Architectural Consideration to Planning in the Extreme Environment- Antarctica

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Abstract- *Extreme environments in Polar Regions share similar facilities and operations, design, and planning challenges: extreme cold temperatures, structural problems, high standards for materials, resource limitations (including people), transportation, and logistics. Nevertheless, they differ depending on local cultural and social traditions and climate challenges specific to a particular region. Environmental hardships create challenges that reflect on sets of architectural requirements. The paper discusses these challenges and their influences on form-developing factors, site orientation, and circulation, - factors that affect budget considerations as well. The paper also discusses the criticality of addressing such impacts at the programming design stage, especially in challenging environments, to avoid costly adjustments at later development stages.*

The paper argues that integrating an architectural approach into the planning of construction and related activities in Polar Regions is critical for enabling sustainability and resilient strategies there. The importance of such integration comes from the fact that engineering-oriented developers strictly follow industry-specific technical regulations and standards. Simultaneously, planning construction work and design in extreme conditions becomes a more complex process that calls for a new methodology, which would differ from common regulatory "checklists" that most companies implement in their practices there.

Keywords: Antarctic architecture, extreme environment adaptability, modular construction, renewable energy, ecological responsibility, environmental constraints, scientific research, prefabricated construction.

1. INTRODUCTION

Located on the polar plateau at an elevation of 2,835 meters (9,301 feet) above sea level, the South Pole is arguably the most pristine and extreme environment on Earth. Antarctica, Earth's southernmost continent, presents a formidable challenge for architectural planning and design due to its extreme environmental conditions. As human activities expand in this inhospitable landscape, there arises an urgent need for innovative architectural approaches that can seamlessly integrate with the unique challenges posed by the continent's harsh climate, isolation, and pristine ecosystems.

This research paper delves into the development of an "Architectural Approach to Planning in the Extreme Environment - Antarctica," with a primary focus on climate-responsive design, spatial optimization, and sustainable solutions. By addressing these critical aspects, this study aims to contribute to the creation of resilient and adaptive architectural frameworks that can thrive in the demanding conditions of Antarctica while supporting scientific research and human habitation.

Today life conditions in the Antarctic are changing rapidly due to climatological changes, recent trends in industries, demographics, and the built environment. In an antarctic extreme environment, it becomes essential to respond to those changes with design and planning just as fast as they occur. It is also critical to proceed with construction almost immediately after a decision to begin any type of development is made and the personnel and crew have to be moved to a remote location within a limited timeframe.

Engineering objectives-oriented developers in antarctic and sub-antarctic regions usually follow industry-specific technical regulations and standards "checklists" that lack a deeper understanding of extreme environmental implications on human factors and local communities' essentials. The situation affects operations and planning as well as required technical and logistic support. Applications of advanced technology and social and psychological sciences need to become mandatory components of processing projects in the Antarctic.

Therefore, special attention should be given to environmental characteristics that influence architectural and planning requirements and program prerequisites definition. Patterns in architectural requirements for different extreme locations have to be analyzed before design decisions are made. Comparisons between infrastructure elements conditions in case studies referred to in this paper demonstrate that they share similar characteristics that can be addressed by following related procedures. For example, extreme conditions of investigated case studies pose limitations and hardships for people surviving and maintaining relative physical and psychological comfort. The limitations include resources, availability of services and spaces, mobility, and transportation. These limitations lead to hardships that include all or some of the following:

• Strong restrictions to execute everyday work tasks

• Impossibility to perform social interactions or maintain necessary privacy level

• Impossibility to fulfill necessary living needs.

This conceptual paper introduces the idea of a new interdisciplinary and comprehensive approach that includes highlighting extreme environmental influences on general habitat requirements, constraints upon delivery, construction, and special provisions for safety and hazard intervention. Consolidation of such design requirements based on the summary of vital design aspects is a key logic for developing a new planning methodology.

As a result, some of previous experiences are used in new conditions but without comprehensive arrangements and systematic methodology, the result of such application can be misleading, causing abuse and waste of resources and vital time delays. (UNESCO, 2009) Federal laws, standards, and regulations generated by companies, local authorities, developers, and other entrepreneurs are disconnected at many levels and often have different objectives. That leads to unbalanced design and planning failure in one or several areas of development (Bell, 2014). This is also critical for creating sustainable and environmental and social systems ,Social systems in extreme environments are more vulnerable and sensitive to changing conditions in any of their subsystems, such as cultural, political, ecological, technological, and societal (Rasmussen, 1999). A malfunction in one of those subsystems may easily make the whole system dysfunctional and handicapped (Nuttall, 2005). Any planning project in the Arctic is a system where all subsystems play their roles within the environmental boundaries of extreme conditions. Identifying aspects or elements of the proposed methodology as well as understanding why they are connected is important for building a dialogue model for local communities, engineers, and individuals, that will serve as a design and development planning tool.

2. PRECEDENTS AND LITERATURE REVIEW

There is scarce literature concerning the development of a system of systems methodological approach for planning large-scale activities in arctic and subarctic regions. (US National Research Council 2014, Expert Group on Ecosystem-Based Management 2013) Therefore, the approach in the literature review is a combining approach that includes construction experience in Antarctica and design precedents and projects for the Antarctic.

There is a long history of Antarctic and Arctic exploration but the operations and activities in the North and South are different. While Antarctica is protected by the Antarctic with the permanent presence of countries participating in the Treaties supporting strictly scientific goals with limited tourism and other commercial activities, the Artic is open for commerce and divided by northern countries' specific political agendas. In addition, there is no indigenous population present in Antarctica, while the coast of the Arctic Ocean is inhabited by diverse population groups. Since the research presented here focuses on a methodological approach to planning diverse activities in arctic and sub-arctic regions, only building structure-related aspects of the Antarctic endeavors can be considered as reference material.

Nevertheless, increased public interest in the Arctic in recent years triggered the launching of several art and social programs and projects for the Arctic. They include initiatives by the Art Catalyst program in the UK2 and Arctic Perspective Initiative3 supported by the Culture Program of the European Union. These programs address social, political, architectural, and design issues in the Antarctic and other extreme environments. Yet, their architectural projects are mostly object-oriented design competitions and are not realized in the real conditions of the Arctic. Large-scale planning endeavors commercial and even military activities and population expansion are evident during the last decades there.

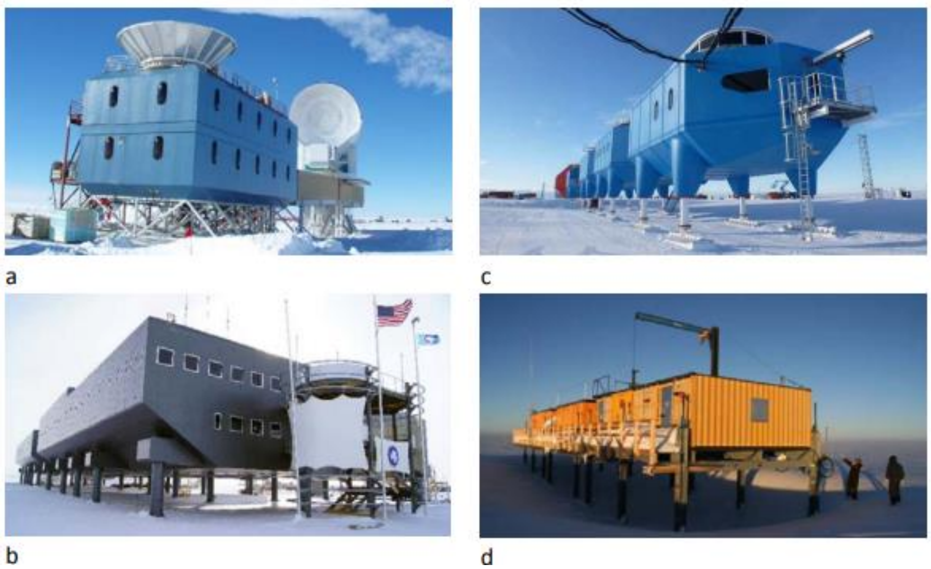

Figure 1: Antarctic Elevated Stations: a – the BICEP4 and South Pole Telescopes building

(Credit: Yuki Takahashi, NSF);

b – Amundsen-Scott Station (Credit: Elaine Hood, NSF);

c – Halley VI station (Credit: British Antarctic Survey);

d – Kohnen station (Credit: Stein Tronstad, NPI).

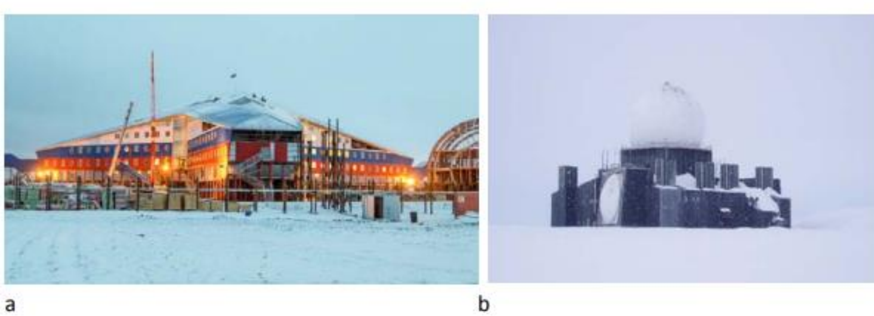

Figure 2: Russian military base "Severnyi Klever" (Northern Clover) on Kotelnyi Island of Novosibirsk Archipelago under construction in 2015 (Credit: Russian Federation Defense Ministry Multimedia Center5); b – The US military abandoned radar station DYE-2 in Greenland (photographed by the author in June 2005).

3. METHODOLOGY

The paper briefly describes several research methods that were used as the foundation for the development of the proposed methodology. These methods including transdisciplinary participation are still absent in the landscape of the Antarctic, although more

• Verbal data collection (mono- and transdisciplinary)

• Case studies analysis

• Selection of Figures Of Merit (based on NASA's approach to data analysis and systematization) and application to case studies projects

• Analysis of effectiveness and verification of the proposed method utilizing the Living Lab project

The data available for collection in Case Study research are usually not precisely measured and may be partially subjective, the application of multiple sources of evidence is necessary for a better understanding of the research problem and theory argumentation. All of them deal with scientific evidence and can have quantitative or qualitative dimensions. Applied analytical strategies include:

- Relying on theoretical propositions
- Developing a case description
- Using qualitative data
- Examining competing explanations.

Extrapolating from James Reason's "Swiss Cheese" (2000) theory is widely used in the healthcare field, and applying the theory to the planning process in the extreme conditions of the Antarctic multi-dimensionally leads to the argument that a transdisciplinary approach should be part of the design and planning prerequisites, programming and project execution .

The multi-dimensional character of the process affects the overall design methodology in a way where all components are influenced and influence one another. Figure 3 summarizes the idea in a multi-dimensional diagram where straight horizontal and vertical connections represent direct dependencies and influences while indirect connectors represent conditional but permanent relationships between elements. The integration model or tool's role is to facilitate these relationships and promptly respond to their demands.

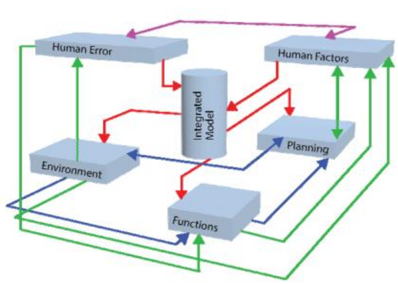

Figure 3. The multi-dimensional model is applied to the project development process.

The ultimate goal of any design process depends on the successful identification of a design research problem, which lies in finding a proper "translation from individual, organizational and social needs to physical artifacts" . The architectural approach also includes an understanding of consequences of inadequate behavior or actions caused by inappropriate attitude to the project development which may lead to non-desirable or even catastrophic events.

4. Data collection. For a better understanding of the current situation with energy companies' exploration plans in the Antarctic, professional engineers and managers from several energy companies answered a structured questionnaire about projects in extreme environments. Three ConocoPhillips managers were interviewed referencing multiple projects at four different locations by a researcher. The interviews aimed to expand and summarize the knowledge after the respondents answered the survey. The locations of discussed projects include off-shore platforms, several Alaska North Slope developments, the Russian Antarctic region, and Northern Alberta County in Canada (Table 1). The schedule was the main driver for all projects as well as cost and safety for operational projects. All of them were challenged with remoteness, communication issues between contractors, local authorities, workforce, and project management, and logistics problems to different degrees.

Table 1. Projects referred in survey responses.

Characteristics	Off-shore rigs	Alaska, North slope	Arctic Russia	Northern Alberta, Canada
Environment/ climate	Deep water	Polar, cold and dry	Polar, cold and dry	Permafrost, cold and dry
Development stage	Finished	Finished	In transition	In progress
Within schedule and budget	Yes	Yes	Schedule – yes, Budget – no	N/a

Although all mentioned projects were referred to as successful, the corporate criteria for "success" or "failure" is only based on safety and execution within a given timeframe and budget .It was revealed during follow-up interviews that many of the other elements of planning and execution processes are either dismissed or not given proper attention and that may sometimes threaten the project flow.

Interviewed professionals and practitioners from other energy companies and researchers pointed out independently that effective and timely communication between all participants and at all stages of the process is a foundation of success regardless of major drivers and criteria of the success applied in the project. The most important drivers of success in all projects are safety, cost, schedule, and quality while the last three may not necessarily be placed in that order. Other impacting aspects of success or failure include:

- Professional level of personnel
- Number of qualified personnel on site and in decision-making
- Available infrastructure
- Available resources. Case studies.

Table 3 summarizes the environmental and geographical characteristics of projects used as case studies for the development of the proposed methodology.

Table 3. Characteristics of investigated case studies.

Case Study/ Project	Characteristics Zone/Climate	Temperature	Weather	Geography
Case I Summit Science Station	Polar/Year-round cold temperatures with the warmest month less than +10°C	Average: winter: -35°C summer: -10°C Lowest t° -67.2°C Highest t° +3.6°C	Highly variable harsh weather, annual precipitation ~3,000 mm (sleet/snow)	Above Polar Circle, top of Greenlandic glacier
Case II Muraviovka park for Sustainable Land Use	Subarctic/ Boreal*- Long, very cold winters, short, cool to mild summers	Average: winter:-26.2°C summer:+27.3°C Lowest t°-45.4°C Highest t° +39.4°C	Very cold, dry winters, warm and wet summers, annual precipitation >563mm	Russian southeastern Siberia, wetlands of Amur river
Case III Conoco Phillips projects reviews	Deep water, cold and dry polar, permafrost	Year-round cold temperatures, very cold winters, cool and short summers	Highly variable and harsh weather	Off-shore rigs, Alaska, north slope, Arctic Russia, Northern Alberta, Canada, Gulf of Mexico

* Most extreme temperature variations, at least one month must have a 24hr average of 10°C.

Case study I (Polar desert) is located above the polar circle on the top of three kilometers of Greenlandic glacier and in the center of Greenland. The subject of Case Study II (Boreal) is in wetlands of the Amur River of Russian eastern Siberia. Both geographical locations present challenges for life conditions and demand a proper response from architects and planners when planning development activities in the regions. Projects from Case Study III are sited in multiple locations of the Arctic region.

5. Figures Of Merit (FOM)

Figures of Merits can be justified as Characteristics of Values where the designer of the method identifies the values. Using the FOM method helps to identify important lessons that can be applied across different settings, which present common priorities, issues, and challenges. Such environments include future bases on the Moon and Mars, offshore surface and submersible facilities, polar research and energy exploration stations, military desert operations, and emergency shelters in disaster zones. Even though it may not seem to be very practical to compare proposed case study elements using the FOM technique as many of these projects' attributes are rather qualitative than quantitative by nature, it appears to be important to understand the FOM approach when different design solutions are compared and evaluated.

6. RESEARCH APPROACH

A concept of a new interdisciplinary and comprehensive approach highlights extreme environment boundaries to be applied to general habitat requirements, and constraints upon delivery, construction, and special provisions for safety and hazard intervention. Consolidation of such design requirements based on the summary of vital design aspects is a key logic for a new programming and planning methodology. Identification of common priorities, issues, and challenges leads to the possibility of creating a common methodology that can be applied to design and planning for various extreme environments and adjusted to diverse harsh conditions. Human requirements and environmental factors specific to each different type of environment, operation, and facility must be correlated with resulting planning needs. Some general considerations are listed in Table 4.

Table 4. Planning considerations.

Human requirements	Environmental influences
Number of occupants	Structure selection and construction options
Social/cultural influences	Site climate/thermal characteristics
Time frame/mission duration	Logistical requirements and scheduling
Special safety hazards	Types and levels of danger
Emergency escape means	Proximity to major transportation modes
Recycling of expendables	Type of surface transportation
Primary mission objectives/purposes	In-situ resource utilization possibilities

Analysis of the case studies demonstrated shared and recurrent design aspects that need addressing in the design process in a similar way, which perhaps can help to optimize planning processes for extreme environmental conditions starting from the first stages of their initiation. Table 5 summarizes structural and infrastructural similarities and differences between case planning and design requirements.

Table 5. General and specific planning and design requirements.

		General	Specific
Polar desert (arctic)	Facility and elements structure related	Avoid heavy construction needs; Interior zoning; Use of renewable energy and recycling systems; Apply tight building envelop; Optimize elements packaging for efficient transportation.	Strict limitations for structural elements mass and dimensions; Structurally balance weight distribution; Incorporate automatic and robotic systems.
	Existing infrastructure related	Plan for tight transportation windows; Develop site zoning; Minimize environmental impact.	Year-around assembly operations possible; Very limited transportation means available.
Boreal (sub-arctic)	Facility and elements structure related	Avoid heavy construction needs; Propose interior zoning; Use of renewable energy and recycling systems; Apply tight building envelop.	Constrained construction and assembly time; Many transportation means available but limited for economic reasons.
	Existing infrastructure related	Plan for transportation limited by weather conditions; Develop site zoning; Minimize environmental impact.	Many transportation means available but limited for economic reasons. Create economic and social sustainability

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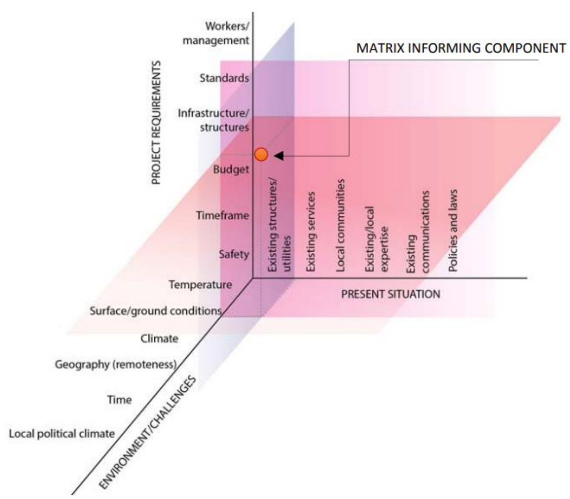
Other design influencing aspects are associated with human factors. They combined under non-structural, human-related categories where psychological, societal, cultural, and mental challenges demonstrate comparable levels of stress and other risk factors. Table 6 summarizes some of them.

Impacts of those influences are evaluated and categorized based on levels of demand, effect on safety procedures, dependency, intrusiveness, and effect on local infrastructure and community.

Optimization of design requirements based on the summary of design aspects presented in Tables 5 and 6 is the next step of the research. Sets of requirements become key elements of a new methodology for design and planning in Polar Regions.

The research presented in this paper is built upon personal and academic work experience, a review of performed projects, literature indication, and experts and practitioners' reviews. The verbal data of the research was collected from diverse sources and at different times. It is recognized that this research has limitations, which come from Case Studies projects' conditions: both were earlier performed student projects and both were retrospectively reviewed. Other limitations come from the inadequate number of existing records about planning large-scale projects in the Arctic.) Nevertheless, understanding that these limitations open possibilities for failure of the proposed concept leads to opportunities to learn and improve the Matrix and its application process when applied to a new project. Matrix methodology simulation is attempted through its application to the current ConocoPhillips project in North Slope Alaska – GMT



The purpose of the Matrix application to the GMT1 is to demonstrate how a transdisciplinary logic of the Matrix can identify the most critical points of the project development. Figure 4 depicts systems that need attention in any planning process in Arctic conditions: project requirements, environmental challenges, the present situation of conditions, and physical structures. The figure illustrates how elements of the Matrix are created. The Figures Of Merit of each system are placed along the axes according to their importance and criticality to the realization of the project. For example, project-required infrastructure and structural decisions depend on temperature conditions and the availability of existing structures and utilities at the location. The intersection of these systems creates Matrix informing components. The most critical components of the Matrix are closest to the axes' intersection point.

7. CONCLUSIONS

In summary, a transdisciplinary, comprehensive approach includes highlighting influences upon general habitat requirements, constraints upon delivery and construction, and special provisions for safety and hazard interventions. Common design influences with different levels of impact include:

- Influences driven by transport to remote sites
- Environmental influences upon facilities and construction
- Influences of crew sizes, types of activities, and occupancy durations
- Influences of construction methods and support infrastructures
- Special safety and emergency response requirements (Bannova, 2010).

Reflecting dialogues with industry professionals, researchers, logistics, and support crews operating in polar and other remote locations, it is understood that the most critical MATRIX INFORMING COMPONENT 12 influences upon operating and living conditions are related to safety, communication, and transportation availability.

Analysis of patterns in architectural requirements for different extreme locations demonstrated conditions that influence architectural and planning requirements and program prerequisites definition. Comparisons between investigated case studies stressed the limitations and hardships people experience in the extreme environments of the Arctic. The impacts of those stresses need evaluation and categorization based on levels of demand, effect on safety procedures, dependency, intrusiveness, and effect on local infrastructure and community. A new methodological approach addresses these influences on design and planning for applications in extreme conditions of Polar Regions.

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