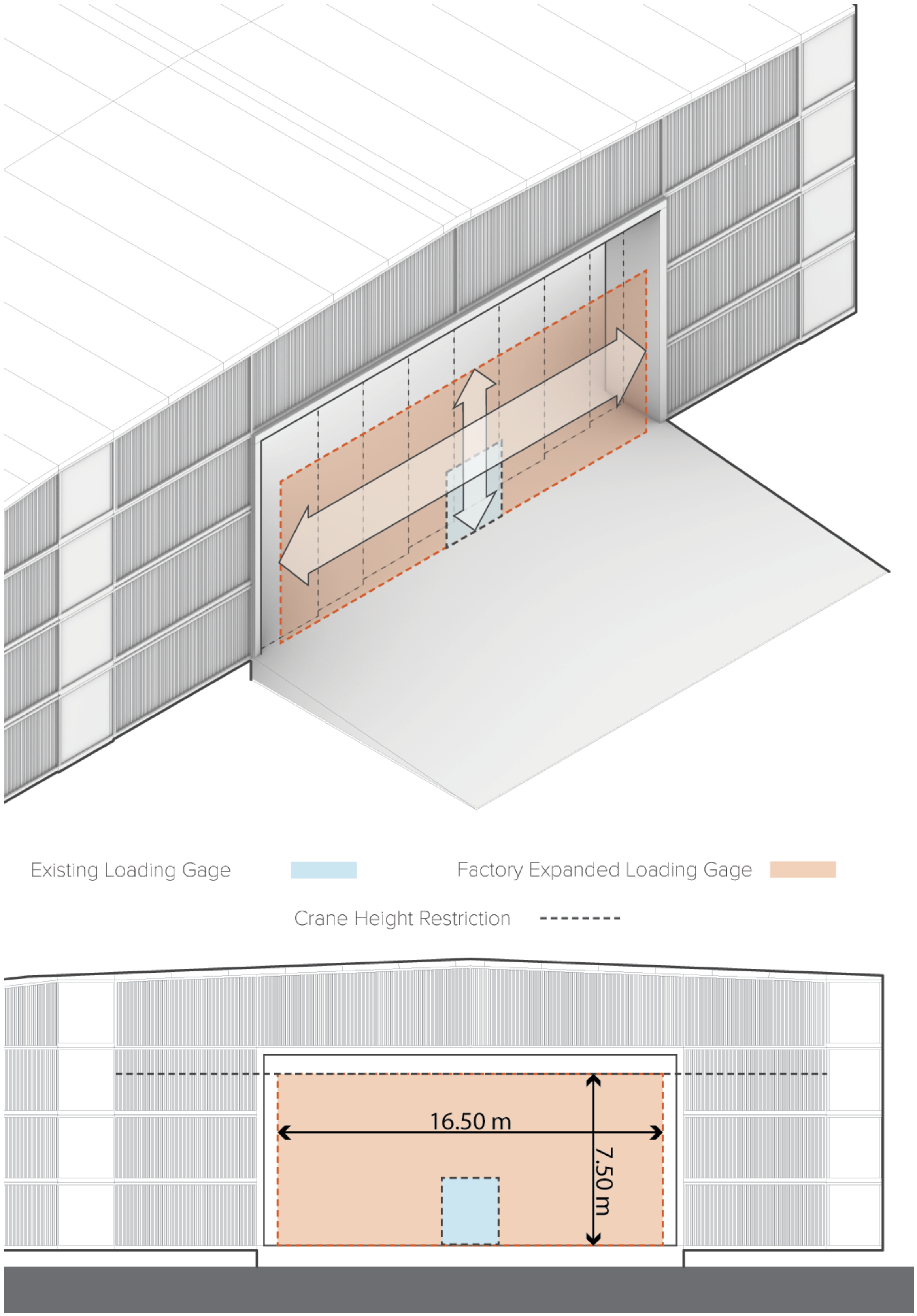


Figure 34: The dramatic increase in cross-sectional area that the factory provides compared to the established loading gauge of a shipping container.

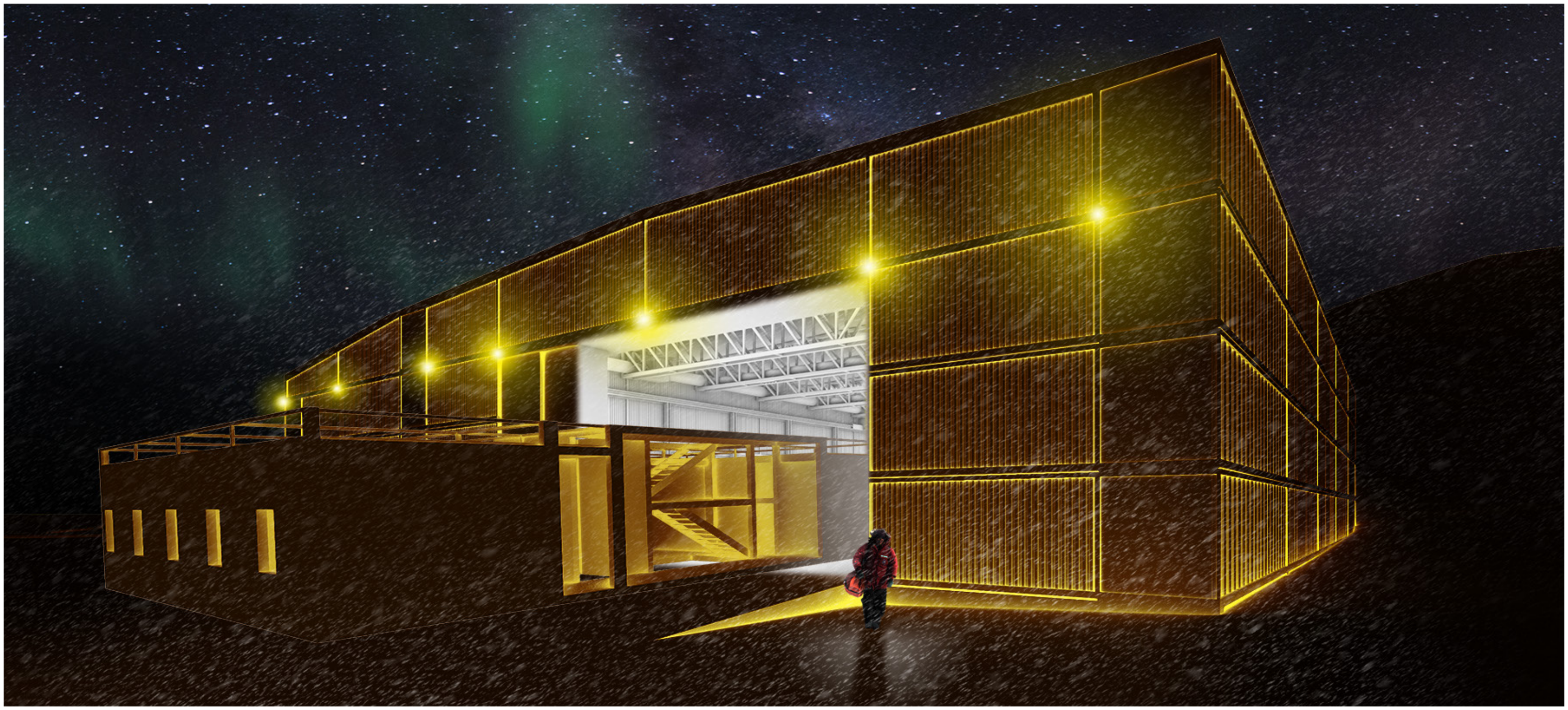

Figure 35: A completed assembly leaves the factory to be stored nearby.  This assembly will be used to create part of the test habitat erected in the summer.

## 6.5. The Habitat: Exploiting the Factory

The factory's capacity to produce prefabricated assemblies beyond the limitation of the international loading gauge will enable the erection of complete structures more rapidly than before. This negates the compromises and inefficiency of shipping low specific-value assemblies to McMurdo Station. By producing these larger assemblies, the total number of assemblies can be reduced.

The habitat will be the first test-product of the factory, signifying a new capacity of building for the region. It will include both a variety of programs and prefabricated elements to demonstrate the possibilities the factory can produce. This is advantageous for McMurdo Station as the site requires a variety of spaces to operate and to maintain


Figure 36: Moving the assemblies from the factory to the site of the habitat. Rerouting of existing utilities will be required to fully maximize the factory potential. Original photograph by Jeffery Donenfeld (USAP n.d.)

the well being of its inhabitants. In the coming years much of the aging infrastructure and buildings at the station may fall into obsolescence and require either major renovation or replacement. The habitat will act as a test platform combining several programs under a single roof, unlike the more distributed site plan that McMurdo Station currently has. This habitat could also be the first stage in a large-scale station-wide rejuvenation, alleviating pressure on buildings in need of demolition, construction, or maintenance work.

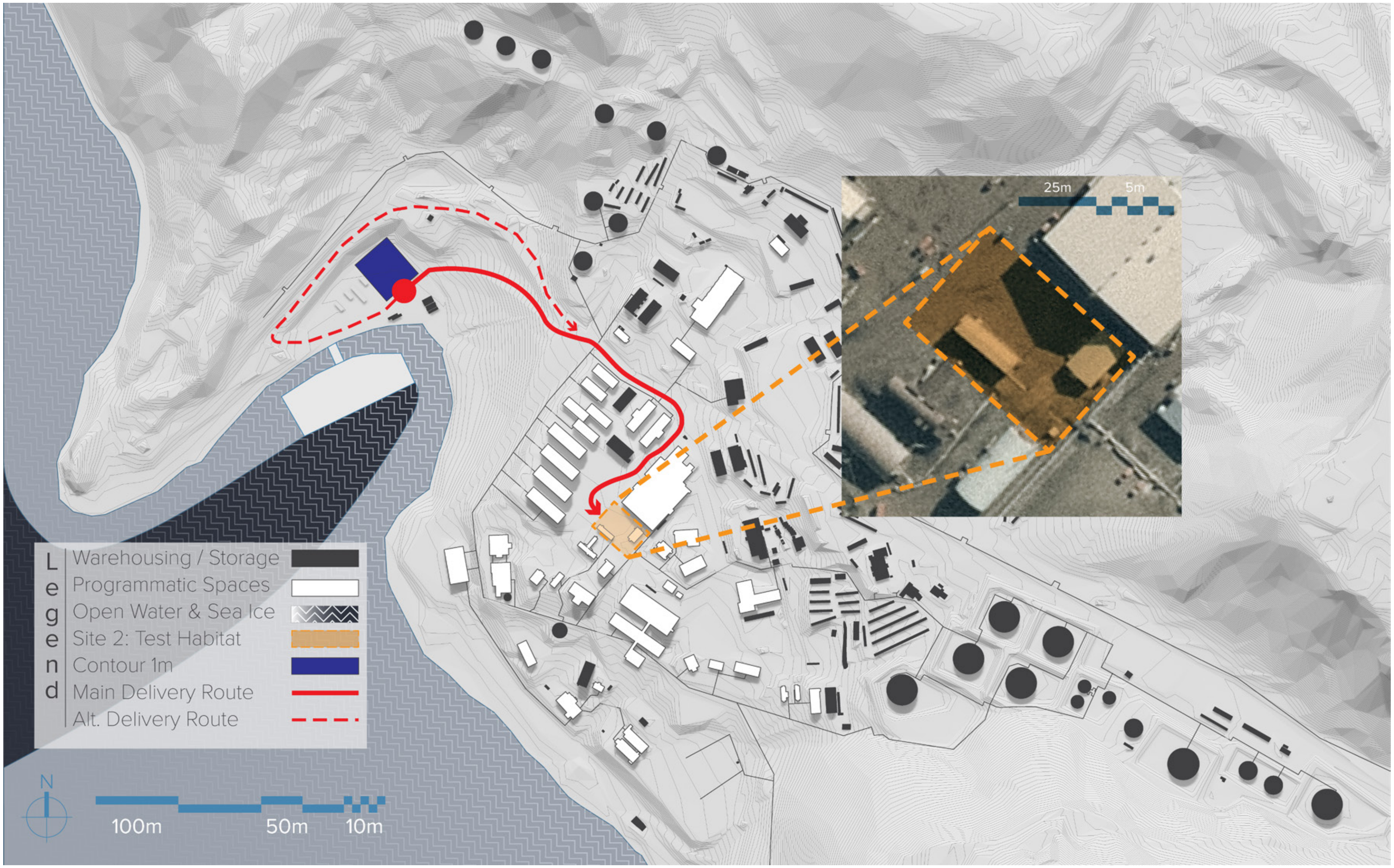

Figure 37: McMurdo Station site plan indicating the routes taken from the factory to the proposed site of the test habitat, map data from lidar imaging of the McMurdo Valley, Antarctica (Fountain et al. 2017).

### 6.5.1. Habitat Assembly

As mentioned, the prefabricated assemblies produced by the factory during the winter operational season will be used to erect the test habitat. Completed assemblies that have been stored on-site will be transported from the harbor area to central McMurdo when needed (Figure 36). Similar to the factory, the test habitat will be erected on a precast concrete foundation and assembled in a series of sections (Figure 38). Unlike the factory, the entire building will be enclosed in insulated panels as the building sections are put into place (Figure 39). This will enable better treatment of joints between sections and openings in the building envelope. As with the factory the test habitat will use prefabricated trusses to create a pitched roof, similar to many other buildings on site. Some parts of the program will be housed within modules whereas larger spaces will be created between multiple modules and assemblies. As much as possible, building systems will be complete within modules to minimize field connections. Some finishing work may be better completed once sub-assemblies have been brought together, especially in the large spaces.

### 6.5.2. Habitat Functionality and Program

Unlike the factory, the test habitat will consist of multiple levels containing a greater variety in programs and functionality. These spaces will be organized around a central atrium spaces that stretches the full height of the building. This will allow for casual interaction and gathering between inhabitants of the station, encouraging personal interaction (Figure 44). The levels within the habitat will transition from more communal and open spaces at the bottom to more private and intimate spaces above (Figure 41). The ground

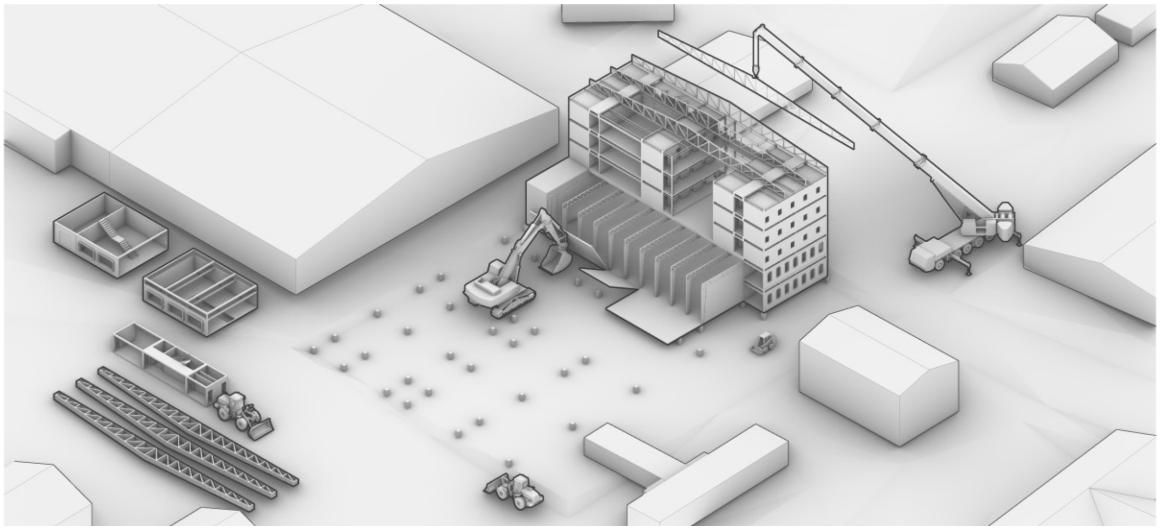

Figure 38: Similar to the factory the habitat will be assembled in a series of sections.

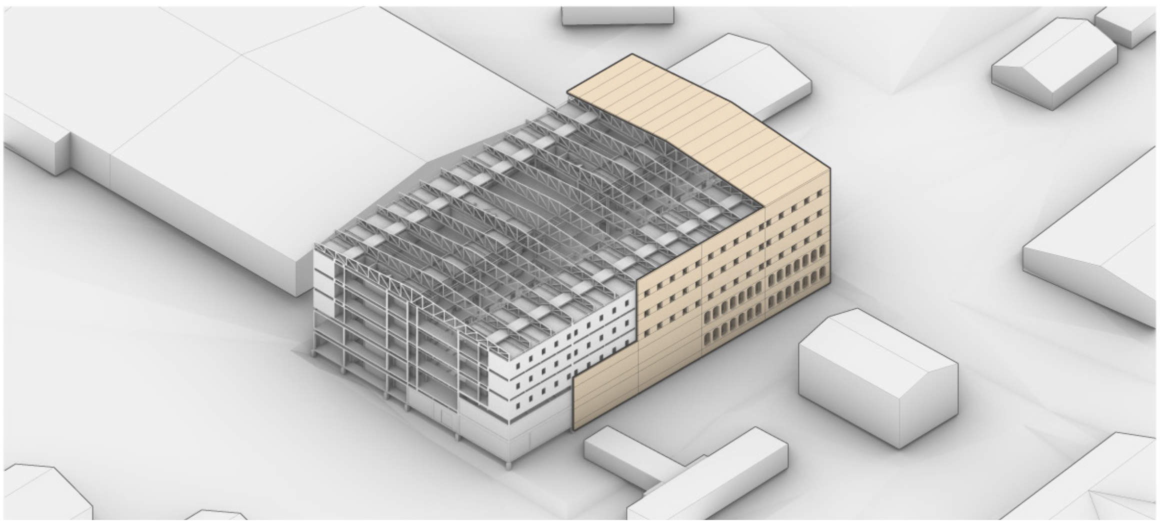

Figure 39: Once all sections are complete the external insulation and cladding can be installed.

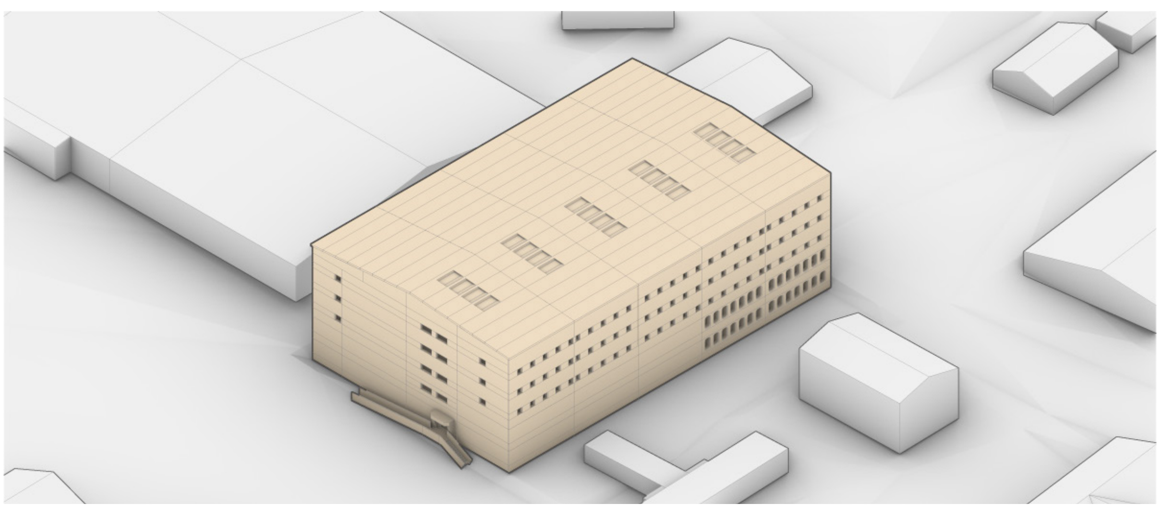

Figure 40: Control of natural light is important so windows and skylights with integrated shutters within the envelope will help regulate a proper 24 hour cycle in times of excess darkness and daylight.

floor will contain several protected areas to transition from the exterior Antarctic environment to the safe and hospitable interior. Utilities will connect at or under the lowest level. The first two floors will accommodate most of the communal spaces (Figure 41) and will include a full gymnasium and activity area as well as a large lecture hall. Currently, large groups of people can only assemble outdoors. Larger double height spaces will allow many kinds of event to take place indoors (Figure 46). To enable better views of the surrounding landscape, an observation lounge has been included in the program which could be especially popular during the first sunrise and last sunset observed during McMurdo's annual cycle (Figure 47). For more practical functions, a reference library doubling as the administrative hub and offices is also located within the habitat. Unique to McMurdo Station, a large two-storey greenhouse will serve several key functions for the inhabitants (Figure 43). The heavily-serviced climate-controlled space will enable a steady production of fresh fruit, vegetables, and greens, to supplement the inhabitant's diets. To contrast the frozen desert of Antarctica, the greenhouse will serve another important function: it will be a source of light and greenery. Therefore, the viewports of the greenhouse will be enlarged, with those on the ground floor incorporating integrated seating.

In the interest of creating a complete habitat for living and socializing at McMurdo, the upper levels of the habitat will contain both accommodation and relaxation spaces (Figure 48). Housing at McMurdo has been of limited quality. The transient population and difficult building condition result in many people sharing a single-space or bunk room. Privacy is further compromised by a split 24 hour working schedule causing personnel to come and go at all hours of the day. Therefore, the test habitat emphasizes individual sleeping quarters, with shared hygienic facilities (Figure 51). This should achieve a reasonable balance of density and privacy. Upper levels will include quiet relaxation spaces to contrast the openness and communal nature of the lower levels. The test habitat will represent a new development in building at McMurdo Station, and the whole community could be transformed over several years to become more condensed and inclusive under a protected prefabricated roof of possibility.

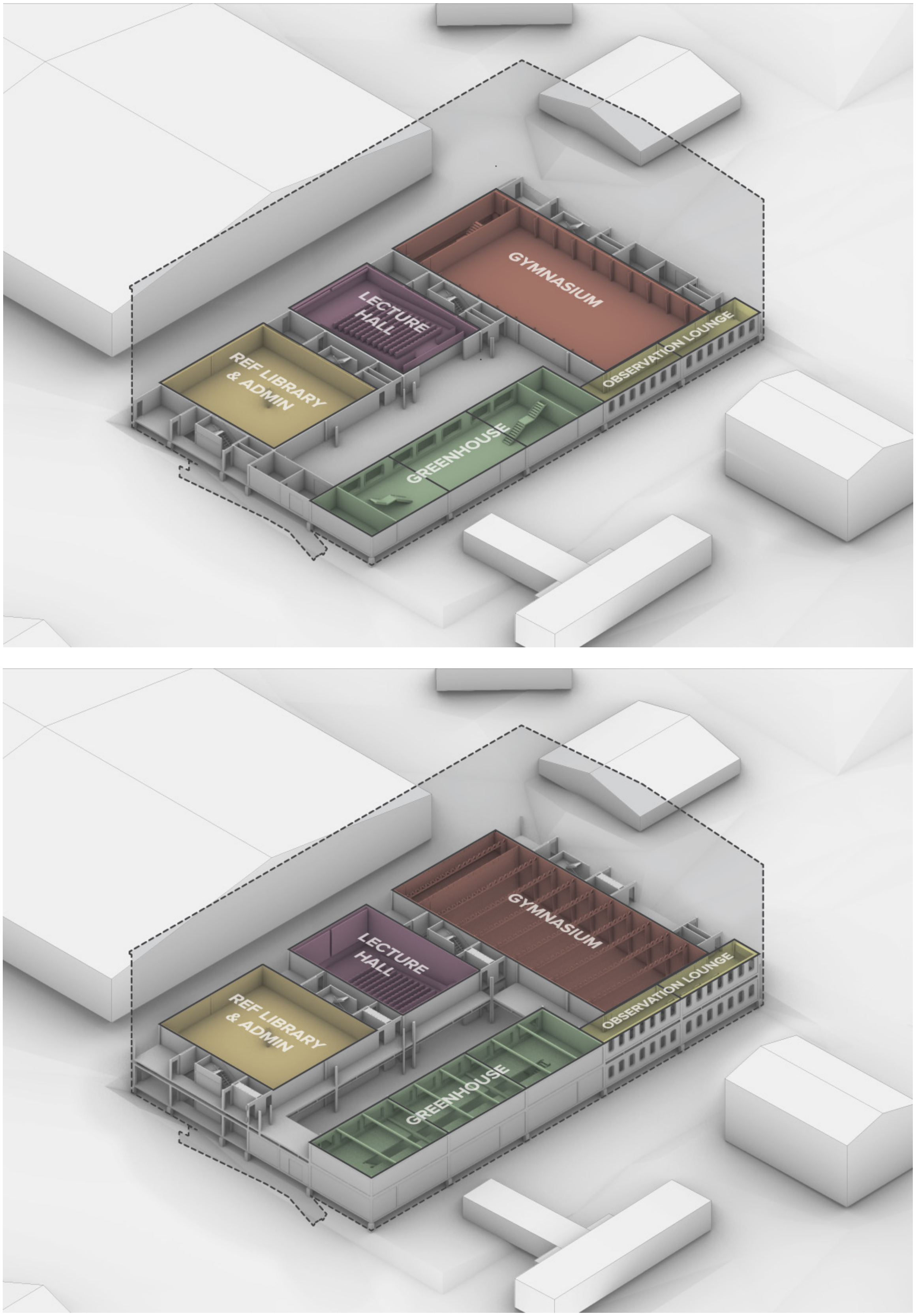


Figure 41: The first and second level of the habitat will consist of public and communal spaces.

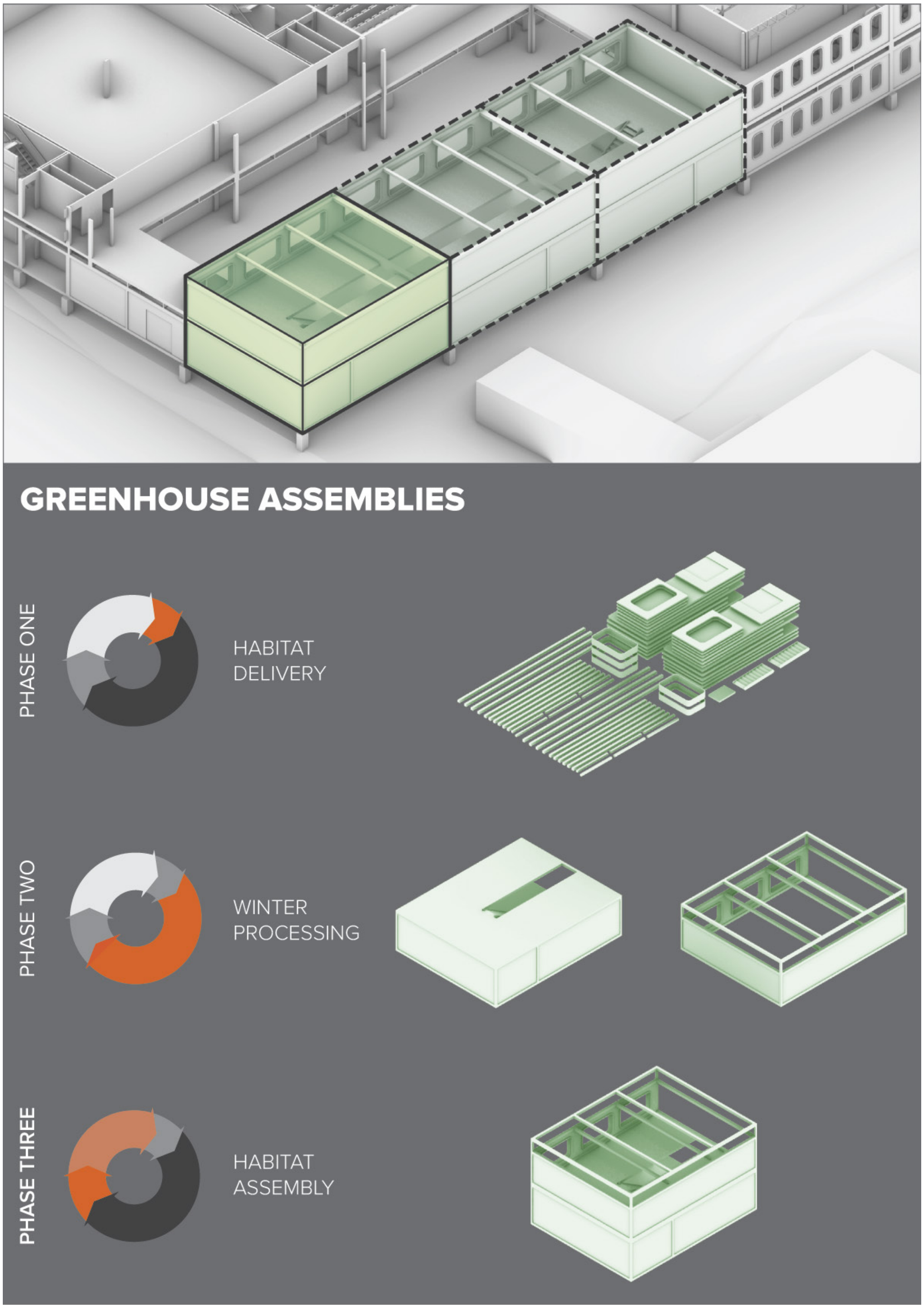


Figure 42: The sequential phases that illustrate how sub-assemblies will be processed by the factory to produce the assemblies for the greenhouse.


Figure 43: Sectional perspective of the greenhouse illustrates how this heavily-serviced space will do more than simply produce greatly needed fresh fruits and vegetables for inhabitants of the station.

Figure 44: The lower levels of the habitat are meant to create a more communal space protected from the harsh Antarctic environment. The green house will be a crucial feature providing a refreshing greener and light, especially during the long darkness of the winter operational season.

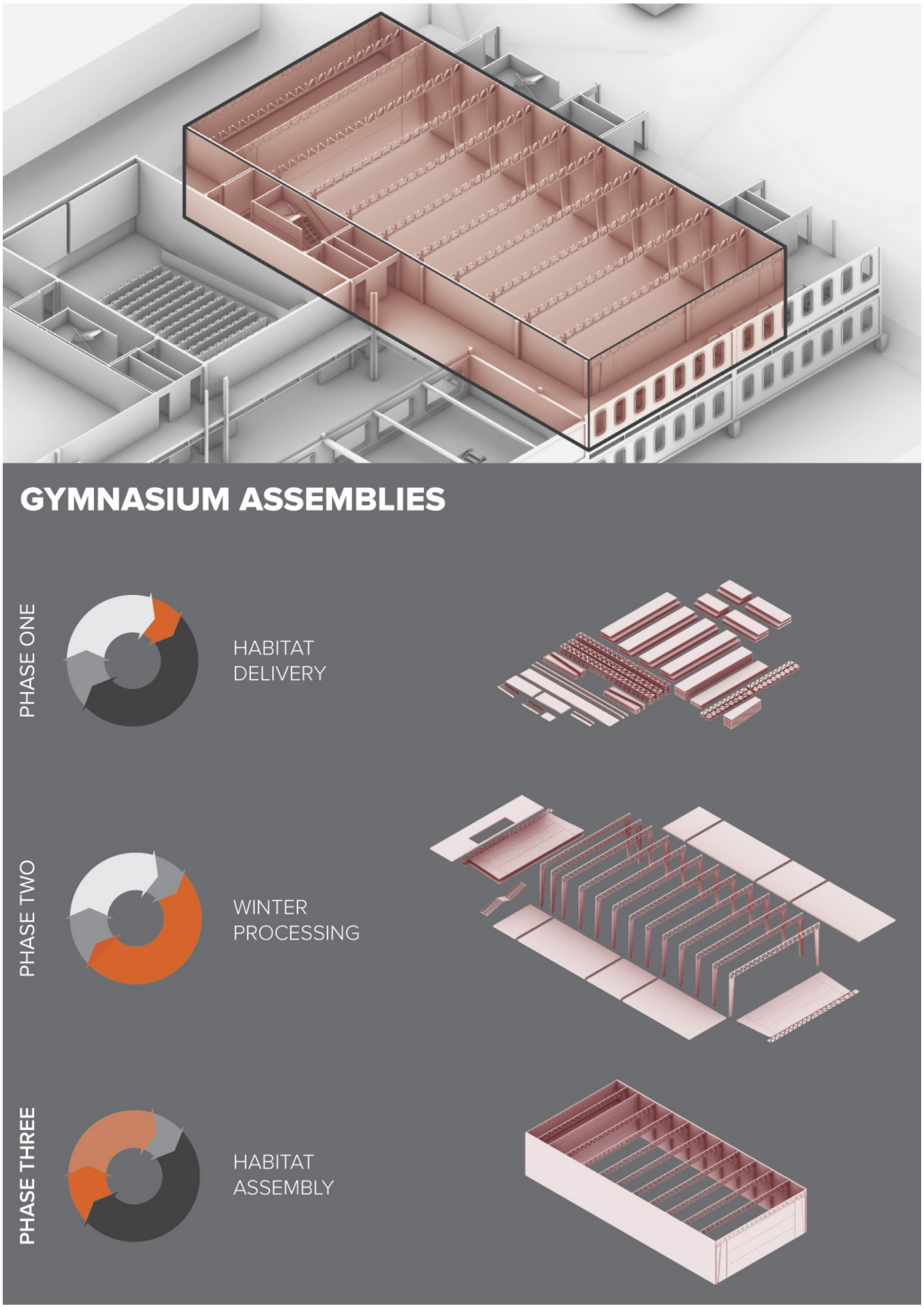


Figure 45: The sequential phases that illustrate how sub-assemblies will be processed by the factory to produce the assemblies for the greenhouse.

Figure 46: The gymnasium will not only provide a space to maintain the inhabitants' physical well being, but also provide a unique spatial experience previously unavailable at McMurdo Station. With such a large volume now available to the station, a large range of activities such as musical performance or social events could be hosted as well.

Figure 47: The observation lounge as seen during the first sunrise of the season.  This marks the transition out of the winter operational season into the pseudo spring.

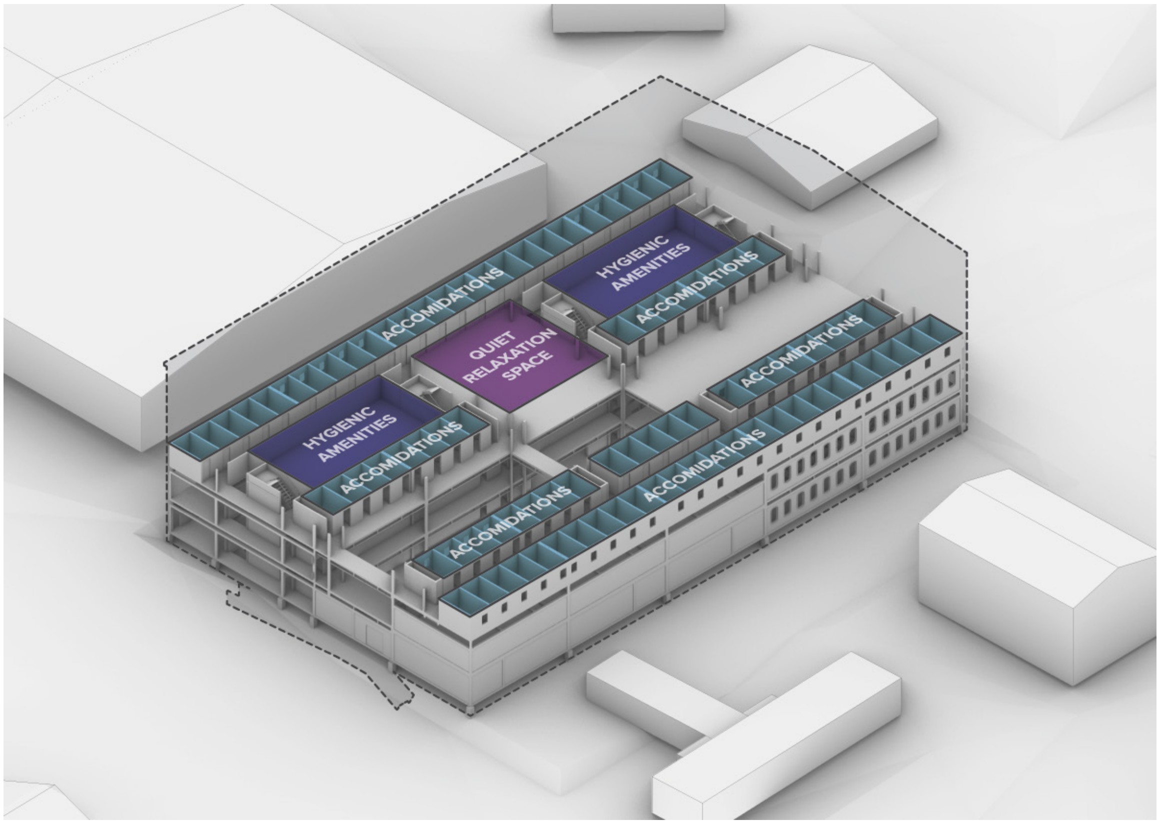


Figure 48: The third to fifth levels of the habitat will consist of private spaces including individual accommodation, amenities spaces, and quiet relaxation spaces.

Figure 49: To alleviate existing pressure on the existing housing situation in Mcmurdo, the habitat will emphasis single rooms for its inhabitants.

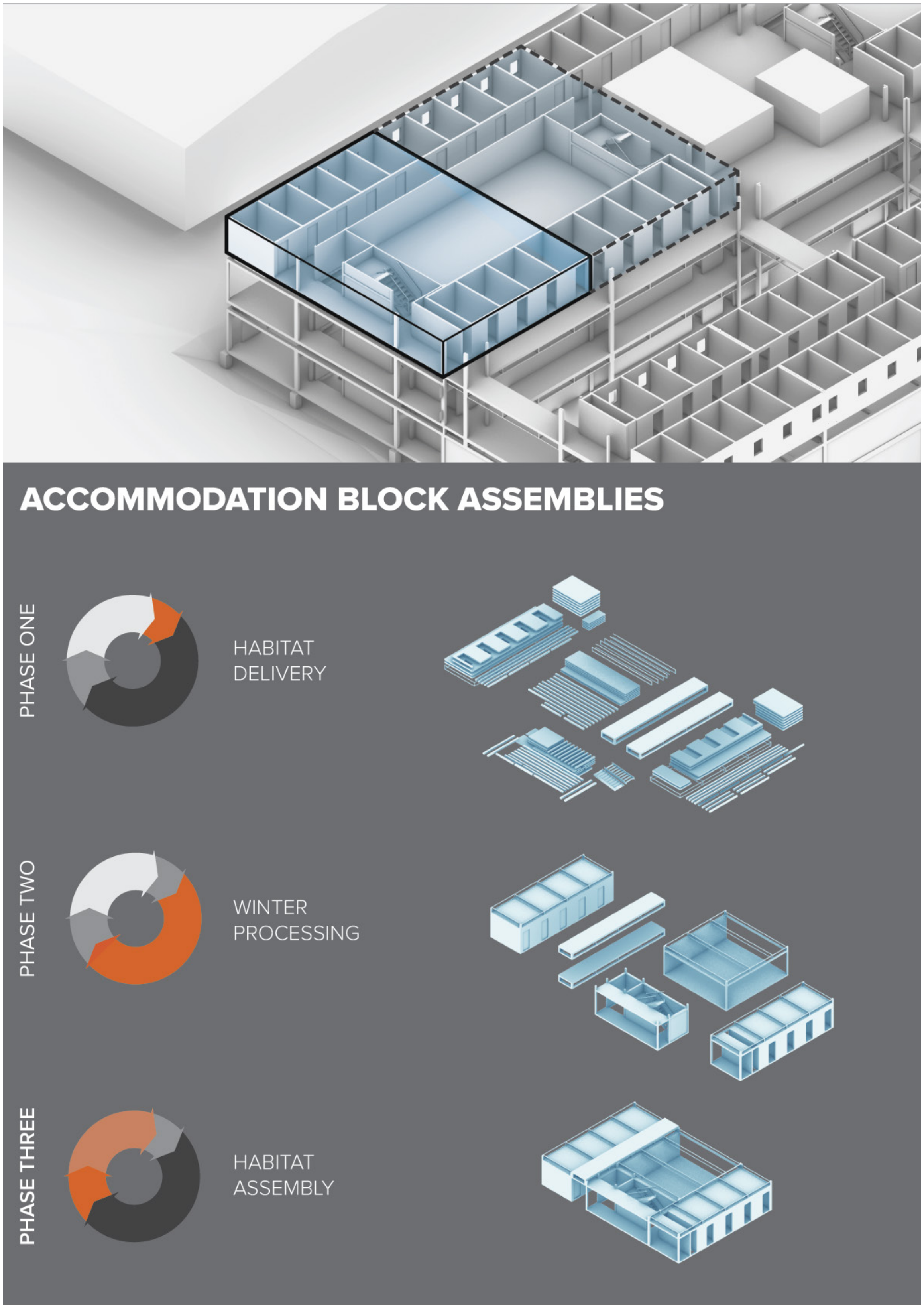


Figure 50: The sequential phases that illustrate how sub-assemblies will be processed by the factory to produce the assemblies for the accommodation block.


Figure 51: Sectional perspective of the accommodation block illustrating both the individual private quarters and the shared amenity spaces that will provide essential services for both hygiene and relaxation. The included saunas will provide much needed reprieve from a hard days work in the cold landscape of Antarctica.

Figure 52: The upper levels of the habitat will accommodate private quarters for the inhabitants of the station.  While natural light from the skylights will help to illuminate the central atrium during the summer months, each individual room must be able to regulate these light levels based on their personal needs.  Especially during the opposing seasonal dates when a 24 hour cycle is dominated by complete light and darkness.

Figure 53: Communal activity and interaction is crucial in maintaining physical and mental well-being.  The multi-purpose functionality of this upper atrium space enables casual interaction within the community with an impromptu yoga class.

# Chapter 7: Conclusion

## 7.1. Future Opportunity for Building in Antarctica

The factory is a prototype facility for on-site assembly of large-scale prefabricated structures. Given the factory scope and scale, it could also produce assemblies to be shipped beyond McMurdo Station as well. Existing precedents illustrate how these assemblies could be moved to other sites in Antarctica. Large sleds and convoys have been used in the resupply of Amundsen-Scott South Pole and could be adopted to handle large prefabricated assemblies. As with newer stations like the British Halley VI station, entire sections of these station could be designed to move across the Antarctic landscape after assembly.

As previously stated, a limiting factor in transporting building modules is loading gauge. One way of increasing the size of modules shipped to McMurdo would be to propose special new ships, but that was deemed unrealistic, inviting new challenges such as loading and unloading the outsized cargo, and surviving the long voyage through the stormy Southern Ocean. In this proposal. All parts shipped to McMurdo conform to existing limitations.

No one can predict the future scientific, political, commercial, or touristic opportunities of Antarctica. The current treaty limiting inhabitation to scientific endeavours is due for review in 2048, leading to its possible expiration. However, whether one is building research stations, military outposts, company towns, or adventure resorts, the advantages of rationalized prefabrication will inevitably apply. If these strategies of prefabrication set a new precedent in the region for a cyclical process of assembly and disassembly, larger scale settlements could be established and recycled as needed.

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