THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Designing for Extremes:

A methodological approach to planning in Arctic regions.

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Abstract

The starting point of this research is based on personal experience in research and design for extreme environments, including orbital and lunar planetary facilities, disaster shelters, polar stations and offshore surface and submersible habitats. This work reflects on research-related technical papers, discussions with professionals about their work experience with projects in extreme conditions, and students' workshops debating strategies to form sustainable behavior and design practices.

Generally, projects in extreme environments are conducted following corporate and professional checklists, which often fail to integrate important and interrelated elements of the design process. In addition to technical and environmental challenges, people in extreme environments deal with psychological challenges, due to isolation, confinement, deprivation, and risk factors that planners and designers must consider. The complexity of such problems requires a multi-disciplinary approach. Therefore, this research proposes a methodology where human-related sub-element connections and influences are also addressed.

This study finds that an interdisciplinary, comprehensive approach includes highlighting influences upon general habitat requirements, and constraints upon transportation, construction, and special provisions for safety and hazard intervention. Optimization of such design requirements based on a summary of design considerations is a key element of this proposed methodology.

In summary, this methodology offers a consistent strategy for design, staff operations and training, as well as equipment and logistical requirements for human activities. It facilitates a dialogue between all areas of expertise involved in designing, planning, living and working on site. This will emphasize the importance of equal attention to all elements of the project development, including human factors and psychological aspects, in the design and planning processes. Such an approach is essential to enable successful sustainable development and maintenance practices.

The next steps of advancing the research are discussed including potentials of the proposed methodology, which includes evolutionary databases, to serve as a foundation for developing an interactive software program for risk assessment, system-operations integration, logistics and safety.

Keywords: *Architecture, Engineering, Extreme environments, Design, Planning, Human Factors, Architect, Engineer, Multidisciplinary and Trans-disciplinary Design and Planning.*

LIST OF PUBLICATIONS

This thesis is based on the work contained in the following papers.

Roman numerals are used in the list of publications:

I. Experiments in mapping human factors for sustainable design and living, Article in "Urban Sustainability Innovative Spaces, Vulnerabilities and Opportunities" ISBN: 978-84-9812-243-5, University of A Coruña, 2014.
II. Testing and Evaluating Sustainable Design Practices, ARCC, 2014.
III. Architectural Engineering Approach to Developing a Matrix for Planning in Extreme Environments, ASCE 2014.
IV. Extreme environments – Design and human factors considerations, Licentiate thesis, Chalmers University, December 2014.
V. Architectural approach to planning in the extreme Arctic environment. archiDOCT: Transformable Architecture, Vol. 4, ISSN 2309-0103, ENHSA (European Network of Heads of Schools of Architecture), July 2016

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Olga Bannova

Contents

1 Introduction

This PhD thesis is a continuation of the research presented in my licentiate study that addressed design and planning commonalities between various extreme environments. This work is built upon the research conducted at the Sasakawa International Center for Space Architecture (SICSA) at the University of Houston and the Department of Architecture at Chalmers University of Technology. Some results of the research were shown in technical papers presented at various international conferences and articles published in scientific journals.

There is a growing concern about the Arctic environment, the future of its indigenous people, and the way resources are and will be explored in the North Polar Regions in general. Infrastructure, housing, and other living and working facilities have to be erected and maintained responsibly with equal integration of inputs from all participants in a project. However, today the only entities involved with projects in the Arctic and Subarctic territories are the project contractors and local and state authorities. They share responsibilities as well as rights during their work on projects. The commonly used approach involves fulfilling professional, local and state regulations that are usually applied independently from each other and at different stages of work on a project.

Integrating an architectural approach into the planning of construction and related activities in the Arctic where engineering-oriented developers follow industry-specific technical regulations and standards are critical for enabling sustainability and resilient strategies in these environments. Simultaneously, planning construction work and design there 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.

In a similar way, following a strictly architectural design process is not sufficient when designing and planning for diverse human activities in the Arctic and Subarctic. Deeper understanding of the circumstances affecting extreme environment operations and planning, which include required technical and logistic support, applications of advanced technology, and social and psychological sciences, are all necessary components of conducting projects in Polar Regions overall.

The purpose of this thesis is to develop a new methodology that tackles these problems. The new methodology actively incorporates architectural vision into an otherwise typical engineering checklist-like approach to building environments in North Polar Regions. This tool is also intended to facilitate a dialogue between all parties involved in designing, planning, living, and working in extreme conditions of the Arctic and Subarctic locations. To achieve this goal, research strategies including case studies and systems analysis approaches will be considered. Case study projects include: I - Greenland Summit station, initiated by management and supported by VecoPolar Resources Company and the National Science Foundation (NSF); and II - Muraviovka Park for Sustainable Land Use, initiated and supported by the International Crane Foundation (ICF). Other discussed projects are ConocoPhillips exploration and production projects in Arctic and Subarctic locations.

Applying case studies projects, personal and experts' experience, discussions with specialists and practitioners, this thesis research work builds a case for creating a new methodology to be used by multidisciplinary professionals, developers, and local communities. A new research methodology introduces *mitigation strategies* for possible *human error* complications within environmental and technological boundaries.

The PhD thesis includes seven main chapters with subchapters and sections, references, along with an appendix with synopsis of recent technical papers, case studies and other supplementary materials such as questionnaires, summaries of discussions, project programming, and structural and materials estimates.

This work does not exclusively concentrate on the demonstration of the differences between architectural design processes for extreme conditions and conventional architecture, but rather emphasizes the importance of including an architectural viewpoint and input in planning and constructing artificial environments in extreme conditions of the Arctic. Furthermore, a new methodology addresses issues and aspects of planning and design processes to guide architects and planners who work on diverse types of projects in extreme conditions of Arctic and Subarctic regions; where the criticality of well-orchestrated efforts increase due to environmental challenges and multiple resource limitations. Additionally, one of the implications of the new methodology is to provide a foundation for developing an interactive software program in the future to be used by professionals involved in different aspects of planning construction projects in the Arctic.

All figures and pictures used in this thesis are the work of the author unless otherwise specified.

1.1 Thesis structure

The subject of this research and anticipated outcome of the PhD investigations are presented in **Introduction (Chapter 1)** and its subchapters. The Introduction Chapter begins with the most essential terminology used in this thesis with its explanations in section 1.2.

An overview of determining factors for formulating a research problem are presented in the introduction subchapters 1.3, 1.4 and 1.5. Those factors include existing situations in the Arctic, concerns about directions of current and future developments there, and contributing factors to existing and potential problems in Arctic regions. Subchapter 1.3 discusses extreme environments and human factors definitions and characteristics in relation to existing conditions and challenges in this area. Analysis of contributing factors of all parties involved in the Arctic and Subarctic projects emphasizes human-related causes of existing problems, especially during new developments in these regions. Two major definitions that refer to the roots of the research problem describe special extreme environmental conditions and interpretation of "human factors" terminology.

As stated in the US National Science Foundation's report '*The Arctic in the Anthropocene: Emerging Research Questions',* the Arctic is described as:

> *…the northern region where physical, biological, social, economic, political, and other changes are leading to the emergence of new characteristics, relationships, and systems. Specifically, (focusing) on the area where change is rapid and far reaching, overturning the status quo (US National Research Council of the National Academies, 2014, p.11).*

The Arctic includes regions beyond the Arctic Circle, and extends to include boreal forest and discontinuous permafrost (Anisimov, et al. 2007). The main geographic area of this study – the Arctic and Subarctic – calls for urgent implementation of strategic planning and sustainable practices in the design and construction of artificial environments due to the vulnerability of their ecosystems, rapidly changing demographics and climate change-related challenges (Ahlenius, Johnsen and Nellemann 2005).

The roots of manifold conflicts in the Arctic and the problems caused by them are instigated by drastic changes in the area, which are caused by shifts in physical, social, economic and technological environments:

> *The changes taking place in the Arctic, from physical, biological, and social shifts driven by worldwide human activity to economic expansion and technological advances, are hallmarks of the Anthropocene epoch, in which human activity is a dominant force on the global environment (Crutzen and Stoermer, 2000, p.17).*

Literature Review and Research Boundaries (Chapter 2), reviews Antarctic and Arctic exploration outlining differences in operations and activities between the north and south. The chapter presents an overview of the most recent Antarctic stations' construction approaches. The discussed structures are elevated stations including: the US Amundsen-Scott station, the British Halley VI station, and the German Kohnen station. Amundsen-Scott and Halley VI stations advantages and problems are discussed based on publications and personal conversations with Jerry Marty (US station general manager) and Hugh Broughton (British station architect).

Historic and contemporary design precedents in the Arctic presented in the chapter are analyzed from a methodological perspective. Contemporary Arctic military developments of Russia are compared to earlier US military experience in the Arctic also from a methodological point of view. The results are reviewed based on their applicability to this research's objectives.

Finally, the chapter presents existing contributing factors to problems in the Arctic. The chapter summarizes with discussion of a research gap, issue, and formulating questions to be investigated through this research.

Research Design (Chapter 3), introduces an applied research methodology, case study methodology and systems analysis approach. Different types of case studies are discussed and compared. Included are explanatory, descriptive and exploratory (Yin 2009), and their application to selected representative projects. Other complimentary case study methodology sources are examined and evaluated to consider their applicability to the main field of study (Gillham 2010).

The Figures Of Merit (FOM), which in this thesis can be addressed as a figures of importance approach to compare and categorize research findings. FOM is a common format used by the National Aeronautics and Space Administration (NASA) to serve as a *"practical and efficient way to characterize and compare project's attributes and to evaluate them"* (Schrader and Rickman, 2010). This method will be applied to the results of case studies research. It precedes the testing and validation stage of the new methodology.

The two platforms of knowledge production (Mode 1 – mono-disciplinary systems, and Mode 2 – transdisciplinary research) used for collecting scientific and quantitative evidence and as verification methods for developed concepts and theories (Nystrom 2002, 4). Application of Mode 1 is used to verify solutions proposed by transdisciplinary research of Mode 2. This research calls for the two platforms of knowledge since, as Dunin-Woyseth and Nilsson emphasize (2011), both modes are necessary for development of a balanced research process and knowledge accumulation.

Research Concepts (Chapter 4), is based on case study and systems analysis research results. A proposed concept of a systematic theory for planning, design and implementation (Matrix methodology) is explained through levels of importance and the influences of: human factors and extreme environments, individual responsibility, sustainable practices and behavioral tendencies, and understanding the real outcomes of enabling sustainability efforts. A transdisciplinary design approach is a foundation of sustainable practices and perceived through two paths:

- Creating a means for advancing individual responsibility.
- Providing ways for better understanding of real outcomes of developed projects.

In addition, environmental and social impacts of the built environment are increasingly important factors for the sustainable development around the world (Schweber and Leiringer 2012). This has further become a critical element for the success of designing and planning for extreme environments where construction and utilization processes developed may also be tested in terms of success rate and effectiveness. The chapter also discusses validation methods applicable for design methodologies justification, and suggests an appropriate approach for a proposed Matrix methodology.

Architects and especially engineers now often apply a Decision Based Design or DBD approach in their projects (Pandey 2013). Many methodologies related to DBD and supporting it are recently created and require new criteria for their validation (Olewnik and Lewis 2005). Literature review of criteria selection and validation techniques are summarized in the identification of three key elements (subchapter 4.4). The three elements that are applied in this thesis work include logic consistency, using of meaningful and reliable information, and avoidance of designer biases by the previously proposed method.

Case Studies and Other Evidence Collection (Chapter 5), aims to demonstrate recurrent design implications and planning challenges in Arctic and Subarctic regions that can be addressed in a similar way by using an optimized organizational technique. The primary case studies projects used in this thesis are: I – Greenland Summit Science Station (instigated and supported by NSF through VecoPolar Resources logistic company specialists and NSF researchers)[1], and II – Muraviovka Park for Sustainable Land Use (commenced and supported by ICF scientists and sponsors)[2]. A third type of evidence collection includes structured questionnaires on projects conducted in the Arctic by ConocoPhillips Company. Another presents interview discussions with managers and engineers who worked on those projects.

This chapter discusses and examines information obtained through questionnaires and open-ended and semi-structured interviews with professionals working in energy fields and scientists conducting research in Arctic and Subarctic locations. Analysis of that data provides a further in-depth view on what is neglected but essential to enable sustainable practices in design and planning in Arctic regions. The research process focuses on and derives from:

- Analysis of physical evidence: structures and infrastructures under environmental influences.
- Analysis of interviews and discussions involving various professional society practices and perspectives regarding client's needs and concerns, requirements specific to a project, and environmental conditions.
- Analysis of non-physical evidence: psychological, social, and cultural influences.
- Synthesis of data and evaluation.

The analysis of the Case Studies projects, summarized in lessons learned include: parallels between case studies aspects and issues; human factors, and human dynamics affected by extreme conditions of each project location; and the need of an interdisciplinary input that was missing during research and design stages of Case Studies' projects. The projects were focused upon specialized architectural or engineering design organizational approaches that did not engage the process inputs from other disciplines and practices.

Modeling the Matrix (Chapter 6), the research results demonstrate connections and relationships between environmental as well as other challenging issues impacting planning and design considerations. The research investigates how a systematic methodology can enhance the design strategy in extreme conditions revealing measures needed to improve planning and designing for extreme environments in general, and most particularly in Arctic

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[1] http://www.uh.edu/news-events/archive/nr/2005/05may/051205spacearch_sstation.html
[2] http://muraviovkapark.ru/engCooperationUhouston.html

and Subarctic regions. It also proposes ways to optimize the organization and phasing of issues and aspects of design and planning processes in the extreme environment of the Arctic and Subarctic. This methodology is to facilitate active and constructive communications between all parties involved in designing and planning for extreme conditions of Northern Polar Regions.

The Summary and Discussion (Chapter 7), this thesis finds that a transdisciplinary comprehensive approach must address influences upon general habitat requirements and constraints upon transportation, construction, and special provisions for safety and hazard intervention. Classification of design requirements built upon a summary of systems analysis and synthesis of findings is a key element of the proposed Matrix methodology for Arctic and Subarctic applications. Environment-specific and general observations that are related to different extreme conditions (desert, mountains and other remote locations, and space) are identified in the summary for further examination. Appropriate to diverse environmental conditions, modifications and adjustments of the Matrix are discussed for future research prospects.

Abstracts and Synopses (Appendix), refers to papers produced during this doctoral research. There are two categories of publications used in this thesis: early papers published before the beginning of this PhD work which contributed to conceiving the research idea, and recent peer reviewed conference papers and publications that have arisen from this research. Early papers included in the bibliography are used in this monography as data and case studies sources, while the latter five papers from the Appendix are produced for presentation and discussion of thesis theory with professionals from multi-disciplinary backgrounds.

1.2 Used terminology

The terminology used in this thesis is from a perspective specific to the context of this research. Although some terms are common to many different fields and sub-disciplines, certain features and aspects specific to the subject of this thesis warrant specific explanation.

Aspects – parts or features of objects, events or systems that passively present some of their characteristics.

Boolean operators – connect and define relationships between certain terms. They can be used to either narrow or broaden data sets.

Correlation – correlations exist between variables when they are related to each other in a certain way.

Decision Based Design (DBD) – a method that attempts to foresee the process and possible results of actions based on available information, risks, rewards, objectives, and rational behavior (Olewnik and Lewis 2005). The structure of the DBD framework usually aligned to satisfy requirements for successful performance in design environments with risky, uncertain and insecure conditions (Wassenaar and Chen 2001).

Dependency – the quality characterized by something else's control or decisions.

Designerly approach – dealing with complex design problems characterized by many uncertainties, nevertheless following design structure, procedures, activities, systems and elements (Cross 1982).

Extreme environment – the definition is given and expanded in application to this research in the section 1.2.1. Important aspects of an extreme environment are weather conditions including temperature highest and lowest, humidity, and natural disaster potential. Other include dangerous and difficult terrain, remoteness, confined living conditions, and limitations in the life supporting resources.

Figures Of Merit (FOM) – a method to assess and compare selected parameters of research, project, or approach, based on their performance. In this research, it is used as figures of importance for qualitative comparisons of project aspects' qualities or performance.

Habitability – design quality with a focus on refining every aspect of design, equipment, gear, food, and interior environments while improving safety, living conditions and maximizing work performance.

Human factors – a general definition can be found in subchapter 4.1. Architectural understanding of human factors is more inclusive than in other disciplines because it considers physical conditions of a human body as well as its psychological status and health, and effects of surrounding to an individual and a/or a group. A comprehensive architectural approach includes understanding of consequences of inadequate and inappropriate design and planning solutions during project development that may lead to non-desirable or even catastrophic events.

Influences – abilities to affect something causing changes without forceful demand for them to occur.

Issues – important topics, points or problems, addressing of which determines a situation and its outcome.

Matrix – In this thesis, the Matrix is understood as a combination of systems where complex human issues are correlated with data sets of environmental aspects and design attributes. In addition, the Matrix is a visualization of variables involved in the design and planning processes in extreme conditions.

Matrix methodology – a planning *tool* or *means* for planning, building and managing activities in Polar regions. The closest reference to such an approach can be considered the Geographic Information System (GIS) logic. Discussion about applicability of the GIS as a reference can be found in the section 3.2.2 of the chapter 3.

Optimization – refining or making a design, system, or decision fully perfect, functional, or effective as much as possible.

Participatory design – in the relation to the research goals and based on retrospective reviews of the case studies, a participatory design idea reflected here refers to implementation and correlation of actions of all involved in design and especially planning processes in polar regions.

Permafrost – A frozen soil or bedrock layer. It can be continuously frozen for at least two years and up to thousands of years. Its depths can reach up to 1,524 m (4,999 ft) but the surface may be periodically thawing during the summer. Permafrost is found over most of the Polar Regions and underlies about one fifth of the Earth's land surface.

Project development – the act or process of construction or building structures, infrastructures, or facilities. That can include but are not limited to initial structures for beginning exploration work, growth towards production, deployment of services and operations to support work, science, tourism, etc.

Taxiway – roads or pathways where airplanes taxiing to and from runways and terminals or loading/offloading positions.

Transdisciplinary research – a research process when resources from multiple disciplines are connected and applied simultaneously for project problem solving process. Merritt Polk describes a 'transdisciplinary' concept as a combination of several different types of integrative research (Polk 2014), and includes values, knowledge, and expertise from non-academic sources as well.

Validation – recognizing, establishing, or illustrating the worthiness or acceptability of solutions, methods or actions.

Verification – establishing the truth, accuracy, or reality of a situation, event or system.

Wind tunnel – a tool used to research and study the effects of air moving past solid objects and behavior of structures in simulated wind conditions. A wind tunnel consists of a tube with the object under test mounted in the middle and the airflow is moved by powerful fan systems through the tube.

Winter over – time when people stay in polar locations while transportation to and from the mainland is not possible during winter season of 24-hour darkness.

1.3 Problems and conflicts in the Arctic and Subarctic

It is important to note that needs and priorities in extreme environments also represent some of the most pressing challenges and issues that face our entire planet. Increased difficulties and urgency in addressing human needs and requirements in extreme environments often motivate efforts to find new and better organizational, planning and design solutions. The complexity of the problem calls for a *transdisciplinary* approach that addresses multiple facets of human activities and sustainability. Useful program advancements related to the extreme environment of space, for example, include important contributions to fields associated with computing and information management, material sciences, energy technologies, sustainability, environmental monitoring and life sciences. However complying with sustainability principals is not necessarily an architectural requirement because applying those principals at every facet of development from transportation to a building envelope becomes not a goal but rather a method to achieve acceptable deliverables within a short timeframe and limited budget (Duhaime and Caron 2008).

The Arctic faces multiple regional and global challenges and problems. Accordingly, there is a need for fundamental evaluation of the current situation and establishment of an integrated organizational system with a comprehensive development strategy. For example, in the Russian Arctic neither a consistent nor a scientifically grounded approach has been offered; nor a methodology to create a regional development strategy has been conceived (Kozlov et al. 2015).

Arctic living conditions and the environment itself are changing rapidly. It therefore becomes essential to respond to that in design and planning just as fast (US National Research Council of the National Academies 2014). It is also critical for successful architectural and planning practices in extreme environments to be able to proceed with construction almost immediately after a decision to start exploration or other types of development are made and personnel and crew have to be moved to a remote location within a limited timeframe. Transportation windows and construction opportunities depend on a site’s location, season of the year and local weather patterns and conditions (Lempinen 2013). These new circumstances and problems related to them lay within environmental, social, technological and cultural boundaries.

Ecological, social, and political conditions in locations with extreme conditions are also very vulnerable to changes. Stability there, either related to human life or natural surroundings is fragile and requires exceptionally thoughtful planning of any new activities (Walker et al. 1987). Other factors present additional conditions and influences contributing to the environment being extreme for living. Those factors are discussed further in this thesis in chapters 4 and 5 and their subchapters that describe case studies.

1.3.1 Characteristics of extreme environments

Although the term "extreme environment" is used in the literature, there is no single definition of what extreme conditions are (Wingfield, Kelley and Angelier 2011). As defined by NASA Astrobiology Institute:

> *'Extreme' is a relative word. An extreme environment can be characterized by conditions that are far outside the boundaries in which we humans dwell comfortably in these categories: pH (measure of acidity), pressure, temperature, salinity, radiation, desiccation (measure of dryness), and oxygen level (NAI)*[3].

Typically, an extreme environment is understood as meteorologically challenged and described by its climate or weather conditions and therefore mostly defined by its geographical location. Nevertheless the definition should be broader than that when we take into consideration all aspects of human life and lifestyles.

Echoing NAI's description, "extreme environment" in Wikipedia is defined exclusively by extreme physical conditions (the definition is considered in this thesis due limited literature references for extreme environment characteristics and presentation of a popular understating of the term is important for this study):

> *An extreme environment exhibits extreme conditions which are challenging to most life forms. These may be extremely high or low ranges of temperature, radiation, pressure, acidity, alkalinity, air, water, salt, sugar, carbon dioxide, sulphur, petroleum and many others.*
>
> *An extreme environment is one place where humans generally do not live or could die there.*
>
> *Examples of extreme environments include the geographical poles, very dry deserts, volcanoes, deep ocean trenches, upper atmosphere, Mt Everest, outer space and other planets.*[4]

While these conditions can definitely be described as extreme and hazardous to human life, an environment may pose danger to people even without those factors being present. This includes social and political situations that lead to limitations in life support supplies, limitations in transportation, communications and different combinations of all or some of those factors together. That complexity is often overlooked in planning and design efforts, causing contributing factors to be ignored in an overall design process.

[3] http://nai.nasa.gov/ask-an-astrobiologist/answered/2001/10/29/24/

[4] https://en.wikipedia.org/wiki/Extreme_environment

What makes a place we visit or live "extreme"? This research suggests that it is an environment that poses special limitations and/or hardships for people to survive and maintain relative physical and psychological comfort. These limitations usually include:

- Resources
- Availability of services and spaces
- Mobility and transportation

Such limitations lead to hardships that may include all or some of the following:

- Strong restrictions to execute everyday work tasks
- Impossibility to perform social interactions
- Impossibility to fulfill necessary living needs

1.3.2 Extreme environments affecting Human Factors

Extreme environments on Earth and in space share many similar design and planning challenges involving facilities and operations. Each environment presents special lessons regarding housing design, crew/staff operations and training, including equipment and logistical requirements for human activities.

There are certain similarities between cold deserts, permafrost and other polar regions with respect to facilities and operations: low temperatures, foundation problems, high standards for insulation materials, and resource and workforce limitations. But they differ depending on local cultural and social traditions and climate challenges specific to a particular region (Nuttall 2005). Environmental hardships create structural and infrastructural challenges affecting all aspects of planning and design and therefore have to be addressed in architectural programming and requirements.

Hassan Fathy wrote in his book "Natural Energy and Vernacular Architecture" that any building or structure is affected by its surrounding environment and even though social, cultural, and economic aspects of the site location are important to consider, the shape of the building or structure is formed by environmental factors (Fathy 1986). That is also true for overall planning of the site, architectural and managerial programming, and even more so in extreme environmental conditions.

According to statistical research from Antarctic stations, a productivity factor of 2.16 was determined for construction work at South Pole stations. It means that time to accomplish construction work in such an extreme environment takes 2.16 times longer than under normal circumstances (Marty 2000). Even though productivity factors are not expected to be as low in the Arctic, such reductions in productivity may delay construction and have to be included in planning and design considerations. Additionally, the conditions displayed at the locations of the case studies projects, characterized by extreme low temperatures during the winter, transportation limitations and constraints, and cut-off days and months depending on weather conditions. It is important to take into consideration that over 50% of the projects' population is comprised of visiting scholars and researchers who are not adapted to the extreme conditions of the sites and therefore are more constrained by associated limitations and hardships.

1.4 Architectural assumptions and guidelines

There are two broad common values for architecture as a discipline. First, it suggests benefits to the client and some practical advantages and profits. Second, it is considered to deliver a design with the deliberate effect and results to provide the user/client with anticipated practical advantage. This may include all but not limited to: functionality of systems and interior arrangements, cost effectiveness and aesthetics. The final product – design of a habitat or other types of facilities cannot be considered as a successful experience if any one of these facets of architecture does not fulfill people's needs or expectations.

Architecture is transdisciplinary by its nature, and an architect's main role is to make sure all elements of the project receive an appropriate amount of attention and apply that knowledge to the design. An architect can be considered for example as "*an attending physician, who, through using the expertise of the physiologist, radiotherapist, or bacteriologist, is the only person who can actually undertake the treatment of a case*" (Fathy 1986). This means that an architect should be able to summarize multidisciplinary knowledge, experience, and expertise and apply it to the design process. That approach also involves incorporating sustainable ideas into the design. Sustainability becomes a more and more important factor in construction development everywhere in the world, but has to become a *critical* element for the success of designing and planning for extreme environments. The idea of sustainability can be applied practically to all aspects of human society, creating multiple facets of sustainability that include (Brundtland 1987):

- Ecological/environmental
- Economic
- Social
- Political

Essential conditions for sustainable development vary depending on regions, climate, and existing site settings. In combination with traditional building requirements, prerequisites for sustainability can be brought in to architectural practice under one of a few major sets of requirements including satisfaction of client's expectations, functional efficiency, enhancement of systems' effectiveness, and budget optimization.

Architectural clients and/or users belong to specific groups when designing in extreme environments: they live and work in such conditions mostly by choice: either the choice is economic or professional satisfaction (in the case of geographically remote locations); or they happened to live in an environment vulnerable to natural cataclysms. Although they are sometimes in different locations, "client" and "user" can be referring to the same person or group. In design and planning for remote areas and extreme conditions it is very often different groups of people. In the extreme environment of the Arctic and Subarctic regions, a "client" can be a corporation or scientific organization and a "user" – a group of workers or researchers doing jobs designated for those locations, or local communities who have to adjust to newcomers while preserving local cultural and social traditions and customs. That creates a significant and even dramatic difference between architectural practice for extreme and regular conditions. The client/user groups that I address in this research study belong to following categories:

- Local communities
- Exploration companies
- Production companies
- Researchers
- Logistics companies

In many cases populations of local communities are represented as “clients” and “users” at the same time. Those communities are also the most vulnerable to the changing conditions of Arctic regions (Hovelsrud et al. 2011). The Architectural task in this case is to identify problems they may be facing during interventions of “newcomers” and define practical solutions for their co-existence with new developments in their natural environment. Discussions about local communities’ involvement as a missing component of the Case Studies projects are presented in the subchapter 5.3.

Clients’ and users’ functions and relationships define their major activities and therefore influence design solutions and approaches. Extreme environmental conditions impose a special impact on performance of major activities by restricting many of them and significantly limiting others. These conditions also influence levels of operation and communication between the different groups of users, imposing either a specific to professional field hierarchy or other operational rules and procedures defined by safety requirements and other regulations; usually related to machinery or equipment that is used and administrative procedures that are also related to production and operations.

Major human activities specific to earlier described client and user groups can be categorized as follows (Bannova 2007, Bannova and Smith 2006):

- Living
- Exploration
- Scientific research
- Social activities
- Construction and assembly operations
- Support operations

Actions referring to these categories are not necessarily present at the same time and at the same location. Activities such as eating, sleeping, hygiene, exercising etc. referenced here as *living* activities. *Social* activities include all actions when people have to interact with each other on different levels and situations. Scientific research activities in the Arctic are very diverse and mostly identified with geological, atmospheric, chemical, climate, biological, sociological and ethnographical sciences.

Specifics of every “major” activity depend on the level of development, timeframe, available resources, social conditions etc. For example, the amount of human and technological resources required for exploration depends on the type of exploration, location or locations and availability of local supplies. Time required for achieving desired goals also demand planning for extra developments, including social and cultural events.

2 Literature Review and Research Boundary

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

There is a big history in Antarctic and Arctic exploration (Vaughan 1994, Kirwan 1960) but the operations and activities in the north and south are different. While Antarctica is protected by the Antarctic Treaties (Peterson 1988) with 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 (Duhaime and Caron 2008). Since this research focuses on a **methodological** approach to **planning** of diverse activities in Arctic and sub-Arctic regions, only building structure-related aspects of the Antarctic endeavors can be considered as reference material here (Muller 2010).

However, increased public interest in the Arctic in recent years triggered launching of several art and social programs and projects for the Arctic. They include initiatives by the Art Catalyst program in the UK[5] and Arctic Perspective Initiative[6] supported by the Culture Program of the European Union. These programs address social, political, architectural, and design issues in the Arctic and other extreme environments (Arns et al. 2010 Bravo and Triscott 2010). Yet, their architectural projects are mostly object-oriented design competitions and not realized in the real conditions of the Arctic. Large scale planning endeavors with transdisciplinary participation are still absent in the landscape of the Arctic, although more commercial and even military activities and population expansion are evident during the last decade.

2.1 Construction experience in Antarctica

Construction experience reviewed in this thesis refers to structural design in Antarctica due to different settings and goals of human activities in the Arctic and Antarctica. These distinctions caused by different geographical, political and social conditions that affect how planning is approached and handled in both regions (Anisimov et al. 2007).

Traditional techniques for construction in cold regions are not sufficient for polar environments because of the constant generation of snow deposit around buildings and anything else that is located on the surface and the notion of using elevated structures in polar environments is not a new idea. Numerous research stations in Antarctica were constructed after the first International Geophysical Year in 1957-58 (Buedeler 1957) and different types of structures have been tested

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[5] http://www.artscatalyst.org/
[6] http://Arcticperspective.org/

in Antarctica through the years. Elevated types of structures prove to be the most reliable and long-term operable in inland polar conditions and especially under severe snow drifting circumstances (Brooks 2000, Marty 2000). Stations such as the first elevated structure, Australian Casey Station, and following it, the German Filchner Station (later Kohnen Station), the Amundsen-Scott South Pole Station, and relatively recently the British Halley VI Research Station demonstrate the usefulness of raised structures compared with those on the surface. However, they also revealed important challenges (Figure 2.1). Still, William D. Brooks in his paper "The Rationale for Above-Surface Facilities" provides a review of the history of Antarctic exploration and describes advantages and disadvantages of such structures. Specifically, he emphasized that "*no matter how well snow drifting could be controlled, at some point the station would need to be raised*" (Brooks 2000). Brooks continues with an observation that all elevated structures would eventually either exceed their elevation limits or need reconstruction of support structures with new elevation capacities. Such understanding was taken into consideration during work on the Case Study I project. A proposal to add an adjustable to wind speed and direction apron structure below the main structure aimed to minimize negative drifting underneath and positive drifting behind the station structure. That would minimize the need for height adjusting operations from the snow surface and extend the life of the station in its initial configuration.

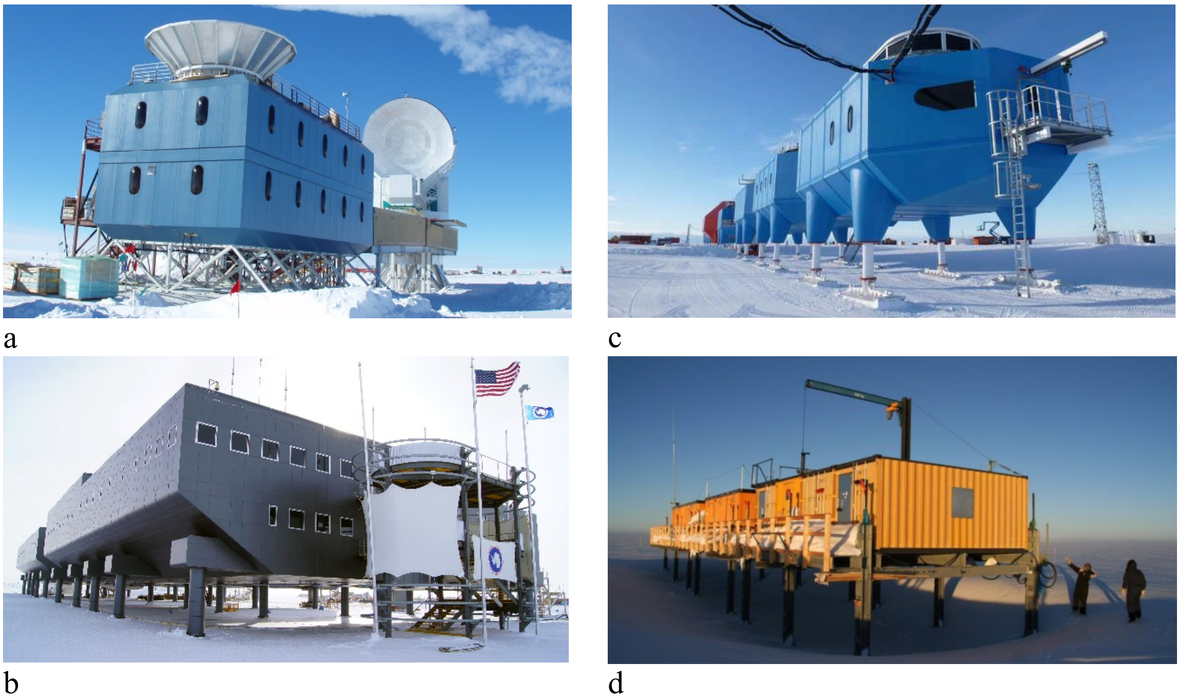


Figure 2.1 Antarctic Elevated Stations: a – the BICEP[7] and South Pole Telescopes building (Credit: Yuki Takahashi, NSF); b – Amundsen-Scott Station (Credit: Elaine Hood, NSF); c – Halley VI station (Credit: British Antarctic Survey); d – Kohnen station (Credit: Stein Tronstad, NPI).

[7] Background Image of Cosmic Extragalactic Polarization

Studies conducted for the modernized US Antarctic Amundsen-Scott South Pole station concluded that aerodynamic shapes do not minimize snowdrift issues and as a result the station was designed as a linear set of modular structures (Marty 2000, 2004) (Figure 2.2).

In private and semi-private dialogs with Jerry Marty, he mentioned several problems the structure faced, that include differential settlement of joint modules and weight distribution control. In addition, micro-vibration of supporting structures cause snow melting, which contributes to the differential settlement problem.

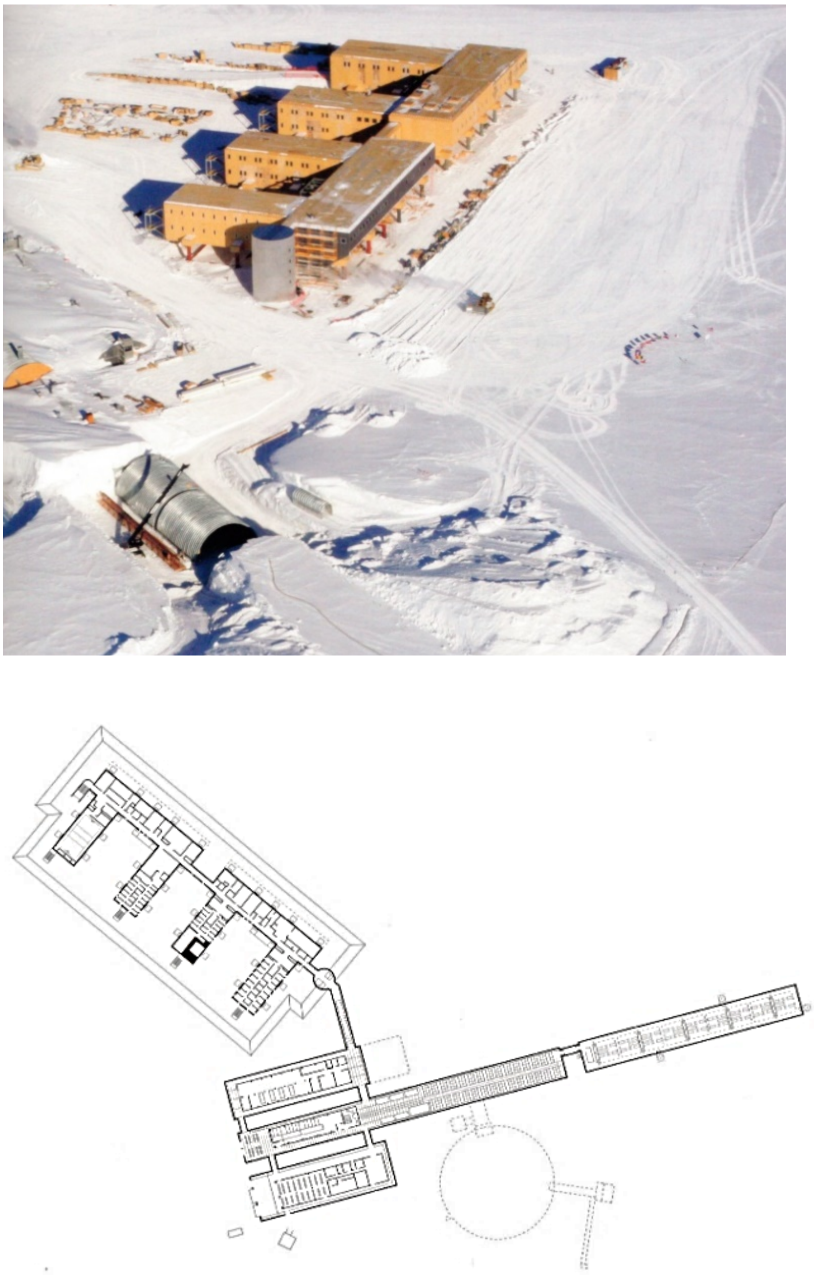
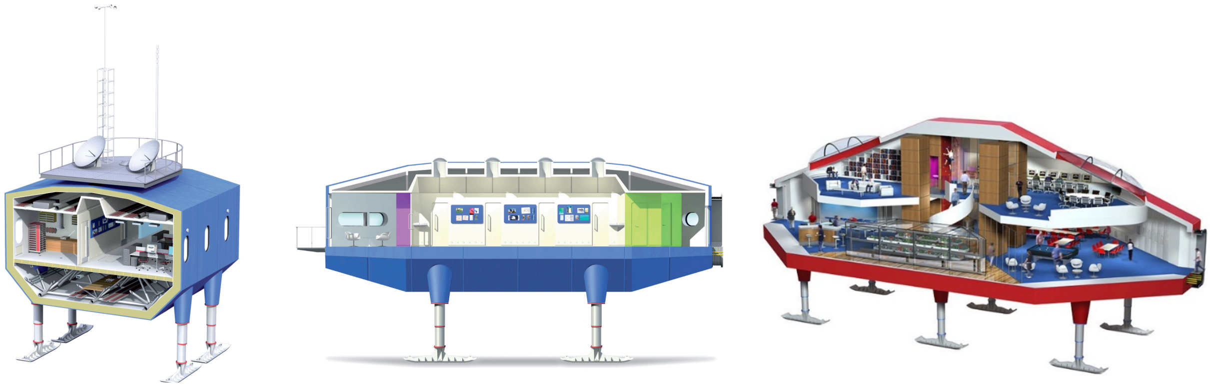


Figure 2.2 US Antarctic Amundsen-Scott South Pole Station aerial view and site plan (Slavid 2009).

Hugh Brougton’s design of the new UK Antarctic station Halley VI adopted a different approach where adjustable legs with skis support station modules (Howe and Sherwood 2009, Slavid 2009). Hugh Broughton paid close attention to interior arrangements of the station (Figure 2.3), as he says: “*One of the key reasons that we won (a design competition) was because of the interior design*” (Slavid 2009, p. 97). The setting of the station close to the shore requires its relocation once the ice sheet underneath it becomes unstable and incorporating skis in supporting legs allows relocating the whole station when needed. Such design still has its drawbacks as the station modules are very heavy and require major heavy pulling machinery on site is one of the issues (Figure 2.4).



Section through sleeping modules Section through common module

Figure 2.3 Interior views of Halley VI (UK) (Hugh Broughton Architects)

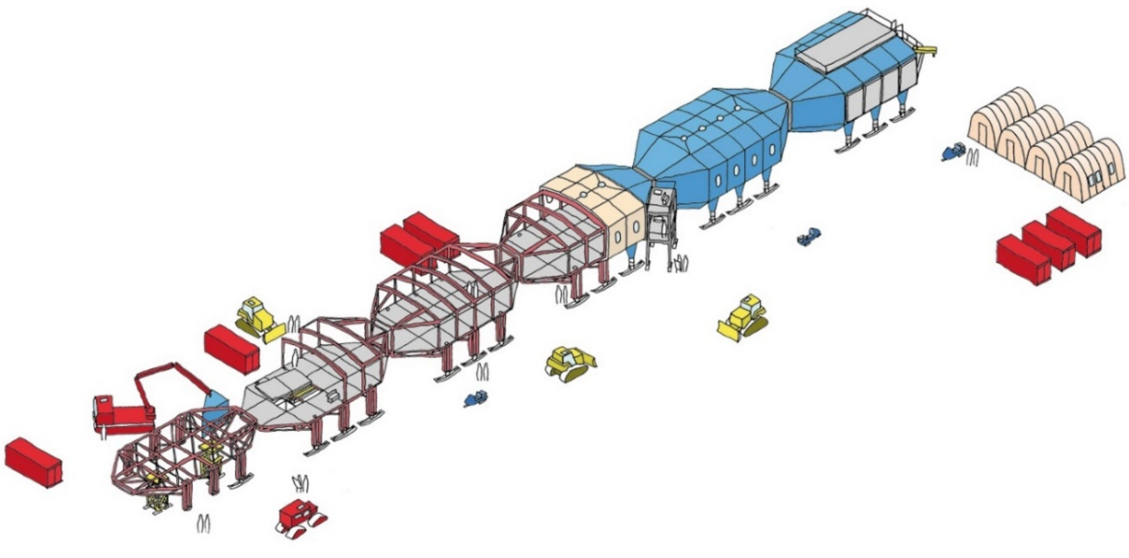


Figure 2.4 Halley VI (UK) configuration (Hugh Broughton Architects)

2.2 Arctic design precedents

Since the beginning of the 20th century, architects and designers have experimented with the design of climate-responsive buildings, utopian urbanism, and sometimes even military bases and complexes. Those projects were under impact of political, economic, and geographical decisions. With respect to historical precedents, British-Swedish architect Ralph Erskine's work in 1950s, -60s and -70s may come to mind although it was often not realized or only partially finished in the Arctic. A picture of his utopian design of an Arctic city on the cover of the Architectural Design magazine in 1977 (Figure 2.5) illustrates the philosophy of building in the Arctic focused on seasonal rhythms of the north (Muller 2010).

Although Erskine talked about his approach as focused on people, local populations were not reflected much in his Arctic designs. For example, his project for the Resolute Bay in Canada ignores knowledge of local indigenous populations; creating "new" indigenous architecture very much reflecting the colonial style of intruders of new territories. Of course, it was led by the Canadian state proposed approach of relocating local populations to satisfy economic or social ideas at that time (Marcus 2011). The design proposed an inhabited horseshoe-shaped wall structure, slightly raised above the permafrost on supporting legs. The wall encircled houses in the center for the relocated Inuit community from the shore. Non-indigenous city population was supposed to live in apartments within the wall structure reflecting a colonial approach to urban and social organization (Jull and Cho 2015). From an urban planning perspective, the design ignored local knowledge of living in the area: the walls prevented a wind flow through the city creating a positive snowdrift problem around the walls and in the center of the city; the city was moved further from the shore creating additional logistic and transportation issues and problems for Inuit traditional hunting. As a result, the project was abandoned and deserted in 1978.

Figure 2.5 Resolute Bay city in Canada, cover image of the AD 11-12 (1977).

Therefore, Erskine's Resolute Bay design did not present strategic or a methodological approach to planning in the Arctic but rather a list of the few points in his opinion to follow in architectural design for the North. These points include protection from the environment, following weather year cycles, and focusing on people, although the last one can be argued in case of the Resolute Bay project as it resulted in segregation of the local population.

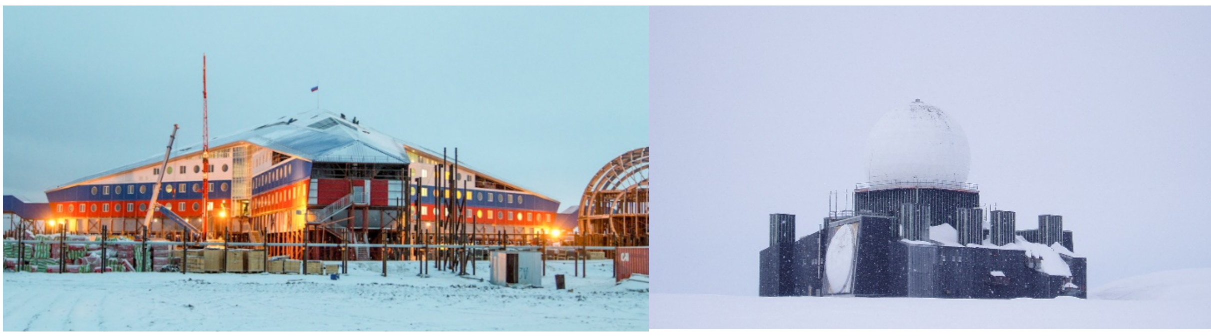
2.3 Contemporary design in the Arctic

To acknowledge Arctic projects that are under construction right now, a Russian military base Arctic Shamrock on Kotelnyi Island is investigated. It is especially interesting to review it in correlation to the abandoned US military base DYE-2 in Greenland (Figure 2.6).

According to publications in Russian newspaper "Krasnaya Zvezda" (Red Star) in 2014-2016, the "Northern Clover" military and radar station project began in 2014 and completed in 2015, another similar project "Arkticheskii Trilistnik" (Arctic Shamrock) on Alexandra Land island of Franz-Josef Land Archipelago is under construction and planned for completion later in 2016 (Figure 2.7).

Both Russian projects are modifications of a new standardized design developed especially for military formations in the Arctic (Figure 2.8) with autonomous diesel power generators.

The project utilizes a modular approach that provides complete isolation from the surrounding environment habitation. Modularity is an expected approach to building in remote locations although the scale of elements and modules themselves depend on available transportation means, workforce and machinery. Complete isolation from the environment also is a common approach to building in the Arctic, especially facilities for military operations due to security requirements.



a b

Figure 2.6 a – Russian military base "Severnyi Klever" (Northern Clover) on Kotelnyi Island of Novosibirsk Archipelago under construction in 2015 (Credit: Russian Federation Defense Ministry Multimedia Center[8]); b – The US military abandoned radar station DYE-2 in Greenland photographed in 2005.

[8] http://мультимедиа.минобороны.рф/multimedia/photo/gallery.htm?id=25668@cmsPhotoGallery

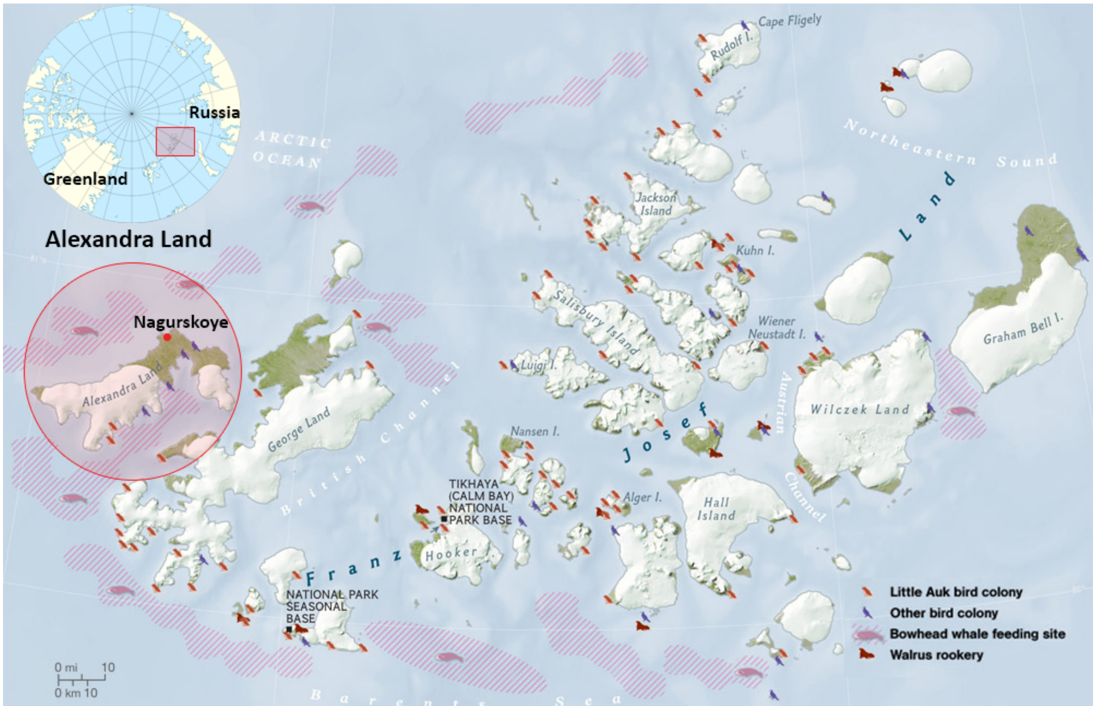


Figure 2.7 Franz-Josef Land biodiversity map and location of the Arctic Shamrock on Alexandra Land island (Modified from the source: National Geographic online[9]).

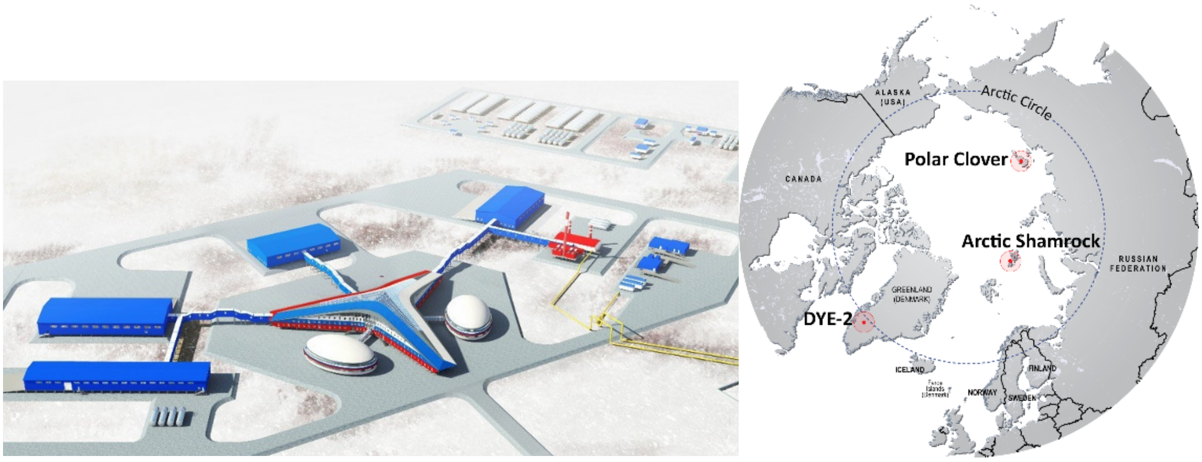


Figure 2.8 Russian Arctic base standardized design (Source: Spezstroi in the Arctic[10]) and locations of bases: DYE-2 (USA), Northern Clover and Arctic Shamrock (Russian Federation).

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[9] http://ngm.nationalgeographic.com/2014/08/franz-josef-land/archipelago-map
[10] http://www.sdelanounas.ru

2.4 Research gap

In fact, not much has changed during the last fifty years. A good example is the US DYE-2 military radar station, which was part of the Distant Early Warning (DEW) Line in the Arctic that consisted of eight radar sites across North America, Greenland, and Iceland. First stations were built in the late 1950^{s}, and after operating for 30 years, the stations were abandoned in the late 1980^{s}-early 90^{s} when radar systems became obsolete, the DYE-2 station was deserted in 1988 (Walsh and Ueda 1998). The same military approach of ignoring the environment and biodiversity needs, access to budget abundance, and concentrating on maximum isolation and obliviousness to natural settings – characterizes military developments then and now. Since this research aims to investigate possible methodological approaches to planning construction operations in the Arctic, the architectural and structural features of DYE-2 and Polar Star do not need examination. On the other hand, approaches planned for those facilities to be developed, present a certain interest for this study (Table 2.1).

In table 2.1 three major systems presented in relation to DYE-2 in Greenland and Arctic Shamrock on Alexandra Land Island are: environmental challenges, pre-existing conditions and issues, and project approach descriptions. The reason for comparison using those three systems lays in analyzing if two military projects offer some insights into planning approaches that can be useful for this research. The magnitude of both projects and difference in time when projects were constructed present a remarkable perspective on their planning and development approaches. Interestingly, in spite of political, cultural, technological, and time differences, military-related activities have been performed in a similar way.

	DYE-2 (built in 1958-1960)	Arctic Shamrock (2016)
Environmental conditions and challenges	Arctic polar desert with average T° -30C°, located at 66° 29′ North 46° 17′ West. Snow and ice surface.	Arctic polar desert with average T° -40C°, located at 80° North, Alexandra Land of Franz-Josef Archipelago. Snow, ice and permafrost.
Pre-existing conditions and issues	Infrastructure did not exist; Kangerlussuaq is the closest town and the US airfare base. Transportation is available with LC-130 Hercules airplanes.	Old soviet air force base Nagurskoye is in close proximity, most logistics delivered by ships year around.
Project approach description	Multipurpose building utilized 8 extensible columns (in 20 years the building was lifted over 22.8 m above its original height). Diesel power supply (Walsh and Ueda 1998).	5-story building on pillars with three “leaves” connected to the main core atrium with observation deck on top. Close-loop operations provide total personnel isolation from environment during winter. Diesel power supply.

Table 2.1 Comparison of the US DYE-2 and RU Arctic Shamrock military bases in the Arctic.

Other operations actively expanding in Arctic and Subarctic regions include commercial initiatives and scientific research outposts. Corporate businesses who are dealing with large-scale developments in the Arctic and remote locations are mostly energy or other natural resources companies who are interested in exploration and production with return of investment in the shortest possible timeframe and with maximum profit. That very often means that they cut corners in planning and pre-deployment work, which at the least leads to shortages in accommodations and support for their own working forces before and during operations. In the long-term, such an approach jeopardizes ex-post development recovery.

Science foundations and researchers with support of logistics companies manage scientific research in extreme environments in a similar way as energy companies run exploration and production there. Similarly, scientists and support crews are also interested in fast deployment of their personnel and timely return of investment in the form of research outcome while maximally optimizing budgetary resources for research support. Transportation and logistics challenges they are facing are also the same and have to comply with local authorities and regulations.

Similarities in needs and requirements of development and operational approaches instigate mapping them in regard to their essence, probability to succeed in achieving goals and objectives, reflections on other involved parties and components, and time allocation. That *mapping* results in identifying the most efficient ways for design and planning tactics and for facilitating a dialog between all participants. In conclusion, those approaches perceive goals that are opposite from these research objectives: planning, designing and constructing everything "in-house" with controlled or avoided (military bases) local social and cultural involvement, interdisciplinary knowledge exchange, and openness to failure and reclamation.

2.5 Research issue and research questions

Despite the fact that there are federal laws, standards and regulations generated by companies, local authorities, developers and other businesses; they are disconnected at many levels and usually have different objectives. This consequently leads to unbalanced design and planning resulting in failure in one or several areas of development (J. Bell, 2014). These problems are also critical for creating sustainable environmental and social systems (Sachs 2015, Rasmussen 1999). In extreme environments, social systems and their subsystems are much more vulnerable and sensitive to changing conditions, such as cultural, political, ecological, technological, and societal (Rasmussen 1999). A malfunction in one of these subsystems may very easily make the whole system dysfunctional and handicapped (Nuttall 2005). Miscommunications or even absence of communication between diverse professions involved in developments in the extreme environment of Northern Polar Regions leads to critical mistakes and may result in vast environmental, time and money losses (Rasmussen 1999).

Efforts in fixing or solving improperly addressed problems later in the development process are very costly, time consuming and sometimes too late to be corrected (Reason 2000). Creating a logical path for planning and maintaining activities in extreme conditions seems to be a vital necessity in pursuit of sustainability in the Arctic. The study presented in this thesis is based on identifying aspects or elements of the proposed model as well as understanding why they are connected. This is important for building a dialogue model for local communities, engineers, and individuals that will serve as a design and development planning methodology.

An ultimate goal of any design process depends on successful identification of a design research problem, which always lies in finding a proper *"translation from individual, organizational and social needs to physical artifacts"* (Hillier and Leaman 1976). My motivation comes from an observation made during presentations and discussions at different engineering oriented conferences and from my experience of working with space grants and projects together with astronauts, aerospace engineers and managers. There were many occasions of complete obliviousness to the fact that any type of planning project has to deal with *all* components of the whole planning process at *every* stage of it. Professional engineers aim to bring their product to perfection, but often without reference to different aspects and elements or other parties contributing to the design requirements, execution, maintenance of the final product and overall user perspective. Such an approach contributes to the development of planning and maintenance problems that are heavily dependent on technology fields.

Other contributing factors to the research issue in the Arctic are related to a mismatch between existing infrastructures, terrain conditions, population and required resources for sustainable Arctic operations including fossil fuel exploration and production. The map of existing and potential energy resources in the Arctic and permafrost conditions in the Northern hemisphere (Figure 2.9) shows the reasoning for exploration and production continuing to expand there and as a result of it, all spheres of life and environment will be affected (Nielsen 1999, Klett 2011). The Arctic oil assessment and permafrost combined map demonstrates zones where exploration and production has already been done, going on right now, or most likely to happen in the relatively near future (Long et al. 2008). Many of these locations are in areas with conditions from continuous to isolated permafrost where infrastructure and structural developments are very constrained. These challenges combined with transportation limitations and stringent delivery windows create a complex planning and programming task for management and supporting companies.

Permafrost conditions in the northern hemisphere vary from continuous (90 to 100% area covered) in northern Arctic to isolated and sporadic towards the south in Subarctic and boreal regions. Those zones contain a limited amount of fragmented permafrost usually from 10 to 50% of the area. Changes in permafrost conditions affect infrastructures in Polar Regions and sometimes benefit economic conditions while putting the environment and cultural and social stability at risk (Hovelsrud, Poppel, Van Oort, and Reist 2011).

The maps in figures 2.10 and 2.11 display common marine activities paths and population density in the Arctic region. Marine activities include fisheries, research zones, Northern sea route and Northwest Passage (Figure 2.10). Tourist activities take place within Northern route and Northwest Passage. The map depicts a busy activity zone that has to have stable supplies from onshore especially in areas where infrastructure does not exist and population density is low (Figure 2.11).

These diagrams evidently show a lack of population in Arctic regions in northern countries where the largest oil and gas potentials have been recently discovered. Research, tourism, and fishing activities continue to grow. Canada, United States, Norway and Russia (Spencer, Embry, Gautier, Stoupakova and Sorensen 2011, Klett 2011) – all will face logistics and maintenance challenges when moving their massive equipment, large numbers of workers and supporting crews and developing necessary temporary and permanent infrastructures within stringent timeframes of short transportation windows. Developments in the energy industry, expansions of marine, tourism and research activities require substantial workforce and technology involvement as well as advanced infrastructures, transportation and logistic support. Importance of maintaining ecological and environmental stability as well as responding to local communities' cultural and social needs can be reached only through joint efforts and active dialogue between all parties and players involved (Nuttall 2005).

This thesis research goes beyond research questions of the Licentiate research and leads to understanding the driving forces of existing and emerging problems in extreme environments, specifically in the Arctic and Subarctic regions with concentration on human-related design and planning aspects of those problems. That understanding yields the methodology of the Matrix.

On the way to achieving this goal, several research questions require answers:

- Q 1. How the construction projects and other developments in extreme environments have been planned and managed up-to-now?
- Q 2. Are the current planning procedures and approaches effective enough in the Arctic?
- Q 3. What was missing during conducting Case Studies projects and what are the consequences? What approach can improve the situation?
- Q 4. How to organize a new methodology (Matrix) and validate it?

Development of a methodology Matrix for planning in Arctic and sub-Arctic conditions achieved through the investigative process of answering these questions in a systematic way and accommodating multidisciplinary aspects of design and planning processes. Research presented in this thesis has resulted in proposing a Matrix methodology that identifies planning issues challenged by Arctic environmental difficulties and remoteness.

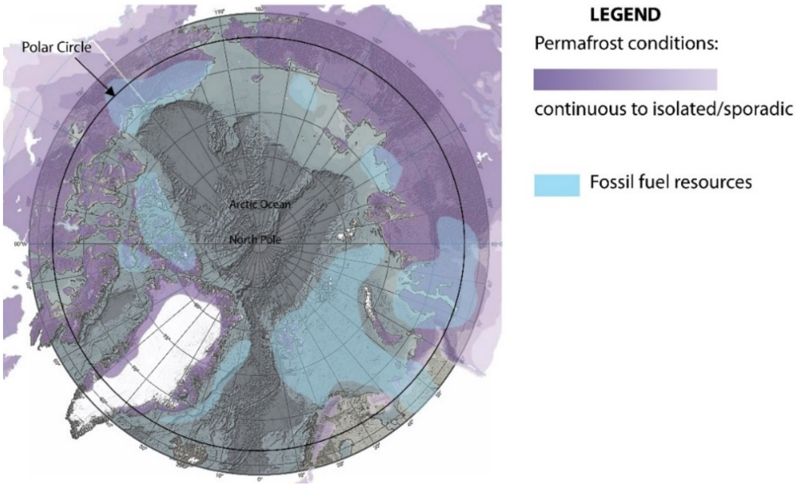

Figure 2.9 Resources and permafrost in the Arctic. Adapted from: UNEP/GRID-Arendal (Rekacewicz 2005); Durham University, The Arctic Institute (Bidder et al. 2012)

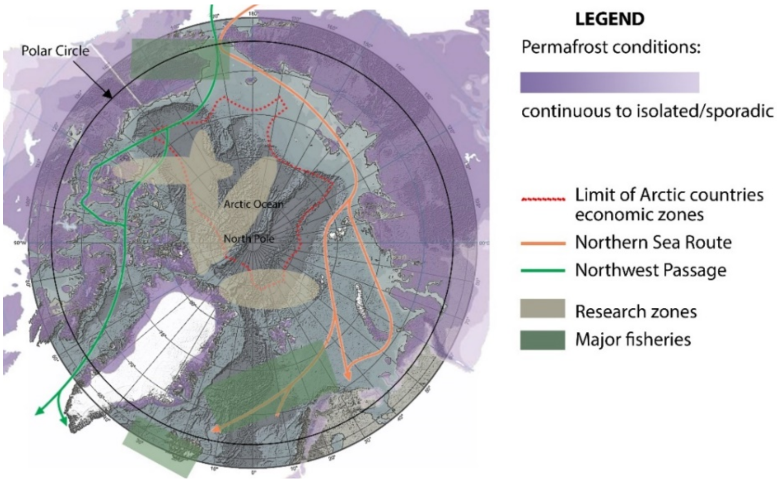

Figure 2.10 Permafrost conditions and marine activity in Arctic. Adapted from: Nordregio 2011, J. Sterling; UNEP/GRID-Arendal (Rekacewicz 2005).

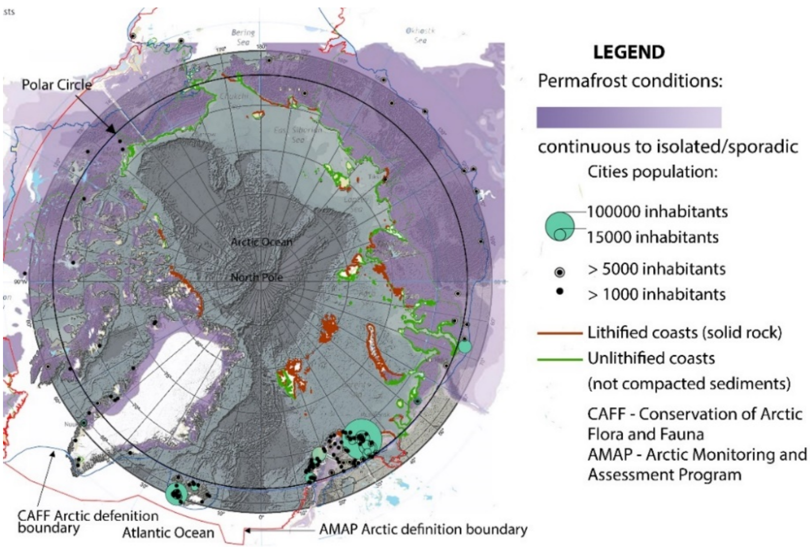

Figure 2.11 Permafrost conditions and population. Adapted from: AWI (Alfred-Wegener-Institute 2011); UNEP/GRID-Arendal (Rekacewicz 2005)

3 Research Design

This chapter presents and discusses the research strategy applied in this thesis, including case study methodology, systems analysis, and validation methods and systems. This chapter with subchapters aims to develop a means to find out on what principles a design and planning methodology can be based upon. The flowchart in figure 3.1 follows the logic of the research design and its position within the thesis in relation to other parts of this thesis work.

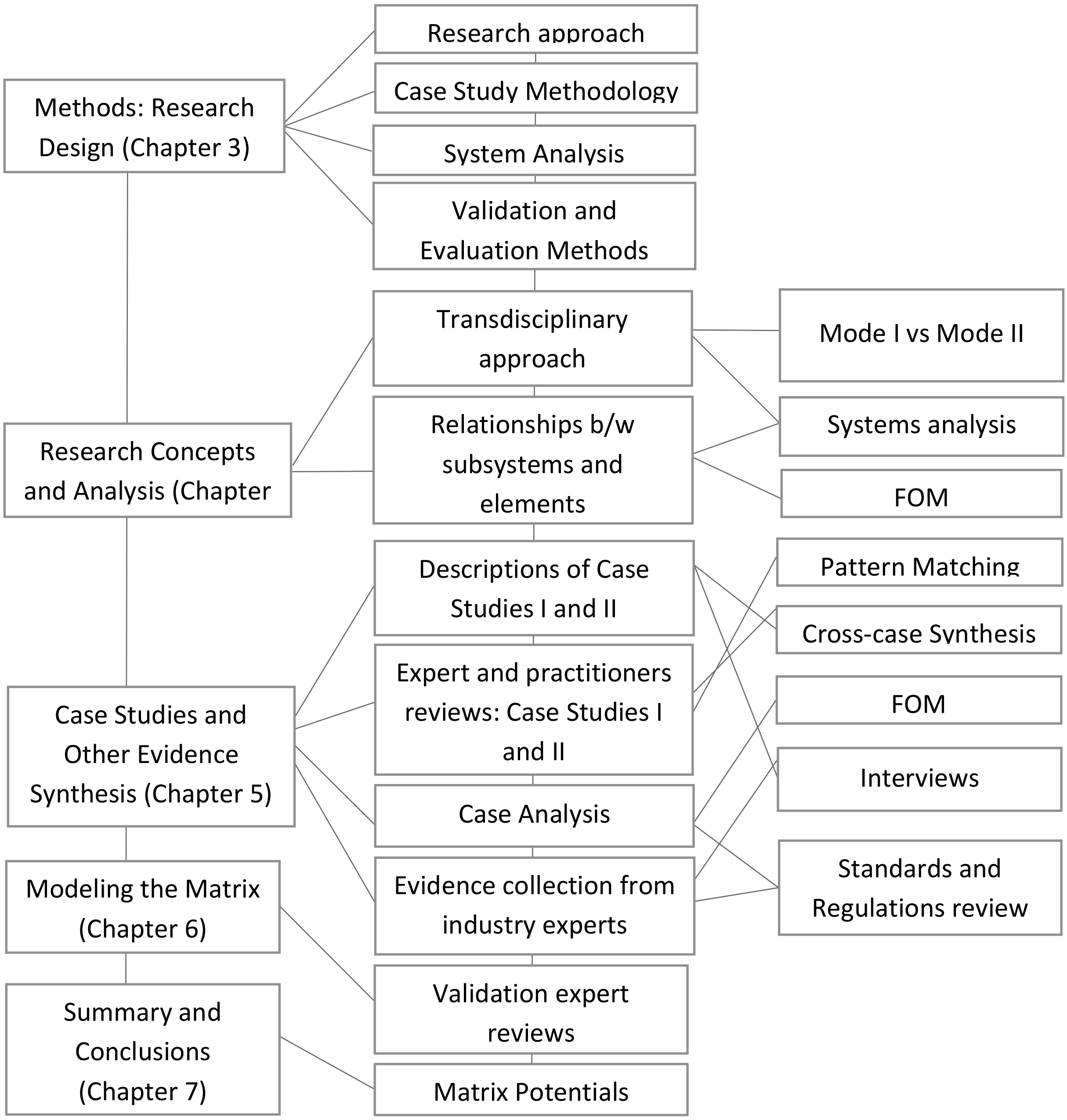

Figure 3.1 Thesis research process.

Design and environmental design research is a complex process and requires well planned transdisciplinary preparation work including non-traditional design-related disciplines such as climatology, meteorology, technology, etc. Therefore, this kind of research suggests the widest variety of approaches in order to avoid the tendency "*to ignore a number of issues of major human importance"* (Bender and Parman 1984, 63).

My research was partially conducted working on projects that are used as case studies in this thesis, and applied here as an important background or *"a kind of cultural exposure that … remains a useful part of* (this work) *background"* (Bender and Parman 1984, 63). The case studies I and II projects (Greenland Summit Science Station and Muraviovka Park for Sustainable Land Use) illustrate and support the importance of the application of interdisciplinary and transdisciplinary approaches throughout all stages of the design and planning research.

Mono-disciplinary and transdisciplinary approaches are two platforms of knowledge production that are referred to as Mode 1 and Mode 2 of the balanced research process (Gibbons et al. 1994, Nystrom 2002). While Mode 1 methods can be used for collecting scientific and quantitative evidence (mono-disciplinary), they can also be used as verification methods for concepts and theories developed in Mode 2 (transdisciplinary) (Dunin-Woyseth and Nilsson 2011, Nystrom 2002, International Council for Science 2005). Both modes are necessary for development of a balanced research process and knowledge accumulation.

Mono-disciplinary research that is referred to in this work is centered on collecting information from disciplines, experts, and resources used by them. Transdisciplinary design research used in this thesis synthesizes information gathered from research disciplines and professional practices and specialists. The latter needs to be included in case studies design processes but was not implemented during the work on projects.

Application of the Figures Of Merit is used to compare and categorize aspects of the case studies projects used in this thesis. Sets of Figures Of Merit for design considerations and comparison tables is an effective methodology for analysis of efficiency and other qualities of all design aspects and for every stage of design and planning projects developments (Bell and Bannova 2011).

3.1 Research approach

The main goal of research is creating new knowledge through the collection of scientific evidence that can be gathered using two approaches: "positivist and naturalistic" (Gillham 2010). The positivist approach emphasizes experimental methods, quantitative data, detachment and objectivity, and constructing evidence. The second focuses on non-experimental methods, qualitative data, subjectivity and participation, and searching for evidence in context (Gillham 2010). Quantitative methods are those that include counting and measuring, followed by description and interpretation of collected data. Qualitative methods although very often seen as 'soft' data, focus on types of evidence and can identify essential issues and help to find possible explanations of a problem. In view of the fact that this work focuses on the process of planning construction and infrastructure work in harsh conditions of the Arctic and Subarctic remoteness and based on retrospective analysis of design case studies, the research is built upon non-experimental methods and qualitative data collection. The data includes evidence brought from personal experience and observations, interviews and reviews gathered from professionals and experts from the fields within the research framework.

There are six sources of evidence that are discussed by Robert Yin in his “Case study research: design and methods”: documentation, archival records, interviews, direct observations, participant-observation, and physical artifacts (Yin 2009). Three of them are used in this thesis (all three sources of evidence include research conducted before and during this PhD studies): direct observations driven by personal experience, structured and open-ended interviews with groups and individuals from case studies perspectives, and participant-observation (Figure 3.2). For the purpose of maintaining objectiveness during categorization of design aspects by their importance level, it is necessary to take into consideration that participant-observation data were collected within the operational and situational context. Viewing the case *“from the inside out”* (Gillham 2010).

Even the idea of creating a *design methodology* has been heavily criticized and discussed since the 1960s (Cross 1982) although it has been more accepted by the architectural community since then. Design theorists have been exploring characteristics and differences between science and design approaches since earlier days (Alexander 1964, 130). Alexander in his “Notes on the Synthesis of Form” compares:

> *Scientists try to identify components of existing structures; designers try to shape the components of new structures (1964, p.130).*

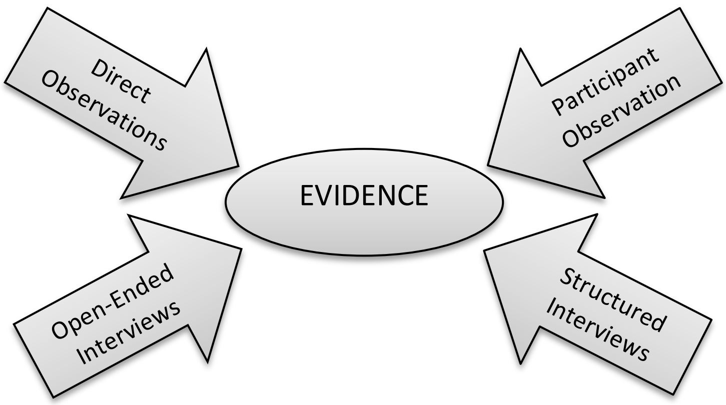

Figure 3.2 Convergence of multiple sources of evidence used in the thesis.

In his “Designerly ways of knowing” Nigel Cross compares scientific, humanistic and designer problem solving approaches (Cross 1982).This is especially interesting and helpful for identification of cross-disciplinary areas within architecture, engineering, social, and psychological studies. In discussion of Lawson’s studies of design behavior (Lawson 1979) he concludes that:

> *... experiments suggest that scientists problem-solve by analysis, whereas designers problem-solve by synthesis (Cross, 1982, p.23).*

Nigel Cross notes that even though design methodology originates from scientific methods, they should not be mistaken, one with the other (Cross 1993).

3.2 Case Study methodology

A case study methodology intends to answer research questions through the collection of a range of different kinds of evidence. Application of multiple sources of evidence is a major characteristic of case study research (Gillham 2010). Case study can be understood and defined in multiple ways and according to Gillham it is:

- A unit of human activity embedded in the real world
- It can only be studied or understood in context
- It exists in the here and now
- It merges in with its context so that precise boundaries are difficult to draw (Gillham 2010).

There are three case studies’ types commonly used in research: *explanatory, descriptive,* and *exploratory*. All of them deal with scientific evidence and can have quantitative or qualitative dimensions. Because the data available for collection in Case Study research are usually not precisely measured and may be partially subjective, application of multiple sources of evidence is necessary for better understanding of the research problem and theory argumentation. Case studies types are distinguished by conditions and consist of: a form of research questions, the level of control over behavioral events, and the level of focus on contemporary events (Yin 2009). The *exploratory* component of case studies was mostly addressed in my licentiate research, answering questions such as: What are the major influencing aspects of development processes in the extreme environment of Northern Polar Regions? In what aspects they are related to each other and what is missing in those connections? Therefore, in continuation of the research process a combination of *descriptive* and *explanatory* components of Case Studies is used in this thesis.

First, a *descriptive* research component is extracted from design cases and evidence collected from interviews and interactions. The *explanatory* component of Case Studies design follows a descriptive stage and supports argumentation in the thesis for the proposed approach to answering “How” and “Why” research questions (Yin 2009). Applied analytical strategies include:

1. Relying on theoretical propositions
2. Developing a case description
3. Using qualitative data
4. Examining competing explanations.

Case Studies analytical techniques

Because this doctoral work is based on prior personal experience in working on design and planning projects for extreme environments, developing a case description is the most applicable and valid research strategy. Along with the general research strategies, this thesis research uses specific analytical techniques selected from five major Case Studies analytical techniques (Yin 2009):

1. Pattern matching
2. Cross-case synthesis
3. Explanation building
4. Time-series analysis
5. Logic models.

Since this research builds on understanding what aspects of design need to be incorporated into a new methodology, *Pattern Matching and Cross-Case Analysis* are two of the most appropriate techniques (Figure 3.3) to analyze the case studies projects. The goal of using the pattern matching technique is to strengthen patterns' internal validity by identifying what patterns correspond with each other and when and how it occurs. I compared design and planning patterns of case studies presented in this thesis at elemental levels as well as at the system level when applied to the design and planning processes. Pattern matching is also applicable for verbal data analysis that includes structured and semi-structured questionnaires and interviews, and natural conversations used to ask research questions. In addition and in parallel to pattern matching analysis, cross-case synthesis needs to be applied to the collected data in order to summarize the outcome of all types of evidence.

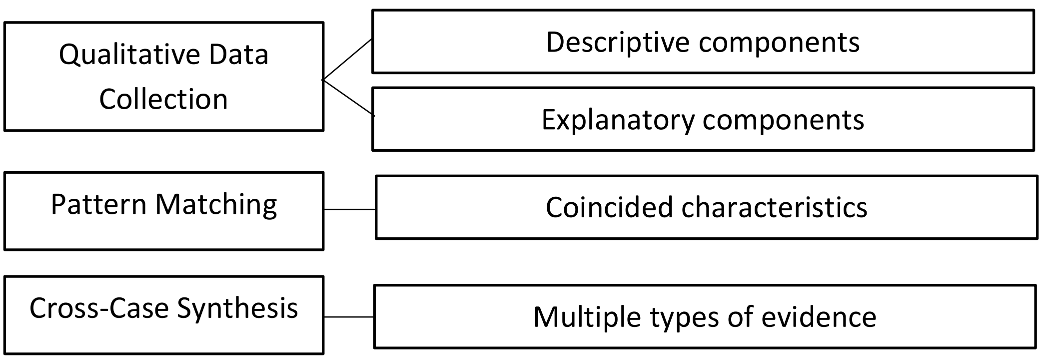

Figure 3.3 Thesis research methods for data collection and analysis.

1. *Pattern Matching* logic establishes relationships between empirically based patterns with a suggested (or predicted) model (Yin 2009). This approach is applicable for two types of case studies used in this doctoral work: descriptive and explanatory with use of competing explanations and/or independent variables as patterns. In the case of explanatory Case Study, dependent variables are used as a pattern while in the descriptive case study; the projected pattern of specific variables has to be defined before data collection (Figure 3.4).

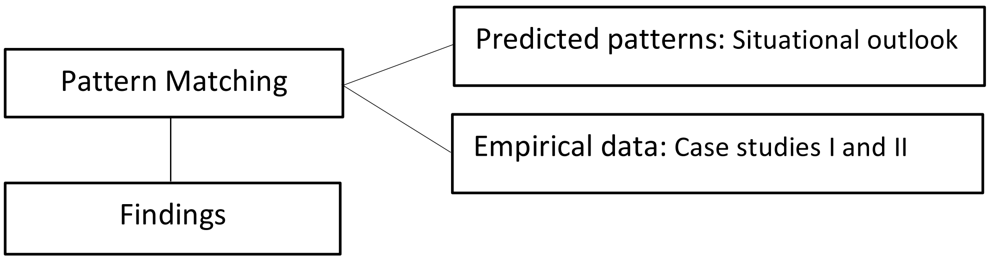

Figure 3.4 Pattern matching analytical technique application process.

2. *Cross-case Synthesis* analytical technique is useful when at least two case studies are investigated. This technique can be applied to the whole study or to parts of it together with other cases (Yin 2009). That characteristic of Cross-case Synthesis technique makes it an appropriate analytical method approach for my doctoral studies. It requires creation of word tables with reflection of processes and outcomes that have to be examined and compared in a similar way (Figure 3.5). Data collected from interviews and questionnaires are analyzed and synthesized using this technique qualitatively. Interviews are helpful when a relatively small group of respondents is used, they are accessible, and questions are mostly "open" and require extended answers. In my work, interviews are useful as a follow up to questionnaires both *anonymous and unique* – qualities required for data collection from such type of evidence according to Gillham (2000, 2007).

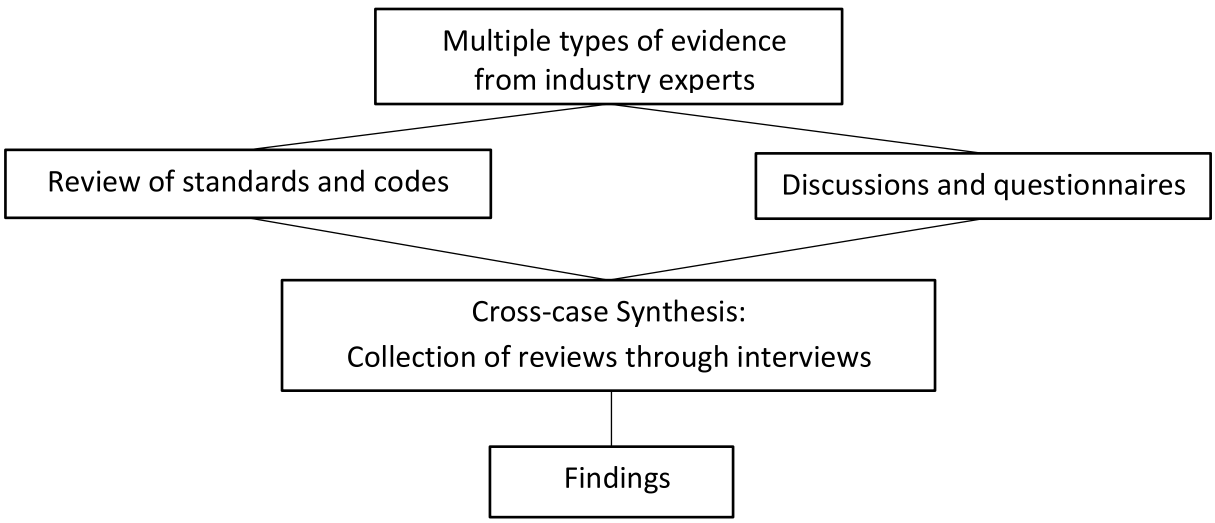

Figure 3.5 Cross-case synthesis technique application process.

The remaining three analyticial techniques are not valid for application in this thesis case studies analysis due to the following reasons:

3. *Explanation building (Yin 2009)* approach is similar to pattern matching and can be considered being a special type of pattern matching. However, I do not apply it in this research due to its requirement of having a continuous series of cases while I use case studies built upon already conducted projects.

4. *Time-series analysis (Yin 2009)* technique is directly related to conducting experiments and comparisons between empirical and theoretical data, and therefore is not applicable to this research as it deals with existing situations in design and planning for extreme environments.

5. *Logic models (Yin 2009)* should be defined before data collection and therefore this technique cannot be applied in this research since the data have been already observed and used for the main concept generating.

3.3 Systems analysis

A system is as a group of elements that are interacting with each other in order to achieve particular common goals and to make the overall functionality better than the result of each element acting individually (Chang 2011, Von Bertalanffy, General System Theory: Foundations, Development, Applications 1969). Each system has its boundaries that separate it from the surrounding environment. Elements or aspects inside the system are its basic components and if two or more of them have relationships, they can be combined in sets based on the character of those relationships and become a subsystem of the main system (Figure 3.6).

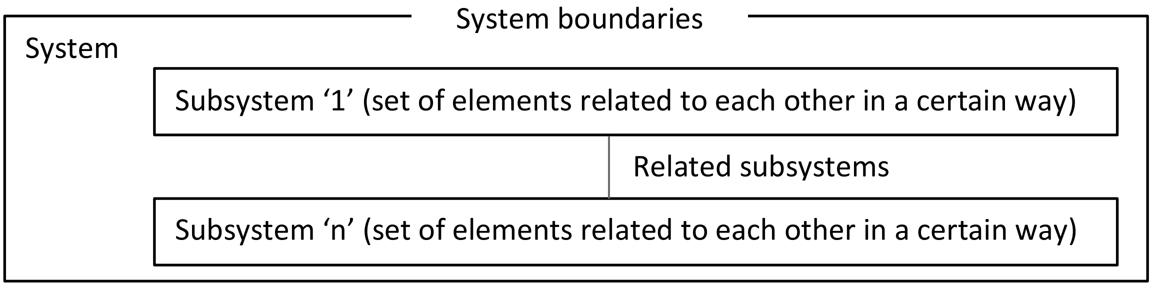

Figure 3.6 System definition modified from (Chang 2011).

The description of a system as a whole leads to the three most important common characteristics that are present in all systems: *organization, generalization, and integration* (Chang 2011, Sage and Cuppan 2001). Maier and Rechtin (2002) support Chang's definition and add: *"systems are collections of different things which together produce results unachievable by the elements alone (p.4)".* Chang summarizes some characteristics of systems as following:

- All systems have some structures or organizations.
- They all function in some way.
- There are functional as well as structural relationships between the units.
- Function implies the flow and transfer of resources, materials, or information.
- Function requires the presence of some driving force.
- A subsystem or system could own several elements that possess different attributes or an aggregation of different attributes.
- System elements or subsystems could range from higher or lower levels of hierarchy.
- A system or subsystem could have several elements.
- All systems or subsystems show some degree of integration or aggregation.

Some of those factors are well recognized within environmental and technological boundaries of the Arctic. Those factors include technological challenges and insecurity, geopolitical unpredictability, environmental risks, public concerns of risks and costs, and uncertainties or lack of budget and political support (Harrison, Clearwater and McKay 1990). Architects have dealt with some of those complexities before "*… but the principles of systems extended the scope to more disciplines and technologies"* (E. Rechtin 1991) that are involved in design and planning processes in the extreme environment of Arctic and Subarctic conditions.

There are common drivers that make a living or built environment more complex in any conditions: either they are remote, urban, or rural. As Moavenzadeh describes (cited in Atun 2014, p. 52) five drivers contributing to levels of complexity of cities: *''population growth, economic growth, increased urbanization, increased dependence on infrastructure, and increased role of technology in society''*, all of those factors are present in any environment but at different levels. With growing infrastructures and job markets that contribute to overall economic growth of the region, the attractiveness of the particular location increases and as a result, causes population, industrial, and living systems' complexity growth (Atun 2014, Berry 1964). The same characteristics of complexity of system growth are present in extreme environments, including Arctic and Subarctic regions.

In order to function as a complete, independent and sustainable system, it has to have at least four characteristics (Chang 2011):

1. *Uniqueness:* elements of the system have individual roles and act together performing integrated operations. All subsystems and their elements involved in architectural and engineering planning in extremes of Arctic have unique regional, geographical, geological and social roles and all of them are present in the overall planning system.

2. *Connectivity:* subsystems and elements have to establish relationships with each other and within the organization. Subsystems and elements of the planning system are interconnected and depend on each other's functional performance.

3. *Hierarchy:* all subsystems and elements must have hierarchal relationships and interact according to established hierarchy in order to provide proper information flow. Subsystems and elements have hierarchy of data production, delivery and integration.

4. *Adaptation:* every system has to be adjustable to changes in the components and environment. Elements of a system have a certain degree of freedom within the system to enable adaptation to new challenges and conditions.

All four characteristics of a complete system are needed to create a methodology for sustainable development planning in extreme conditions of Arctic and Subarctic regions.

General systems laws apply to all systems within specific boundaries and define a concept of system in systems thinking. There are summative and constitutive types of elements that define a type of system (Von Bertalanffy 1969). Describing the systems model he states that *"The system model provides a conceptual framework in which otherwise unconnected currents are integrated, a synthetic view in which many different pieces fall into place"* (p. 38). International Council on Systems Engineering (INCOSE) describes a system following Rechnin's definition:

> *A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results* (E. Rechtin 2000, p. 4).

In addition, integrated sets of elements as systems can include products and processes, people and products, information and techniques, facilities and services, and other supporting and interacting with each other's systems and elements (INCOSE)[11].

[11] http://www.incose.org/AboutSE/WhatIsSE

In order to understand systems behavior, types of relationships between them have to be recognized. According to Boardman and Sauser, the quality of systems interactions and interoperations depends on the level of their coordination, cooperation and collaboration while aiming to achieve a consolidated result or set of objectives (2008). Therefore, interaction patterns are stable until connected systems and/or their elements produce results that are repeatedly inconsistent with inputs they receive from other systems. Characteristics of quality of systems interactions can be defined as following:

- Coordination of systems working together may be achieved with three types of coordination: coordination of actions, understanding, and goals.
- Cooperation between systems requires understanding of a common goal of shared benefits.
- Collaboration between systems happens when they share their information, awareness and understanding, with maximum collaboration when all collaboration attributes are equally shared between all elements of collaborating systems.

The anticipated result of systems interactions – consensus – is achieved when systems work in agreement with at least one form of interaction: coordination, cooperation or collaboration (Boardman and Sauser 2008).

Systems of systems contains several constituent codependent systems and is often described as an integration of complex metasystems (Keating et al. 2003). Included systems can also act independently but within a system their interoperation relationships produce results that may be unplanned and would not be produced by individual systems.

Since Systems Analysis is a method that effectively deals with available resources in the most effective manner (Chang 2011), Systems Analysis is especially useful for treating multifaceted problems of complex systems. On the other hand, complex systems may produce multiple outcomes that depend and may be influenced by diverse and at some degree unverified initial inputs and conditions, biased and sensitive requirements, and specific to situational conditions factors; which requires repetition or parallel-track analysis to help verify the inputs and produced results.

Out of many known engineering processes, the system engineering approach needs to be considered as a recognized method in many current practices (Bellagamba 2012). One of the system engineering representations is a 'spiral model' that depicts a process of a product development (Maier and Rechtin 2000). The original 'spiral model' as is used in software architecture systems, is intended to deliver one version of the product that repeats at every new cycle until the final version is delivered to the client at the end of the last spiral cycle (Boehm 1988). A simplified version of the original model from Boehm, 1988, presented in figure 3.7a, where every cycle is set to resolve the remaining from the previous cycle problems and issues, and justifies the next cycle or the end of the process (Maier and Rechtin 2000). In the case of application of the spiral model to architectural and design planning systems in Arctic and Subarctic regions through application of Systems Analysis, the model becomes multilayered and integrated with additional inputs of selected multidisciplinary data

(Figure 3.7 b). Maintaining intermediate connectivity is important during the whole project development because it provides a method to monitor the progress of the development and possible error checking and elimination.

Since the design disciplines especially in extreme conditions are synthesized disciplines by nature, they require application of a systems of systems approach to design solutions; either they are architectural and engineering or have only an architectural or engineering component in them. A holistic view to the problem helps to bring all components of systems of systems planning together: social, behavioral, technological, political and environmental:

> *The systems analysis approach addresses a holistic view and helps with the increasing complexity that planners, politicians and architects must cope with in society. The systems approach communicates between disciplines and levels, from micro to macro studies (Nystrom 2002, 44).*

Although Systems of Systems as a term is commonly used now, its definition varies in different disciplines and professions (Von Bertalanffy, General System Theory: Foundations, Development, Applications 1969). The current consensus is that a System of Systems incorporates related essential or basic systems that can act as independent systems as well as within a unifying system (Boardman and Sauser 2008, M. Maier 1998, Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008). One of the first uses of the term was in relation to urban development in 1964 in the publication “Cities as systems within systems of cities” (Berry 1964). Since then the term was adopted first in military-related fields and now it is widely used in other than military disciplines. One of the current examples of a System of Systems is Geographic Information System (GIS) whose logic is similar to the proposed in this thesis Matrix methodology.

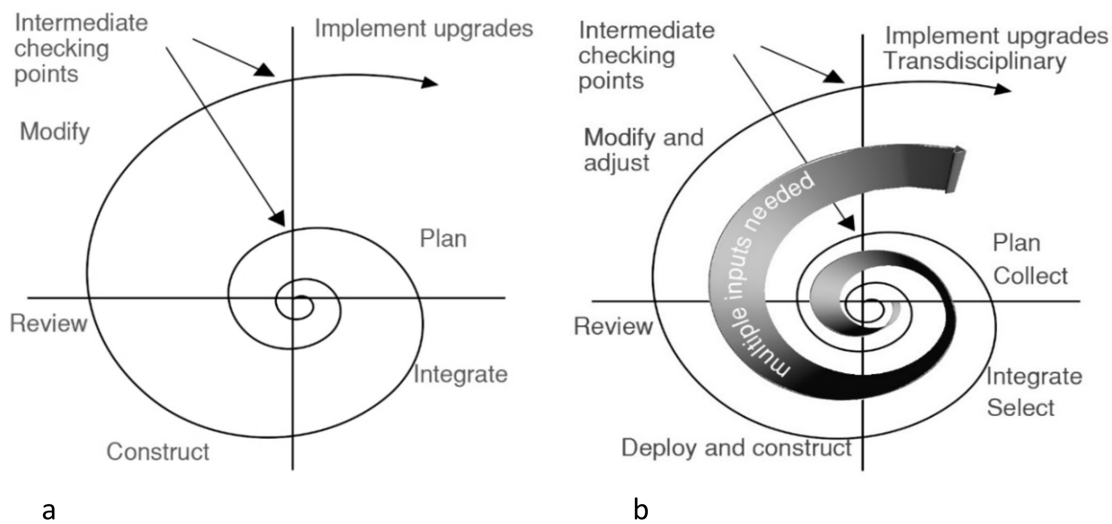

Figure 3.7 a – Spiral and circle model in systems architecting (M. Maier 1998, Maier and Rechtin 2000); b – Spiral and circle model in architectural and engineering planning and design.

Communication and relationships between all systems involved in the System of Systems requires an uninterrupted information flow that improves the credibility and enhances the overall value of Systems of Systems models (Wasson 2005, Von Bertalanffy 1969). Systems analysis techniques help to advance collaboration between all included systems toward environmentally friendly, cost-effective, ecologically sound, and socially acceptable (Chang 2011).

In order to achieve a more advanced systems analysis, system synthesis (Chang 2011) also has to be applied. Systems synthesis suggests how system-level functions and requirements relate and interact with each other in their subsystems and groups. Systems synthesis also proposes how the subsystems are divided, their relationships and what communications exist between the subsystems, what, if any, elements or aspects are critical for the system.

3.4 Validation and evaluation methods

This thesis research is based on the data obtained from multiple and various by nature sources: descriptions of case studies, previous work experience, questionnaires and structured interviews and surveys, open-ended interviews, participant and direct observations.

The techniques used in this doctoral work for validation purposes include retrospective reviews affiliated with Case Study Research and Mode 1 of the research process and Figures Of Merit (FOM) evaluation method to compare variables of systems based on selected criteria such as dependability on critical factors, supportability, and habitability (Schrader and Rickman 2010, Tortorella 2015).

Three-element validation system for design methodology introduced by Olewnik and Lewis (2005) is applied for Matrix methodology validation. System’s key elements include consistent logic when applying design methodology, using meaningful and reliable information, and not setting designer preferences by the method he or she proposes.

In addition, due to qualitative nature of the sources of evidence, using quantitate analysis cannot be applied to the Matrix methodology leading to application of the relativist validation process described in the subchapter 3.3.

3.4.1 Transdisciplinary approach

Discipline-based or mono-disciplinary methods called Mode 1 of two platforms of knowledge production can be used as a verification system for assessment of proposed design and planning solutions. Complex projects require a Mode 2 approach, which is a transdisciplinary research platform of knowledge, where scientific and academic knowledge tends to be deeply integrated in societal context (International Council for Science 2005) (Nystrom 2002). Application of these methods for design and planning verification purposes has to be employed through a participatory design process (Davies et al. 2002) and described in two technical papers that were presented at international scientific conferences (Appendix). A list of disciplines with criteria specific to their characteristics that are involved in the planning and designing for extreme conditions of Arctic and Subarctic environments is proposed for validation data collection. Such system can be used as a whole or in a discipline-based configuration (Figure 3.8).

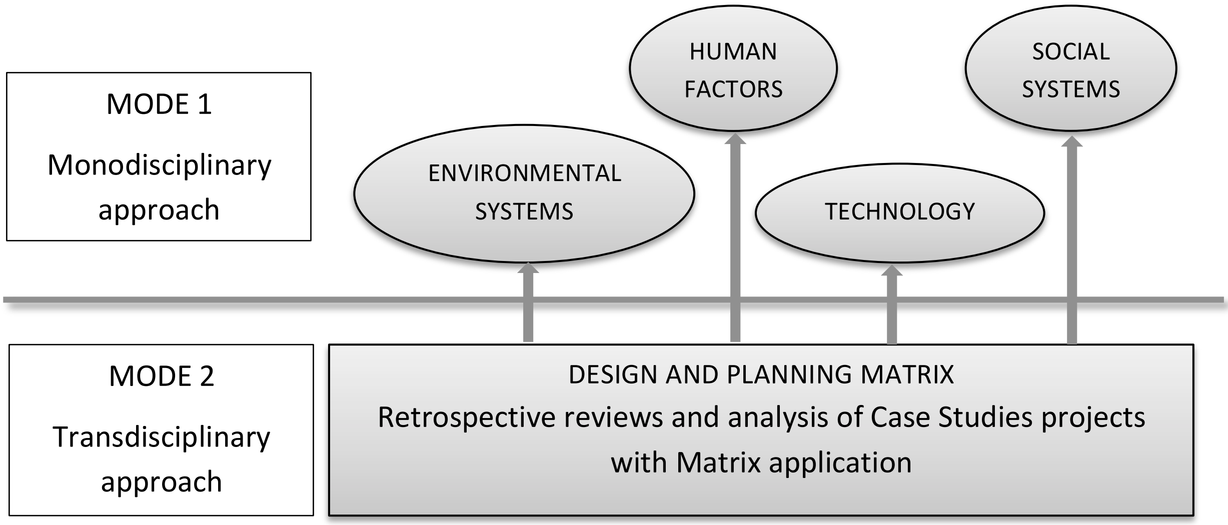

Figure 3.8 Mode 1 and 2 platforms of knowledge (modified from Nystrom M. 2002, 2007).

This thesis research aims to develop a methodology for planning large scale projects in the Arctic involving multidisciplinary knowledge as well as societal and professional expertise. The Matrix methodology therefore belongs to the Mode 2 platform of knowledge. Applicability of the proposed Matrix to transdisciplinary design processes in other than Arctic extreme conditions can be verified through Mode 1 single disciplinary or within a single discipline verification system (Nowotny 2004). Two important qualities of transdisciplinary design approach of Mode 2, accountability and quality control, are directly related to responsible professional practices that are discussed in the Chapter 5.

3.4.2 Selecting Figures Of Merit

Figures Of Merit (FOM) (Schrader and Rickman 2010) or as it was stated in the 'Used terminology' (section 1.2), figures of importance, applied in this thesis for qualitative comparisons of projects' aspects. For example, such aspects as resources, transportation, and infrastructure can be categorized by the level of their dependency on environmental conditions at the case studies projects' locations (section 5.2.3, dependency levels indicated by shading intensity). According to the Business dictionary, FOM represents "*a measure of effectiveness, efficiency, performance or other important factor, and ascertained or approximated from analysis, appraisal, or estimation techniques"(2015).*

The selection of Figures Of Merit attributes (Tortorella 2015) is based on their (attributes) qualitative characteristics and information collected through evidence sources relevant to the case studies (Chapter 5). They provide a foundation for determination and evaluation of recurrent and specific to project design aspects that are necessary for the system analysis and cross-case synthesis in order to develop a Matrix methodology for design and planning project's applications.

3.4.3 Case Study tests

The four tests that are considered for a validating procedure of Case Study research include construction of validity, internal validity, external validity, and reliability (Yin 2009). In order to apply a four tests validating procedure in this research work I used the following approaches:

1. *Construct validity:* this procedure should assist to identify if there are various perspectives on the problem and what those perspectives demonstrate. In the presented doctoral work, construct validity is enhanced through application of multiple sources of evidence and received feedback from questionnaire and survey's participants.

2. *Internal validity* tests concern only explanatory cases and applicable in this doctoral research work through building theory in facilitating responsible client behavior through design and related to architectural practice theoretical propositions.

3. *External validity* tests where case studies' findings can be generalized. The summary or findings of the study research is subject to the analytical generalization of personal and case studies participants' experience and depends on the developed theory.

4. *Reliability* evaluates to what degree the case study procedure can be repeated producing the same results. This doctoral work is based on already conducted design projects and extensive knowledge collected through open-ended interviews, personal conversations, technical presentations and literature overviews.

3.5 Chapter summary

My position as a researcher in this work is based on my experience in research and design for extreme environments, including orbital and lunar planetary facilities (Bannova 2011), disaster shelters, polar stations, and offshore surface and submersible habitats. In those research projects I was investigating such issues as hardships and challenges posed by harsh climate and environmental conditions, remoteness with restricted access and return opportunities, limitations on available equipment and support services, and ever-present safety risks (Bannova 2007, 2010). The two projects used in case studies I and II were performed prior to the doctoral work, therefore the first part of the case analysis is mostly case descriptive with the following more explanatory part presenting open-ended interviews and ConocoPhillips projects.

Since I led the student design work in both projects of case studies I and II, I partially assumed a role of the observer to analyze those cases. Cases where a researcher has to take on a role of observer have certain advantages as well as weaknesses. It is important to be able to see the case from 'within' and be a part of the settings but it may affect observer's judgment and lead to biased conclusions. To minimize such risks other sources of evidence are required when the researcher can be either anonymous or not familiar with the particular group of people participating in answering a structured questionnaire. I used such an approach for collecting verbal data from respondents to a questionnaire and follow-up interviews for all case studies.

Considering that the theory of the Matrix was conceived during and after conducting research and design projects of Case Studies I and II, I used a relativist type of validation. It is based on retrospective analysis of two finished but not built projects (Case Studies I and II) and review of projects examined in questionnaire from the point that it would be done differently if the proposed Matrix was applied during the design process. The validation process consists of four stages:

- Case studies described and their design process critically analyzed emphasizing what was missed during its course
- Projections are made what would be done differently if the Matrix was applied
- Reviews obtained through interviews and discussions with professionals from the industry and scientific community
- Summary of results from applied validation approach.

I selected research theories and approaches that are effective in tackling research questions but they also provide potential directions for further exploration beyond the questions stated in the beginning of this thesis research. The following chapters discuss concepts and theories, case studies, research, findings and analysis, and cross-case synthesis.

4 Research Concepts

This chapter discusses core factors for forming research concepts, such as human factors issues in connection with environmental challenges that become critical for project success and potential. Subchapters 4.1, 4.2 and 4.3 reflect findings presented in technical papers at international conferences correlated to developments and design in extreme environments and enabling sustainability through design practice (Staats, Wit and Midden 1996). The related peer-reviewed papers abstracts and synopses are presented in the Appendix of this thesis.[12] Design requirements and environmental characteristics described in the subchapters 4.1 and 4.2 play an essential role in understanding of the origin of research questions. Discussions about design-aided facilitation of responsible personal behavior (subchapter 4.3) led to conceptualization of sustainability in relation to professional practices and examining possible outcomes of implementation of sustainable practices in the context of extreme environment of the Arctic, responsibilities of a designer and planner during research, design and implementing stages of the project development (Russ 2010, Rasmussen 1999). Subchapter 4.4 presents an overview of design methods validation theories and strategies from point of applicability to the Matrix characteristics. A relativist approach based on qualitative research methods is argued for Matrix validation in subchapter 4.4 and Chapter 6.

A broad concept of sustainability discussed in the subchapter 4.3 reflects the notion that sustainable development (Brundtland 1987) today is an unavoidable mainstream awareness, with increasing implications on how we reside, conduct business and educate the public, professional developers, scientific communities and local authorities (Bannova and Hagbert 2014). Ranging from policy agreements or guidelines to pragmatic in-practice approaches, the global challenges we face in a time of rapid changes (whether climatic, financial or social) are addressed differently. The idea of sustainability can be applied to all aspects of human society, creating multiple facets of sustainability that include (Petersen and Poppel 1999):

- Ecological and environmental behavior
- Economics
- Social habits
- Political actions or strategies and systems.

All of these aspects of sustainability need to be part of the Matrix methodology based on their relationships and correlations. A multidisciplinary, comprehensive approach that includes highlighting influences upon general living requirements, and constraints upon delivery, construction, and special provisions for safety and hazard intervention, is closely related to planning a sustainable habitation system (Bannova and Nystrom 2014). Optimization of such design requirements that are based on the summary of design aspects is a key element of the proposed Matrix. Advanced technologies have been and continue being implemented in the housing and construction industry around the world. Understanding current problems and

[12] The selection of papers based on the data presented and its relevance to the topic of the research.

challenges in construction and housing helps to form and outline strategies and techniques those industries require to be developed and implemented in order to meet sustainability criteria and shape responsible living practices (J. Bell 2014). The proposed Matrix methodology is also based on observations of current trends in housing industries and potentials for incorporating cutting-edge technologies (Sachs 2015, Vergragt 2006) focusing on the following approaches (Bannova and Kristiansen 2014):

- Enabling sustainability
- Merging multidisciplinary approach into design process
- Transferring knowledge between disciplines
- Needs and constraints in housing
- Making living environment interactive to offer a learning experience that becomes more than just operative knowledge
- How to encourage and stimulate people to expand their knowledge
- Creating awareness of evolution of man-machine relationships and influences

Evaluating design and planning decisions throughout the whole planning process including pre-development, sub-processes, and post-development maintenance stages, is very important for understanding of real outcomes of efforts (Vergragt 2006, Bannova et al. 2014). Results of every stage have to be considered in relation to previous and following stages of planning and a methodology to enable that process needs to be developed.

The concepts described in Chapter 4 and its subchapters focus on understanding and proposing how design and planning methodology can address key aspects of planning and construction activities in extreme environments. The theory is based on the transdisciplinary nature of System of Systems design approach described in the Chapter 3. Difficulty of combining extreme environment complications with human factors issues, individual and group psychology along with enabling sustainability – has to be tackled with a systematic approach used in the Matrix in the Chapter 6.

4.1 Human factors and human error

This thesis application of the human factors term presented in the Terminology subchapter 1.2. Human factors is a common vocabulary in many disciplines and sometimes they are limited or confused with other disciplines and branches. For example, The International Ergonomics Association council approved definitions of Ergonomics in the year 2000 as is follow:

> *Ergonomics* ***(or human factors)*** *is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (IEA 2011).*

I suggest that the architectural meaning of human factors terminology should be more inclusive because it addresses physical conditions of a human body as well as its psychological status and health; design plays an important role in maintaining both in good condition. A comprehensive architectural approach also includes understanding of consequences of inadequate and inappropriate design and planning solutions during project development that may lead to non-desirable or even catastrophic events (Reason 2000). Such understanding should be a part of design and planning prerequisites and programming.

Theoretical considerations for this are based on present knowledge about humans in extreme environments and on active anthropological investigation as a key factor in human life. For example, by answering simple questions we may understand defining factors of a quality design for future housing in Northern Polar Regions or habitats in other extreme locations. These questions may include defining a "cozy" dinner: if it is eaten outdoors, in a dwelling in an undeveloped world, in the wilderness or in a middle class home, or a place where people meet and relax together, comparing a crowded submarine and a busy city office (Bannova and Jorgensen 2006). Finally, is it possible to define some key points using anthropological methods no matter what the settings are?

Human factors became a common term when applied to risk management and related disciplines. James Reason's model of organizational accidents is well known and widely applied in healthcare (Figure 4.1) (Reason 1990). It depicts that any system with multi-levels of defense still has a risk of human or human factor error in it:

> *The Swiss Cheese Model hypothesizes that in any system there are many levels of defense… Each of these levels of defense has little 'holes' in it which are caused by poor design, senior management decision-making, procedures, lack of training, limited resources etc* (Reason 2000, 125).

According to the "Patient Safety First: Implementing human factors in healthcare", these holes are known as 'latent conditions' meaning that they present non-active but ever present conditions and potential situations for failure. When the Swiss Cheese Model is applied to systems that operate in extreme environments or under extreme conditions, it may identify potential errors in organizational subsystems of the design process and help with finding error mitigating actions.

The benefits of the 'Swiss Cheese Model' translated into the Matrix and applied to design processes include:

- Swiss Cheese Model can be used as a base for the Matrix.
- The model addresses design and planning errors.
- Can help to build design that tackles organizational errors/failures.

This model becomes multi-dimensional when applied to design process as a reflection to the design and planning 'systems of systems' hierarchal and transdisciplinary nature. The multi-dimensional character of the process affects overall design methodology in a way where all components are influenced and influencing one another and errors may happen in multiple dimensions creating more possibilities for organizational error and failures (Figure 4.2).

Figure 4.3 summarizes the idea in a multi-dimensional diagram where straight horizontal and vertical connections represent direct dependences and influences while indirect connectors represent conditional but permanent relationships between attributes presented in the figure. The integration model's role is to facilitate these relationships and promptly respond to their demands.

Depicting connections between attributes of a process while planning a project shows its complexity at the overall process level. These relationships can be found during work on projects in any environment but since environmental conditions directly influence human functions, error potential, and planning itself, especially in extreme, hazardous and restrictive conditions as in this thesis Case Studies' locations, the complexity increases and methodology to integrate all planning attributes becomes urgent.

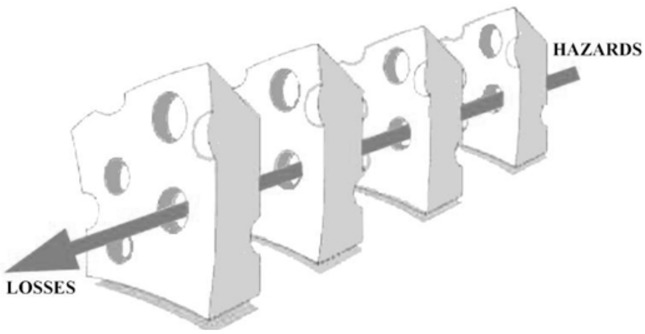

Figure 4.1 Swiss Cheese Model of organizational accidents. *Source: J. Reason* (Reason 1990)

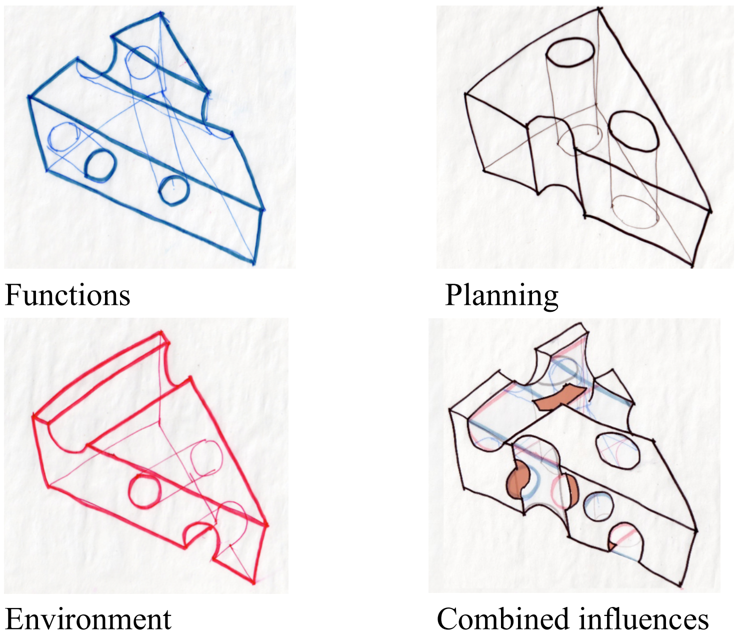

Figure 4.2 Multi-Dimensional Swiss Cheese (SC) Model of organizational influences.

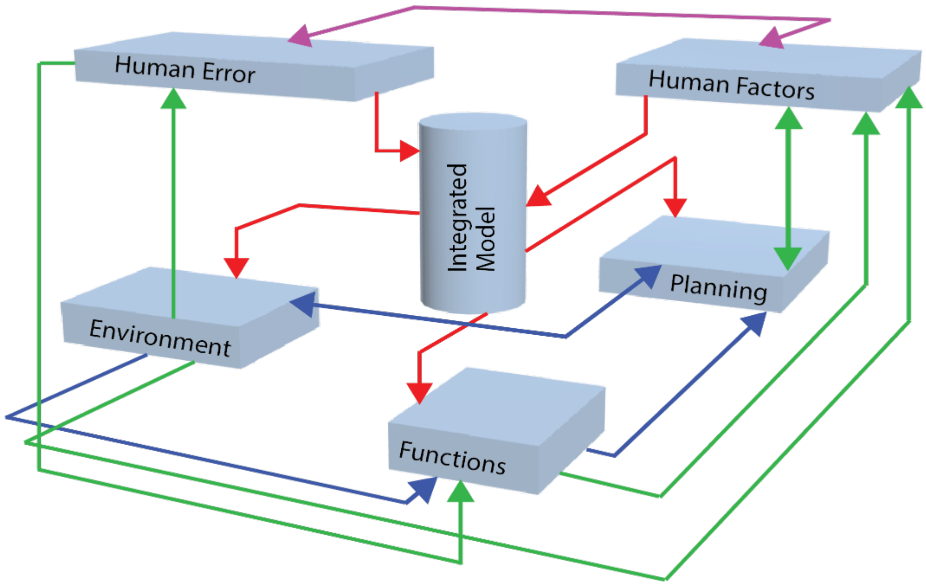

Figure 4.3 Multi-Dimensional SC Model applied to a project development process.

4.2 Extreme Environment impacts

Environmental impacts include effects on design requirements and psychological aspects that influence the design. Those impacts are the foundation for a cross-environmental planning process and require transdisciplinary design and programming. Summarizing reviews of existing design practices in Northern Polar Regions highlighted a few common design and structural responses to environmental conditions. Reviews also demonstrated key issues related to psychological health that influence design in the Arctic, Antarctica and other extreme environments.

There are three key issues influencing design in extremes and other isolated environments:

- Survival and safety of the crew
- Maximum of functional comfort for scientific research and crew habitability
- Maximum of habitable quality, seen as "quality of life in dialogue with quality of design".

Another factor that is shared between environments is unpredictable weather conditions that are very common for extreme environment locations and require a certain preparedness level for all participants in the project development. Weather conditions pose special constraints for physical structures, roads and other infrastructure. Harsh weather also demands more precise and effective safety operations routines. It also requires the work to be accomplished in a short period of time but with a larger number of workers (Marty 2000).

Psychological, social, and cultural aspects of life in the Arctic and Antarctic remote areas, outer space and other extreme environments have similar isolation, confinement, deprivation, and risk factors that building designers and mission planners must consider. There are direct analogies related to symptoms, time lines of missions, and research goals, opportunities and risks (Harrison et al. 1990).

4.2.1 Environment influencing design considerations

Construction methods in extreme environments must address vital structural safety and reliability requirements and take special environmental influences into account. Included are:

- Lack of onsite equipment and limited labor personnel
- Short construction windows
- Equipment breakdowns with limited tools/spares
- Hazardous working conditions
- Extreme temperatures impacting thermal control and structural fatigue

A common construction priority for extreme environments is to design structures that can be rapidly assembled and deployed under harsh conditions. For example, modular approaches facilitate deployment and afford immediate occupancy but usually impose internal volume constraints driven by transportability requirements. Alternatively, erectable structures can overcome volume constraints but add to on-site time and labor required for readiness. Advanced technologies including inflatable and other tensile systems applied to polar and desert environments may have transferable benefits.

Extreme environments offer good opportunities to demonstrate and assess the practical attributes and performance of equipment and operations under rigorous and demanding circumstances. High logistics costs and transportation constraints on allowable volume and weight force designers to create systems that are small and highly efficient. Harsh climates and isolated working conditions impose requirements for ruggedness and dependability.

Limited labor resources and available tools place a priority upon ease of equipment deployment and repairs. Planning and design to optimize human safety under normal and emergency circumstances takes on a special urgency.

Operations in extreme environments often place people in small isolated groups where they must learn to depend upon themselves and their team members for social companionship and support ordinarily provided by large and diverse communities. They often experience dangers and stresses that test their ability to adapt, cope and perform (Harrison, Clearwater and McKay 1990). They are forced to work together and be resourceful in dealing with problems and emergencies. By observing experiences in extreme environments, we can learn about fundamental human capabilities and needs that are frequently overlooked or forgotten in modern society.

4.2.2 Psychological aspects influencing design

Psychological health and support of morale within a limited group and sometimes in confined environments or isolated conditions are vital for successful operations and productivity. Discussing key space architecture aspects of designing for extreme environments and reciprocity between terrestrial and space architecture in a dialogue involving space architecture and space psychology helps to understand how experiences from past polar expeditions and habitats can act as background information in the design process focused on survivability, functionality and quality of life (Bannova and Jorgensen 2006).

In extreme conditions and environments, an advanced design approach should be implemented into practice, with a focus not only on people survival but also on creating 'a place for living. According to a psychological point of view, visual impressions have a high value for humans because we are getting most of our sensory information from our eyes. The majority of the neurons in our brains are processing sensory information that is related to vision (Roam 2009). It is still questionable if visual impressions have an impact on our perception or our perception uses visual information to confirm or change our orientation in space and time. Visual information that we get from the surrounding environment and understanding the extensive use of this information in different brain centers is very important. Experiencing aesthetical visual interactions is linked to this information and interrelated to centers that stimulate pleasure in the brain (Matthews et al. 2000). Details in the design, a choice of materials and active use of three-dimensional space and colors can therefore be important tools to heighten the quality of a habitat environment. The quality of life in relation to the quality of design can be focused on a salutogenic (Palinkas 1986) approach, offering not only mitigation of psychological and sociological personnel problems, but also a health promoting approach when the designed environment stimulates better physical and mental health conditions. Implementation of preventive techniques or practices is critical in Northern Polar environments. Crews, employees, workers – have to be trained in interpersonal relations and social dynamics, leadership skills, and individual coping strategies (Leon et al. 2011). Such preventive countermeasures require certain design optimizations and inclusion in overall planning strategies.

Lack of sensory input

People in remote locations and constrained by harsh weather conditions may experience a paucity of sensory inputs from the outside environment during winter over missions. A history of research and practice has demonstrated that sensory deprivation or exposure to confusing sensory inputs affect individuals in their task performance and well-being. This scenario is close to the conditions during dark or bad weather periods of the year in both Polar Regions. Other conditions causing sensory stress for Polar crews are: snow blindness, “white out” and “kayak dizziness” caused by limited sensory stimulation and almost total white surroundings. Damaging effects of sensory deprivation are well documented in both experimental and clinical settings (Bannova and Jorgensen 2006).

New technologies offer many possibilities in creating an intensive sensory stimulation to individuals and groups as a countermeasure to deprivation from limited environmental stimulation. Visual screens, computer generated images, virtual reality and other recent technological inventions may provide an excellent temporary substitution for common natural inspiration factors (Ridgway O’Brien Bachman et al. 2012).

Total isolation and autonomy

Early polar research missions faced times of lack of regular supply, radio communication and technological aids. Nowadays there is almost always a possibility to contact the rest of the world from everywhere on Earth, even in an isolated polar station, except for periods of magnetic storms, which are common for the northern hemisphere and can cause temporary total isolation.

Another challenge of the Arctic winter time is the impossibility to travel or fly during the 24-hours darkness of winter time, affected by strong winds up to 7 to 12 m/s (25 to 43 km/h), snow storms, and extremely low temperatures. Therefore throughout this time the personnel are left to handle problems and make decisions on their own due to total isolation (winter in Arctic and summer in Antarctica), depending only on materials and supplies at the site.

Time factor and fatigue

Mission duration affects both people’s performance and mood. Longer periods in isolation have a significant tendency to provoke a decline in performance, memory, engagement, and social skills. Fatigue is reported as a normal consequence of being in confined environments for a long time. Research has shown a possibility to hinder these reactions by better structured social activity and design of the interior environment for example, creating small gardens or sensory stimulating areas. Of course, individual response to stressors of a confined environment can vary and that may be important for crew selecting and monitoring (Bannova and Jorgensen 2006). Though stress of confinement cannot be completely avoided and some level of stress is an expected reaction of a normal person, these issues should be taken into consideration during the design process and in developing psychological countermeasures to help the crew to diminish stress reactions and tensions.

Group roles and leadership

A crew in a confined and extreme environment is put under stress. Stressors are long periods of boredom, relations between leadership and a group, cultural differences in living habits, which appear as time is passing by, and complex interactions between individuals and a group.

Crewmembers must act as a group to survive, but their living environment must be spacious enough to offer adequate space for individuals to provide necessary privacy. Most of the documented problems in space and polar settings are common psychological problems of human behavior, and should not be dismissed during the design process. Good leadership, training for conflict resolution and designing habitats while considering these factors can lower the risk, improve quality of life, and increase chances of survival.

A proper planning process that leads to adequate design solutions incorporated into work strategy can facilitate positive aspects of living and working in polar environments, enabling leadership to stimulate sustainable behavior of personnel.

Lessons learned from cross environmental planning and design

Cross-environmental comparisons and lessons learned are derived from the research I have been conducting at the Sasakawa International Center for Space Architecture at the University of Houston for several years. The research focused on identification of important lessons that can be applied to the design process across various environmental settings. Different extreme environments on Earth provide venues for testing facilities, diverse issues and influences that apply to space missions. Identification of common priorities, issues, and challenges leads to a possibility of creating a common methodology for designing and planning for various extreme environments and adjustment of planning approaches to diverse harsh conditions. Human requirements and environmental factors specific to different types of environment, operations and facilities must correlate with subsequent planning needs. Some general considerations listed below in the Table 4.1:

Human requirements	**Environmental influences**
Number of occupants	Structure selection and construction options
Social/cultural influences	Climate/thermal characteristics of the site
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

Table 4.1 Planning considerations.

An example of classification of recurrent and specific across environments factors and qualitatively categorizing them using Figures Of Merit (FOM) is presented in the Table 4.2. The factors are categorized depending on the levels of difficulties imposed on them by the environment. For example, transportation in the Arctic is restricted by weather conditions and available in some locations only during the summer, therefore transportation factors are classified with a maximum level of difficulty.

Since transportation means and schedule is tightly dependent on weather conditions in the Arctic and transportation windows can be unpredictable there, it is classified with a maximum level of difficulty compared to other extreme environments presented in the table 4.2. Other FOM factors classified with a 'medium' level of difficulty to support are due to availability of storing required supplies at the site and potential for using available local resources. Using the FOM method helps to identify important lessons across different settings that present common priorities, issues and challenges. Such environments include future bases on the Moon and Mars, offshore surface and submersible facilities, polar research stations, oil and natural gas exploration platforms, military desert operations, and natural and man-made emergency shelters. Factors identified with maximum or medium difficulty levels should be given extra attention during planning and design processes since they require collection of additional expertise and participation of multidisciplinary professionals.

Settings **FOM Factors**	**Arctic and Subarctic**	**Under water**	**Deserts**	**Disaster areas**
Transportation				
Habitability				
Crew: Size/activities/ durations				
Construction methods				
Safety/Emergency requirements				

Level of difficulty to sustain and support:

Maximum

Medium

Moderate

Table 4.2 Classification and evaluation of aspects of planning in extreme environments.

4.3 Sustainable practices and behavioral tendencies

This subchapter is based on discussion of the importance of design interventions in forming sustainable individual behavior and how responsible professional practices can facilitate that process. In the Arctic, developers and practitioners often plan out of context without seeing a big picture and creating connections to the bigger system that is not visible at the beginning of the process.

Architects and planners should make design decisions based on knowledge gained from comprehensive research prior and during the design process, client's needs and concerns, other requirements specific to each project, and environmental conditions. Making sure that the design solutions will not be harmful for the environment and people is a direct responsibility of architects and planners. Such understanding begins from personal responsibility to perform a proper research study before implementing some design choices.

Individual responsibility in implementing sustainability is very important but in order to succeed, one has to make any possible effort to broaden his or her influence and reach out for other professionals who would support the efforts and bring their expertise to work.

As it is worded in the Ethics of Sustainability Textbook:

> *Limits in human mental capacity, decision heuristics, and experience or expertise conspire to reduce our ability to make wise decisions in the face of complexity and uncertainty which would include most decisions about sustainability. Making decisions may require that people work together, each bringing different expertise to the system. It may also require a common language so that these experts can function effectively as a group* (Kibert et al. 2012, p.216).

Implementing ethical and sustainable decisions into professional architectural practice very often is not a straightforward process and requires reconsidering and reorganizing once accepted solutions. That may happen several times during the work on a project when new information or research data becomes available. Such a process requires strong determination from a leading designer or planner while working under stringent time and budget constraints and under pressure of meeting schedule requirements. A team of similar minded professionals is essential for successful implementation of sustainable decisions into practice.

Functional study – mapping human factors

My personal experience working on projects for extreme conditions and multiple discussions with professionals who work on similar projects made me strongly believe that design for extreme conditions should be based on functionality and a multidisciplinary approach. That includes studying and connecting a functional design approach with sustainable living through the implementation of technological innovations into the design of future residential environments.

Good understanding of how and where human factors influence the design process is one of key elements in any project development. Sustainability in this sense cannot be seen as an addition, but should rather be considered an integrated part of educational and professional practice. In situations where resources are limited, confined or living space is restricted, and the overall environment is challenging and hostile. A design approach has to be optimized accordingly to maximally satisfy personal and group activities requirements while incorporating conservation practices and functional flexibility.

I conducted a short survey on mapping activities and functional allocations among graduate students of the College of Architecture of the University of Houston in parallel to similar activity at the Architectural department in Chalmers University (Bannova and Hagbert 2014). That resulted in mapping human functions in connection to analysis of levels of private or shared use of space and resources are presented in the table 4.3:

Function Privacy	**Sleep**	**Eat**	**Chores / cooking**	**Study**	**Hygiene**	**Leisure**
Collective (sharing and acting with others)						
Individual/ sharing resources						
Private/ not sharing at all						

Desired levels of privacy:

Maximum	Medium	Less	Minimum

Table 4.3 Desired levels of privacy in relation to human dynamics (Matrix, chapter 6).

Functional decomposition of student housing from these initial findings can be mapped according to grouping of activities and human functions and defined or perceived corresponding spatial, energy and resource requirements.

Focusing on developing user-centered and participatory design research methodologies along with technological advancement, the paper explored how sustainable innovations are applied and perceived in everyday life and living environments.

Such research is concerned with the insight studies, with the intention of applying the gained understanding, informative design approaches and further research in the sustainable living lab to be built as on-campus student housing. Advancing the process farther may be achieved through incorporating an explorative design studio environment where a transdisciplinary group of students will be involved.

4.3.1 Enhancing individual responsibility

This chapter reflects my thoughts in searching for life elements that may affect the living environment; pushing it towards the edge of wellbeing. I also think that it can help to understand better how a place or a situation becomes critical for people to survive and what can be done to make the situation if not fully acceptable but at least less intimidating or menacing for people.

I tried to explore and identify a few ‘edges’ of the human living environment that frame and contribute to conditions before they become extreme. All of the edges refer not only to spatial conditions or elements but personal and public social and psychological coherence. There are more edges, faces, vertices interfering and affecting each other at different levels but due to my personal experience and concern, I began from investigating how personal perceptiveness and education can help to advance our built environment (Bannova and Hagbert 2014).

Since enhancing one’s educational background plays a significant role in personal understanding of importance of his or her responsible behavior, one of the major goals of connecting educational and built environments is to produce knowledge to advance and shape new sustainable lifestyles. Several strategies can be used in order to achieve that: information distribution; goal orienting, obtaining individual or group commitment, feedback on individual or group performance. However, some psychological theories emphasize that informative techniques are not very effective if used alone (Staats et al. 1996). Ultimately, a combination of strategies tends to be more effective in promoting sustainable behavior within a community or a group of residents (McKenzie and Schultz 2012, Bannova and Hagbert 2014).

Discussions with students during workshop sessions at the Architectural Departments of the University of Houston and Chalmers University validated a ‘*combination of strategies’* theory, when students pointed out the importance of personal awareness of individual and group sustainable actions. Students also emphasized that proactive, and even demanding behavior, should play a positive role in pushing individuals to join a sustainable lifestyle that was promoted by their roommates.

An important part in the process of shaping a sustainable lifestyle is creating a collaborative strategy towards optimized resource utilization practices. Implementing advanced technology in design affords a means for informing and coordinating residents’ responsible efforts, helping people to make sustainable choices to become a part of their everyday routine. Figure 4.4 depicts basic relationships between an individual as an element and a group and functional design as subsystems of the living environment system. Functional design subsystem assists forming individual and group relationships shaping personal sustainable behavior.

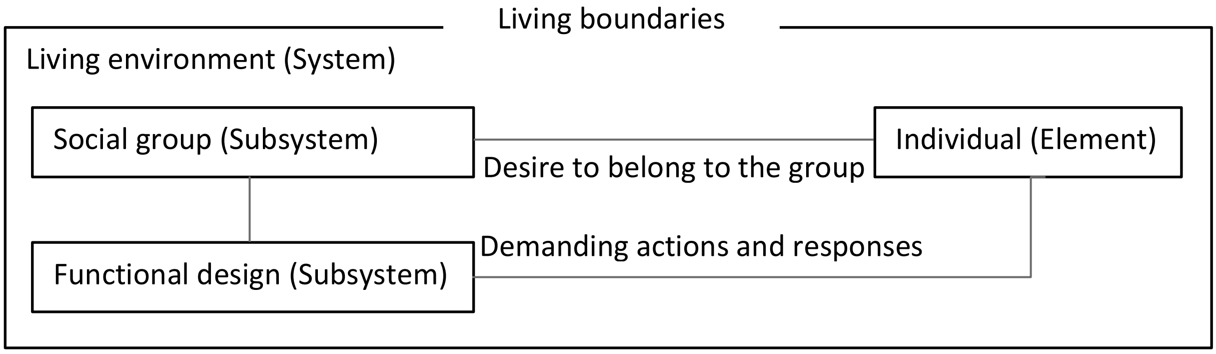

Figure 4.4 Functional design facilitating individual sustainable behavior.

The planning process has to take into consideration the possible influence of human error or undesirable behavior; therefore, relaying information about successful sustainable practices back to residents is a fundamental element of enabling sustainable practices in residents' lifestyles and routines.

4.3.2 Understanding real outcomes

Does sustainability being part of planning new developments, support or contradict local societal ethics and beliefs, principles and cultures, lifestyles and expectations? While trying to satisfy today's sustainable objectives sometimes people forget about real costs of such developments and do not see a 'big picture' where some values may become sacrificed. What are the real results of our efforts?

A new field of sustainability ethics is intended to address questions like that (Rock Ethics Institute 2014). The new field is not environmental ethics but a combination together with societal, economic and political components. Economic growth depends on societal equality as well as on technological innovations, which may be either challenging or beneficial from a sustainable point of view (Kibert et al. 2012). Technology can pose problems and at the same time may offer answers and resolve them. It may turn into some sort of a chain reaction where some positive outcomes produce long-term problems that may also trigger new technological innovations even more beneficial for progress of humankind.

That can be very visible in present developments in the Arctic. Currently, while Polar Regions are still distant from the mainland's developed world, they are already changed by newcomers (Figure 4.5). An example of such activity is an abandoned US military station DYE-2 in Greenland that was discussed in this thesis in subchapter 2.2. Indigenous people of Alaska, Canadian and Russian north, Greenland – although they still maintain their lifestyles – but their means of hunting, fishing and overall living have been changed forever (Malaurie 2009).

Figure 4.5 An abandoned US radar station DYE-2 (Greenland): exterior view, negative snowdrift and icing under the station, and interior of one of the station's rooms.

People there often get governmental support and subsides for purchasing equipment and other resources to support their livelihood and social stability. Such promotions offer inexpensive equipment and supplies compared to the mainland so it becomes cheaper for them to get a new snowmobile than to fix an old one and therefore they may just discard the old piece of equipment to the environment. Diesel and other petroleum products became the major power source and people's survival depends on their supply now.

Designers and architects should apply sustainability rules into practice as well as doctors and teachers and professionals from other human related disciplines. Existence of multiple laws and regulatory documentation does not guarantee that design decisions will not be harmful to people, societies and the environment (Russ 2010). Sustainable regulations although meant to assure implementation of responsible practices very often end up in the agenda just for a 'check' on the list to satisfy a popular trend.

Design and planning developments are parts of societal activities and tightly connected with local social values and beliefs, ideologies and cultures, people lives and hopes. A designer does not have to satisfy every player's wishes but communicate sustainable principles of his or her design choices to the community, discuss design solutions and convince of the benefits of applying those choices into practice.

Controversies in pursuing sustainability through design are between pushing for fast profit industries, military developments, politicians and time-consuming research, planning for sometimes-costly social programs, investments in time and money for new and more sustainable technologies. Implementing all of that in plans of actions will also require time, money and individual responsible practices. Surprisingly, local communities sometimes are not allies in practicing sustainable choices. They are used to technologically enabled convenience of life that may not be supportive of such choices if some part of their convenient life will be taken from them even for a short period of time.

There are uncertainties and controversies in the fields of design and sustainability especially in challenging environments where living conditions and the environment itself are very fragile. Certain aspects have to be considered whatever development or changes are planned there:

- Gathering local communities inputs prior and during planning process.
- Collect data and research all involved ingredients of production of selected materials, equipment, power and other resources.
- Delivery solutions and transportations means: what is involved?
- Multi-levelled evaluation process of design solutions.
- Making the whole design, planning and construction processes open to communities.
- Making every decision with personal responsibility.

Energy, water supplies, waste utilization and recycling, rebuilding social and cultural landscapes – all of that is essential for sustainable developments everywhere and especially in extreme environments. Application of every possible renewable energy source without understanding its real outcomes and required resources for its production will not solve power problems on a global scale nor will it help to protect the environment. Design solutions depend on building locations, requirements and constraints and – of course – on personal responsibility of a planner and designer to make reasonable, well researched and long-term choices.

Investments of assets, resources and efforts in extreme environments can be returned through implementation of advanced technologies, improved education and science as well as truly sustainable practices in all facets of life including social and economic (Figure 4.6). The figure depicts cycles of investments and benefits and returns of investment starting from construction of infrastructures and structures in Arctic and Subarctic regions that requires and depends upon local and state support, local resources and reliable transportation systems. Consequently, advancements in technology, education and science benefit from new developments and allow advantages in social, economic and sustainable practices. Next, the investments returned and provide profit that can be implemented and re-implemented in infrastructures, enhancement of local resource utilization and their restoration, transportation modernization, and other innovations.

For better understanding of relationships between cycles of outcomes from investments and efforts, use a reference to Geographic Information System (GIS) logic that comprises five important steps: ask, acquire, examine, analyze, and act. Following and expanding the same logic, Matrix is an interactive model that enables integrated planning and coordination of comprehensive exploration, deployment and production support projects. That includes strategic planning, work coordination, mapping and visualization, and evolutionary database resourcing. These features of the Matrix are discussed in the chapter 6.

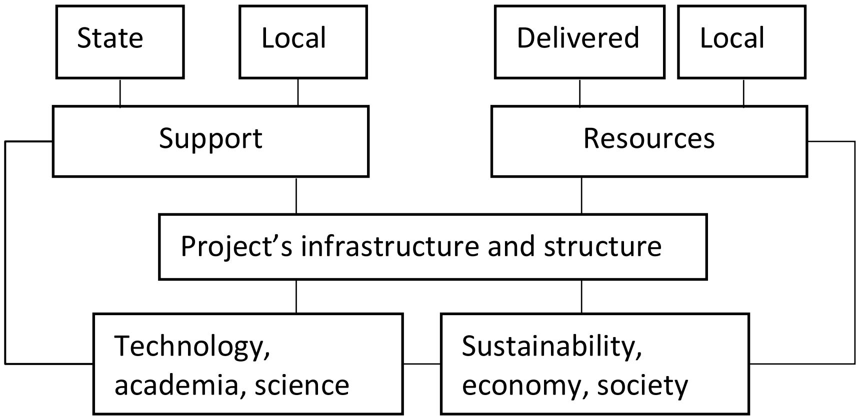

Figure 4.6 Cycles of outcomes of investments and efforts.

4.4 Design methods validation strategies

I described and analyzed case studies and other referenced projects in Chapter 5 aiming to demonstrate that applied design practices left out important instances of what should have been a holistic design approach. Projecting what would be done differently if the Matrix was applied and demonstration of its benefits requires application of a design methodology validation process. Justification of knowledge (Audi 1999) and design knowledge included can be achieved through following some or all three well-known ways:

1. Foundationalism. Relating the knowledge or some of its instances to basic beliefs (e.g. axioms).
2. Relativism. Since the knowledge is subjective, a communal agreement between scientists can be used as a part of a validation process.
3. Naturalistic epistemology. Empirical study when study subjects convert data into theories.

Donald Shon (1983, 34) investigating professionals' envision of practice begins with reviewing and discussing evolution of knowledge production in different professions and in academia, and studied it through five design professions: engineering, architecture, management, psychotherapy, and urban planning. He analyzed technical rationality that grew out of positivist theory where:

> *the engineer's design and analysis of materials and artifacts…, became prototypes of the science-based, technical practice which was destined to supplant craft and artistry. For according to the Positivist epistemology of practice, craft and artistry had no lasting place in rigorous practical knowledge* (p.34).

Such theory raises questions about used design methodologies and indicates difficulties in articulating design knowledge and its evaluation. In another work by Donald Shon and Chris Argyris (1974), four attributes for theories evaluation outlined: internal consistency, correspondence with the adopted theory, testability of the theory, and effectiveness of the theory. According to them, a theory can be testable if it is possible to identify a specific situation, anticipated end result and how the result can be achieved. Furthermore, a theory is effective if an action described in the theory inclines to attain its main attributes (Argyris and Shon 1974).

An approach to design methods and research validation proposed by Pedersen et al. may be considered supporting Argyris and Shon's approach (Pedersen et al. 2000). Through analysis of different views of knowledge and their impacts on research validation, Pedersen et al synthesized design methods validation into a new framework called Validation Square. This validation method consists of 1) theoretical structural validity that is related to theoretical performance validity and empirical structural validity; 2) theoretical performance validity, related to 1 and empirical performance validity; 3) empirical performance validity that is subsequently related to 2 and empirical structural validity; and 4) empirical structural validity related to 1, 2 and 3 (Figure 4.7). In the Validation Square Model the structural validation is considered to be a qualitative process, and performance validation – quantitative. Pedersen et al. defined scientific knowledge within engineering design according to Relativistic School of Epistemology – as socially justifiable belief.

The Validation Square Model as well as Shon and Argyris studies is proposing validation methods that aim for balanced approaches. R. Harrison and S. Counsell agree and call for theoretical validation and empirical evaluation of any sets of metrics, where theoretical validation refers to *consistency* and empirical to *effectiveness* (Harrison and Counsell 1992). Consistency here means that the design methodology used throughout the project is continuous and persistent at all stages of the project, while effectiveness of the methodology can be proven only through physical implementation of design solutions that resulted from application of the proposed design methodology.

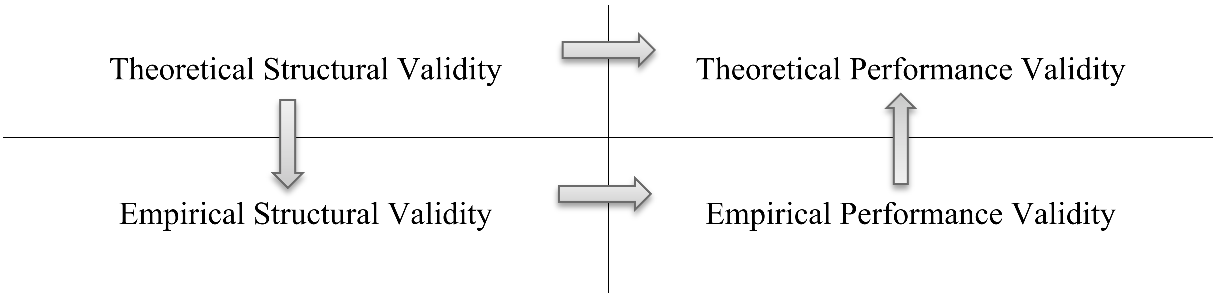

Figure 4.7 Validation Square (Pedersen et al. 2000).

Design methods in engineering and architecture are no strangers to the approach known as Decision Based Design (DBD). Many DBD supporting methodologies have been created recently that required development of criteria to judge if a proposed methodology or tool is valid. Decision support methods belong to a prescriptive model type that "*tries to predict performance or course of action taking into account available information, risks, rewards, objectives, and rational behavior"* (Olewnik and Lewis 2005, 112). Olewnik and Lewis claim that since different models are used in the engineering discipline regularly, expectations of them being close to the reality are widespread, in spite of the complexity of the model. But they emphasize that *"the complexity of prescriptive models makes their validation a difficult task"* (p.112) and as a result, their validation includes subjective elements and therefore should be based on qualitative analysis. Expanding on the idea Olewnik and Lewis introduce three key elements to their definition of validation. The three key elements are clearly present in the proposed Matrix methodology and can be explained as the following:

1. Be logical. Meaning that DBD supporting methodologies should be designed in a way when changes, if needed to be made, will concur with the logic of the proposed tool. This validation element is observed when the Case Studies I, II and industry representative projects were reviewed with the Matrix methodology applied to them and revealing if the logic of included in the Matrix systems, subsystems and elements remains the consistent.
2. Use meaningful and reliable information. Information sources are the key to this element. Incorporated information in the model should be eloquent and important, and coming from proper sources that are appropriate for the purpose of the methodology. Information sources used before, during, and after application of the Matrix to Case Studies projects are consistent, have hands-on experience related to projects and fundamental information from associated to projects, fields of knowledge.
3. No bias designer. The preferences of the designer should not be set by the method. The fact that the Case Studies I and II are based on the performed earlier projects present certain advantages in the light of the third key validation element. The performed analysis of the projects led to the idea of the Matrix methodology and therefore Matrix elements could not influence selection of preferences during the design process.

In view of the fact that three key validation elements are associated with the Matrix, the proposed methodology belongs to a prescriptive model type. A prescriptive type of design methodology is where Olewnik and Lewis suggest using quantitate analysis alone will not validate it or even cannot be possible to apply. As a result, relativist validation for the proposed methodology is applicable through the Matrix rationale or logical value. The validation approach and results are presented in the Chapter 6 and its cub-Chapter 6.4.

4.5 Chapter Summary: research concept

This chapter discussed human factors, extreme environment challenges, sustainable practices concerns, and design methods validation theories as building blocks of generating a new planning methodology for the Arctic idea. Understanding them as systems of systems is a core for developing a Matrix concept. Conformities and clashes between those systems characterize types of Matrix informing aspects/elements for creating project performance criteria. Human factors system related issues in connection with environmental challenges and behavioral tendencies are also critical for project success and implementation. The Matrix methodology concept intends to become a communication means between representatives of systems and subsystems suggesting what subsystems and elements are critical for successful and sustainable project processing and implementation. The essence of the Matrix functionality is in providing simultaneous transdisciplinary references during the whole process of planning, designing and constructing in the extreme environment of Arctic regions.

Evidently, since this research is based on personal previous experience and already performed projects, some shortcomings are present. They lay in strictly educational and academic character of the case studies projects, and limitations of data availability from corporate sources. Those shortcomings create a possibility for failure of the concept and require an open access to new projects in the Arctic and hands-on application of the Matrix methodology to learn from its failures. Still, if the concept is mostly correct then even retrospectively applying the Matrix methodology to case studies projects will identify what elements of subsystems had been missing during the work on the projects.

Because of existing research limitations, several design methods' validation strategies were observed in this chapter. The validation strategies review resulted in accepting three key elements that the Matrix methodology has to be validated with: be logical, use meaningful and reliable information and designer's preferences should not be defined by the method. They are applied in the subchapter 6.4.

The next step of this research consists of analysis of case studies' projects and projects discussed during interviews with industry professionals and experts. The analysis is supposed to answer a second Research Question that may be re-worded. The question transforms into How to make a designerly way (Cross 1982, Stolterman 2008) to be not just an abstract process where the final product may or may not be inserted into the overall planning at some point of development? or How to make sure that it becomes an equal partner of transdisciplinary efforts with established relationships that are clear to all parties involved in the planning, constructing and maintaining a built environment in the Arctic and Subarctic locations?

5 Case Studies and Other Evidence Collection

In the search for foundation principles of design and planning in extreme environments, analysis of case studies is the core of finding a proper response to the first research question. Case Studies used in this research include two academic architectural studios' design and planning projects, Summit Science Station in Greenland and Muraviovka Park for Sustainable Land Use in Russian southeastern Siberia. The third body of evidence is based on verbal data collected from energy industry professionals, researchers, local public and operational crews who have experience of working and/or living in researched regions. Selection of the two projects as Case Studies discussed in this thesis was driven by their locations in extreme and challenging settings, relatively similar design objectives, and research conducted during their program development stages. Case studies have descriptive and explanatory components that are examined in subchapters 5.1 and 5.2 and relationships between them and the thesis structure are presented in the figure 5.1. Transdisciplinary aspects of projects and requirements to provide a means for enabling sustainable practices in building design, maintenance and utilization, were also selection-determining factors. Figure 5.1 presents a flowchart of the case study research process.

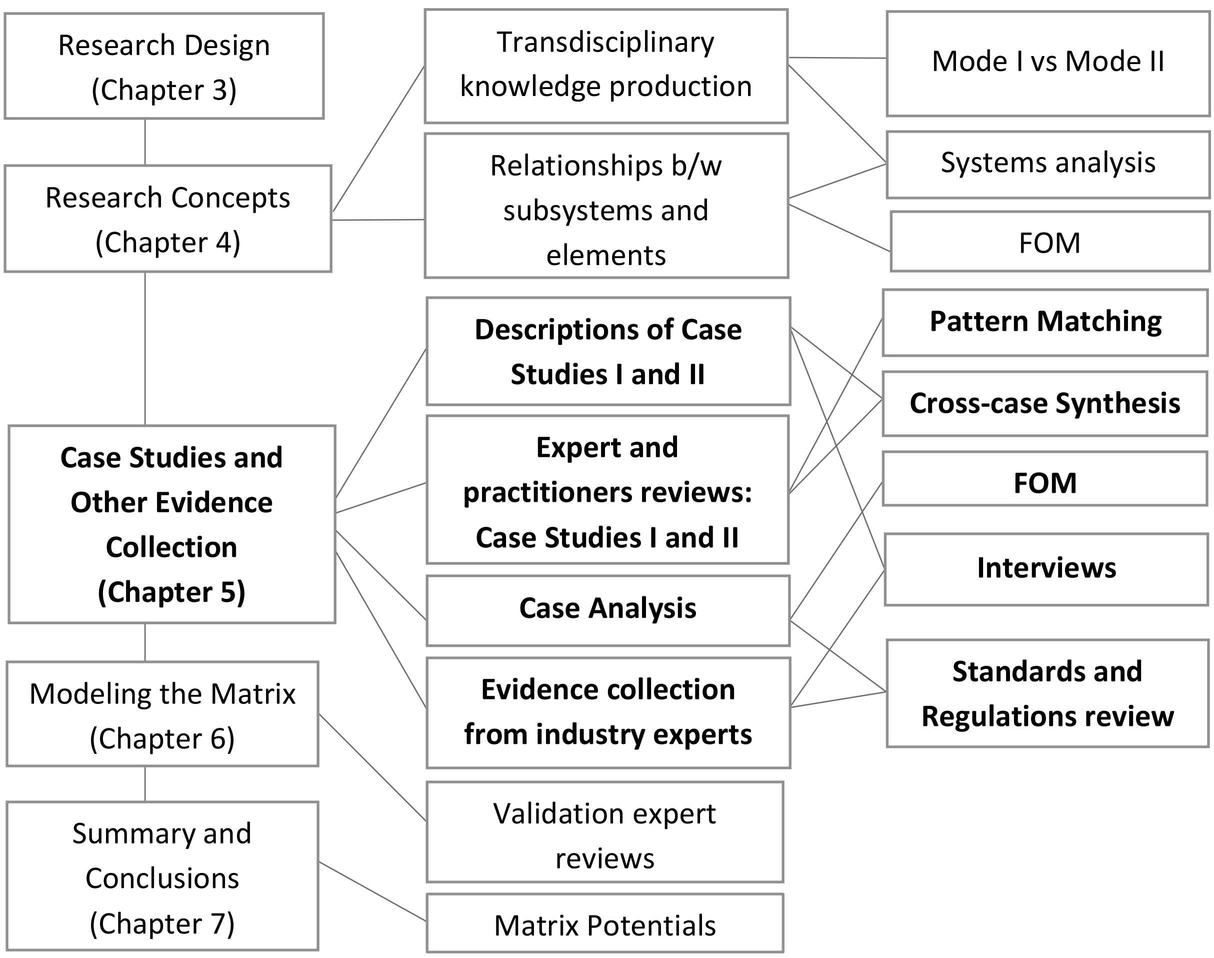

Figure 5.1 Chapter 5 structure (in bold) within the thesis context.

The approach taken in this research is based upon analysis of projects already executed without Matrix' enhancement and comparing them with the reconstructed design process when the Matrix would have been employed. Projects of the Case Studies' I and II were based on common architectural approach, other projects discussed in this chapter – a combination of references to energy industry projects[13] done following common engineering practices and regulations.

The architectural studio project of the Case Study I is a design of the Summit Science Station in Greenland. The station operated by the American-based CH2M HILL Polar Services (formerly known as VecoPolar Resources), the student project received support from the United States' National Science Foundation (NSF) through proposal of the VecoPolar Resources management (CH2M HILL Polar Services 2010, Directorate for Geosciences (GEO) 2014). Seven fifth-year undergraduate architecture students worked on the project during two-semesters, the first semester was dedicated to design-related research and second to design production and visualization[14]. The goal of the project was to provide a high quality environment for scientific research and to minimize development, construction and operational costs while optimizing safety, versatility, autonomy, and human factors and enabling the maximum use of renewable energy sources. Attaining the project's goals required thorough analysis of site influences, transportation constraints, and building and utility systems requirements; altogether, with planning living and research accommodations and support structures while optimizing the construction budget and schedule (Bannova and Smith 2006, Bannova and Jorgensen 2006).

The Case Study II is a design and planning project for Muraviovka Park for Sustainable Land Use in Russian Southeastern Siberia, Amur region (Smirenski 2008). The park is supported by collaboration of many international and Russian organizations and institutions: ISEU (Moscow), International Crane Foundation (USA), POP Group Co, Ltd and Wild Bird Society of Japan, and Korean Federation for Environmental Movement (South Korea).

The project's goal was to plan and design an environment that would benefit wildlife conservation while advancing global and local scientific, academic, and social standards. Five fifth-year undergraduate architecture students worked on the project that included one semester of project-oriented research and one semester of design work and producing presentation materials.[15] A multidisciplinary approach was used to meet those requirements and for program development. The park advancement program included renovation of existing structures, new housing for staff and their families, while providing a means to foster an environmental, academic, and cultural education to visitors and local residents, presenting natural ecosystems preservation opportunities, and facilitation of economic and social sustainability.

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[13] ConocoPhillips

[14] Students participating in the project were Spencer Howard, Clay Richards, Brian Swartz, Veronica Honstein, Mayur Patel, Brian Malone and Andre Thompson.

[15] Students include: Tressa Powell, Erick Diaz, Barry Tse, Nancy Johnson, Candice See.

Other sources of evidence collected from semi-structured interviews and open-ended discussions of existing and performed projects in the Arctic, Subarctic and other extreme environments with management, scientists, and engineers from the energy industry, polar research and logistics companies who have worked on those projects. Their experience related to diverse types of projects including research, early development stages as well as production and operation stages of industry-referenced projects.

Table 5.1 summarizes environmental and geographical characteristics of all cases: Polar desert and Boreal. Case Study I is located above the Polar circle on top of three kilometers of Greenlandic glacier and in the center of Greenland. The subject of Case Study II is in the wetlands of Amur River of Russian Southeastern Siberia.

Referenced projects' geographical locations present challenges for life conditions and demand a proper response from architects and planners when planning any human activities in such environments. Extreme environments investigated in this thesis are Arctic (cold deserts) and Subarctic boreal regions that cause glacier and terrestrial permafrost surface conditions respectfully (Figure 5.2).

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 average:-35°C summer average: -10°C Lowest t° -67.2°C Highest t° +3.6°C	Highly variable and harsh weather, annual precipitation is about 3,000 mm (sleet or snow)	Above Polar Circle, mid of Greenlandic glacier
Case II Muraviovka park for Sustainable Land Use	Subarctic/ Boreal*- Long, usually very cold winters, short, cool to mild summers	Average: winter average:-26°C summer maximum:+27.3°C Lowest t°-45.4°C Highest t° +42°C	Very cold, dry winters and warm and wet summers, more than 563mm annual precipitation	Russian southeastern Siberia, wetlands of Amur river
Conoco Phillips reference projects	Cold and dry polar, permafrost	Year-round cold temperatures, very cold winters, cool and short summers	Highly variable and harsh weather	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.

Table 5.1 Characteristics of investigated projects.

In all projects, external operations are restricted by either temperature, wind, or surface conditions, or sometimes all of them are present at the same time. Remoteness of sites requires not only logistical awareness but also special adaptation from people who work and live there full-time and/or periodically. In addition, in Case Study I users also have to adapt to the high altitude of the Summit Station location (about 3000 meters).

5.1 Case Studies descriptive components

Descriptive components of the Case Studies include suggestion of matching patterns before data collection and analysis (Yin 2009). Such patterns are present in habitat research, planning and design for extreme terrestrial environments, and space because they deal with many similar urgent problems and issues. They typically impose logistic transport challenges for people, equipment, and supplies. Present severe facility construction and operational constraints, demand careful attention to habitability, performance, and safety under isolated and confined conditions and heavily rely upon all practical means to optimize sustainable, energy-efficient, and ecologically responsible strategies. Personal observations during work on case studies projects as well as direct observations during visits to projects' sites in Greenland and Siberia are used for building descriptive components of presented Case Studies I and II (Figure 5.3). The shaded sources of evidence in figure 5.3 are examined in this subchapter. Some evidence on up-to-date site situations and living and working conditions were collected through casual conversations and open-ended interviews with researchers, workers (Case Studies I, II) and local residents (Case Study II).

Environmental conditions that influence architectural requirements and define program prerequisites require special attention (Figure 5.4). They affect design and planning requirements and include:

1. Form developing factors
2. Site orientation and circulation
3. Budget considerations.

These attributes have to be part of the programming design stage in order to avoid costly adjustments at later development stages. Such requirements become even more critical in the case of designing for challenging environments.

There are patterns in architectural requirements sets for different extreme locations that have to be analyzed prior to design decisions being made. Comparisons between infrastructure elements conditions in different extreme environmental settings demonstrate that they share similar problems and tasks that can be solved by following corresponding procedures.

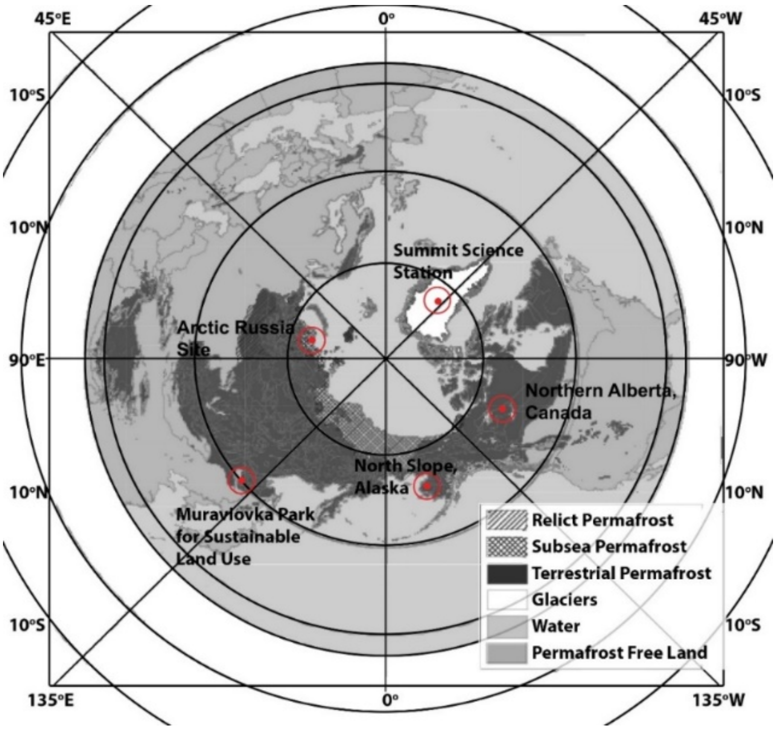

Figure 5.2 Projects' locations in relation to the North Pole and permafrost distribution (Modified from National Snow and Ice Data Center, (NSIDC 2014)).

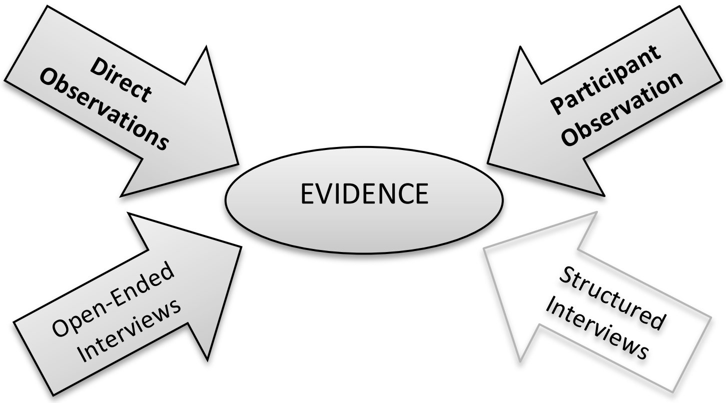

Figure 5.3 Sources of evidence used for case studies descriptive components.

a b

Figure 5.4 Site conditions of the Case Studies projects: a - LC130 plane in Greenland by DYE-2 station; b - Amur river wetlands by Muraviovka park.

5.1.1 Case Study I – Summit Science Station

The goal of the project was to create "green" architecture design with convenient spaces for science research and operations and the maximum use of renewable energy. The last objective is one of the most critical issues for research at Summit. The project included collaboration with the IMAC laboratory of the EPFL[16].

The proposed facility in Greenland was required to support 50 people during summer seasons and 25 during the wintertime. Primary elements of the modular configuration include a triangular platform with two upper floors supported by three jacking columns. This approach allowed the structure to adjust and accommodate to differential settlement of supports.

Design considerations

- All elements designed for transport by ski equipped LC-130 airplane to the site.
- System conceived to avoid heavy construction and transportation equipment needs.
- Construction planned to minimize impact on environment.
- Balanced weight distribution to avoid differential settlement.
- Modular interior design to enable easy and versatile expansion, reconfiguration and equipment change outs.
- Design by zones with possibility of temporary seasonal shut downs by sections, reconfiguration and flexibility of interior arrangement.
- Incorporating an active structure into the main facility platform to minimize snow drifting around the facility and a negative drift crater underneath it.
- Use of renewable energy.
- Modern systems to collect and recycle waste materials.
- Utility interfaces to accept standardized space facilities such as experiment racks and functional units.
- Automation and robotic systems to reduce labor and demonstrate space applications.
- Databases and computing systems to control and monitor diverse experiments.
- Communication and telemetry systems.

Skiway location and the existing taxiway in Summit are key-elements in the choice of the location selection for a new structure. The exact orientation of the buildings depend on prevailing wind direction, site operations and zoning. The prevailing wind direction (S-W with seasonal changes of the wind speed from 21 m/sec to 0.2 m/sec) was a strategic factor in this

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[16] Applied Computing and Mechanics Laboratory (IMAC), École Polytechnique Fédérale De Lausanne (Lausanne State Polytechnic University, Switzerland) (EPFL), http://imac.epfl.ch/page-2663-en.html

study and for proposing to use wind turbines for power generation. Finally, the building positioning aimed to avoid pollution produced by airplane exhaust (Figure 5.5).

Geographical location influences

Sites in the Arctic are either covered with ice, firn (transitional stage between snow and ice) and snow, and in locations where the surface is not permanently covered, the soil is present in permafrost condition. Permafrost covers about 20-25% of the Northern hemisphere open land surface. Soil, covering even larger areas, is seasonally frozen. Variation in permafrost and frozen soil indicates important climate changes, and is particularly useful in testing modeling results. Permafrost is a natural basis for Arctic ecosystems and infrastructure. Permafrost is also recognized as an important matter for the trace gases and the atmosphere exchange.

Greenland is the world's largest non-continental island, its center located at 72 00 N and 40 00 W and approximately 81% of its territory is ice covered. The Greenland terrain includes a flat to gradually sloping icecap covering all but a narrow, mountainous, barren, rocky coast.

Because over three quarters of the country is constantly under the ice, the total weight of it has caused the middle of the country to sag and form a curved in basin, which reaches a depth of 360m (1180ft) below the sea level. Above the ground rising crystal columns of ice spot the landscape, glaciers push huge icebergs into the sea. If it thaws any time in the future, the amount of ice would be enough to put coastal cities around the world under the water.

Summit station background

Summit Camp, located at the peak of the Greenland ice cap, is a scientific research station sponsored by the US National Science Foundation (NSF). The camp is situated atop 3200m (10498 feet) of ice and is nearly 400km (248.5 miles) from the nearest point of exposed land (Figure 5.6 a and b).

A number of science operations have been carried out at Summit Camp during the past decades. It is practically an ideal place for climate change and snow chemistry research. The GEOSummit facility needs to accommodate a larger number of users while maintaining a clean sampling environment to satisfy growing science demand. Proposing a new and advanced Summit Station was a response to increasing research needs in Polar Regions and in the Arctic specifically.

Existing problems to address by design

Site

Multiple structures are scattered on the site and they are widely separated, which amplifies snowdrift, requires individual heating for each building and jeopardizes safety during hazardous weather conditions. Only a couple of buildings are currently elevated at a fixed height after major reconstruction of jacking support structures were rebuilt in 2012. Other structures are constantly buried under the snow and need to be dug out several times during the season (Figure 5.6b).

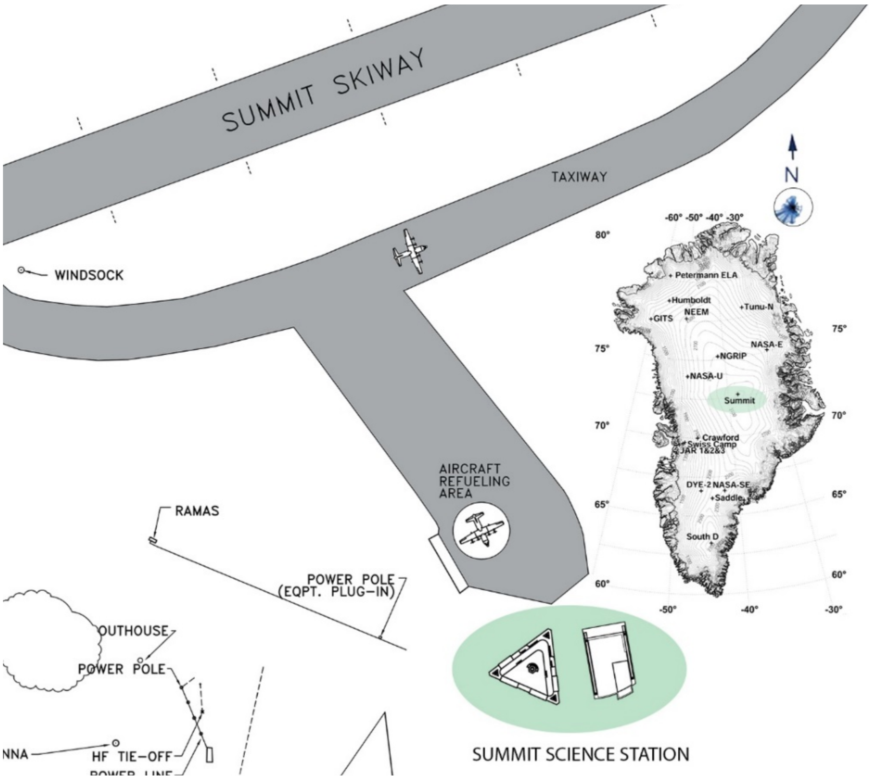
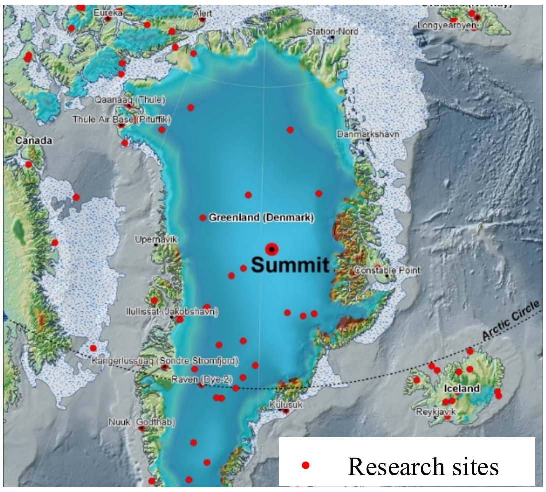


Figure 5.5 New Summit Station site map (1-main building; 2-secondary structure) and station location in Greenland.



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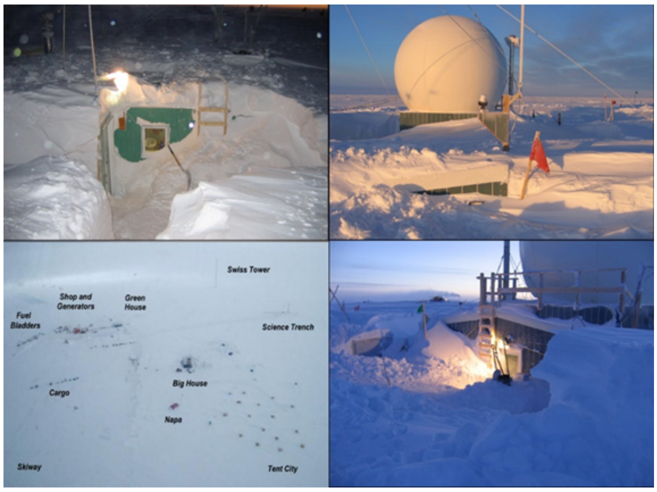

b

Figure 5.6 a - Summit Station location in Greenland; b - Summit Station structures during work on the Case Study I project.

Power

A redundant 100kW (actual capacity at 3,230m/10,600ft elevation is approximately 70kW) diesel generator system provides all of the electricity on station and the entire station is heated year around regardless of its occupancy. Pollution from the diesel generator hinders scientific research where many activities require a clean environment. This type of power is also expensive in Greenland and especially at Summit. Diesel fuel can be delivered there only by air, making its cost at Summit at least $2 per liter or $8 per gallon and this significantly increases the total operational cost of the station.

Operational capacity/volume

Lack of the dedicated lab space on the station complicates and limits research possibilities. In addition, the station did not have enough flexibility for seasonal changes in station population.

Client/user support requirements

Extreme polar conditions affect many aspects of life and work at the Summit station. Important aspects are transportation, occupancy (summer/winter), life support and emergency, work requirements.

Transportation

The only transportation available to Summit is a ski-equipped LC-130 heavy-lift aircraft during the summer. The dimensions of its payload cannot exceed the size of 2.4m x 2.4m x 10.9 m (8 x 8 x 36 ft) and 11340 kg (25000 pounds) in weight. A short Greenland summer and therefore a short period of time when flights are available place additional restrictions on payload mass and size. These circumstances may prolong the construction period to two seasons (2 years) before the first stage of a new station can start operating. To simplify construction and to make the most components of the structure exchangeable, all members of the trusses, floor and walls details, and utilities runs are designed to fit the payload size; therefore all dimensions of the elements are divisible to 2.4 meters (8 feet).

Architectural program

Program specifications and assumptions fall into the following categories:

- Identification of requirements for client/user support
- Major activities and relationships between them
- Site influences
- Facility planning
- Budget and schedule

The new facility was proposed for 50-person occupation during the summer seasons and 25-person during the winter. Scientists who come for temporary research projects during the summer stay on the field outside of the building in personal tents. It was observed through years of Summit existence as a science base that the most people who visit the station for a short period of time prefer to sleep outside in tents because temperatures at Summit during the summer can be tolerable if special polar gear is used.

Life support and safety requirements

Apart from the periodically bad weather conditions and depending on flight availability, links between Summit and the coast are good during the summer. However, there are no regular flights offered during the winter (August-April). These conditions present another challenge for design: the station should be operable autonomously and should provide all necessary support for 25 people for 9-months without re-supply. The renewable energy approach can meet all power requirements and excess of the accumulated energy can be stored in batteries for later utilization. The storage area is a part (sub-floor) of the main structure and equipped with containers, which makes it easily accessible and simplifies supply deliveries. In emergency situations on the main structure a mechanical shop (secondary structure) can be used as a temporary shelter.

Safety

- Provide a safe haven with food and shelter.
- Design structures and select materials to reduce fire hazards.
- Design structures to withstand lateral loads caused by high winds.
- Provide backup power and communication systems.
- Design systems for reliability, easy maintenance and repair.
- Provide means for emergency crew evacuation.

Work requirements

The goal of the project was to create a clean, pollution free green energy environment to provide optimal conditions for good scientific research. The research topics which can be investigated both at Summit include human factors research, hydroponics study, psychological factors and physical factors and conditions for people during a long stay in isolation, and finally, snow drifting.

Client/user major activities and relationships

Summit Station supports a wide range of scientific research on a year-round basis. Represented fields are: meteorology, glaciology, atmospheric chemistry, and astrophysics. In addition, the station serves as a base for long-term environmental observations. Such scientific diversity demonstrates the significance of Summit Station as a research base, but also creates certain operational challenges. Sometimes research projects require conflicting methodologies, and even operational requirements of the station itself can negatively influence research performance. There are two fundamental types of activities at Summit: scientific (research) and logistic (support).

Population of the station is divided approximately 50% - 50% between scientists and the operational crew and that provides good support for scientific experiments. To accommodate both types of activities, the main structure was divided into several zones and has dedicated areas for both: science and support operations.

Applied design approach (Figure 5.7)

Primary elements of the modular configuration include a triangular platform with two upper floors, which is supported by three jacking columns that maintain the facility at a preset average distance from the surface. Extra 2.4 meters (8 foot) truss elements can be added by crane incorporated in one of the legs to provide a possibility of raising the structure above the initial height of the supporting legs. The proposed crane structure is self-climbing and can be adjusted to the necessary height.

Such an approach enables the structure to adjust to differential settlement of supports. An adaptable bottom floor structure can be used to modify the shape and angle of the platform underneath the structure to countermeasure excessive snow drifting. A separate structure for a mechanical shop is added to complete the initial configuration. Important priorities are to provide a high quality environment for research and science experiments and to minimize development, construction and operational costs while optimizing safety, versatility, autonomy and human factors.

Site influences

Skiway location and existing taxi way were considered key-elements for new structure's location. To avoid extra site work and snow removal and minimize construction time, both buildings are placed as close as possible to the taxiway. The exact position of the buildings was based on the wind tunnel study and depends on prevailing wind direction (South-West with seasonal changes of the wind speed from 21 m/sec to 0.2 m/sec), which is a key factor for using wind turbines for power generation and for avoiding pollution produced by airplane exhaust on the skiway. The shape of the main building was influenced by aerodynamics and, with 3 supporting jacking legs, achieving maximum structural determinacy to avoid stresses due to differential settlement.

Facility planning and structural considerations (Figure 5.7a)

- All elements designed for transport by ski equipped LC-130 airplane to the site.
- System design to avoid the need for very heavy construction and transportation equipment.
- Construction planned to minimize impact on environment.
- Balanced weight distribution to avoid differential settlement.

- Modular interior design to enable easy and versatile expansion, reconfiguration and equipment change outs.
- Design by zones with possibility of temporary seasonal shut downs by sections, reconfiguration and flexibility of interior arrangement.
- Incorporating an active structure into the main facility platform to minimize snowdrift around the facility and a negative drift crater underneath it.

The project applied new structures utility systems that be adaptable to new clean technologies, easy repairable, robust, and simple. Their requirements include:

- Use of renewable energy.
- Modern systems to collect and recycle waste materials.
- Utility interfaces to accept standardized space facilities such as experiment racks and functional units.
- Automation and robotic systems to reduce labor and demonstrate space applications.
- Databases and computing systems to control and monitor diverse experiments.
- Communication and telemetry systems.

A minimum of 200 kW of power would be necessary for the new station operations, that can be achieved by 4 up-wind power turbines and 1085 m^2 (11678.8 ft^2) of Photovoltaic (PV) panels incorporated in both structures (Figure 5.7b). Each wind turbine is 12m (40') diameter and produces 55 kW of power. The rest of the necessary energy is proposed to come from solar panels located on the south and east facades of the main building and south and west sides of the secondary structure (Table 5.2). According to NREL (National Renewable Energy Laboratory) report, total cost of energy in Summit will be approximately \$0.35 per liter (compare to approx. \$2/l now) when 80% of energy will be produced by renewables. The surplus of energy produced during summer months is proposed to store in lithium ion batteries or other cutting-edge technology that currently becomes more available and economic (Figure 5.7b) (Lyons et al. 2010, Baring-Gould 2004).

	Wind Power (KW)	**PV Panels (KW)**
Main Structure	110	≈600
Secondary Structure	110	≈400
Total	220	≈1000

Table 5.2 Renewable energy power calculations.

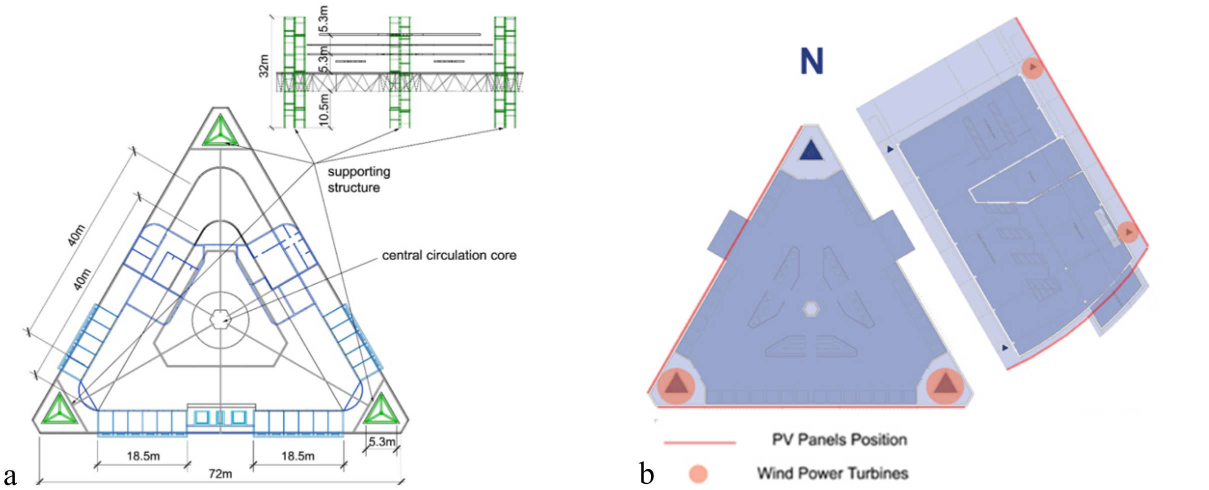

Figure 5.7 a - Plan and section of the main building; b - Renewable energy sources locations.

Facility elements (Figure 5.8 a-d)

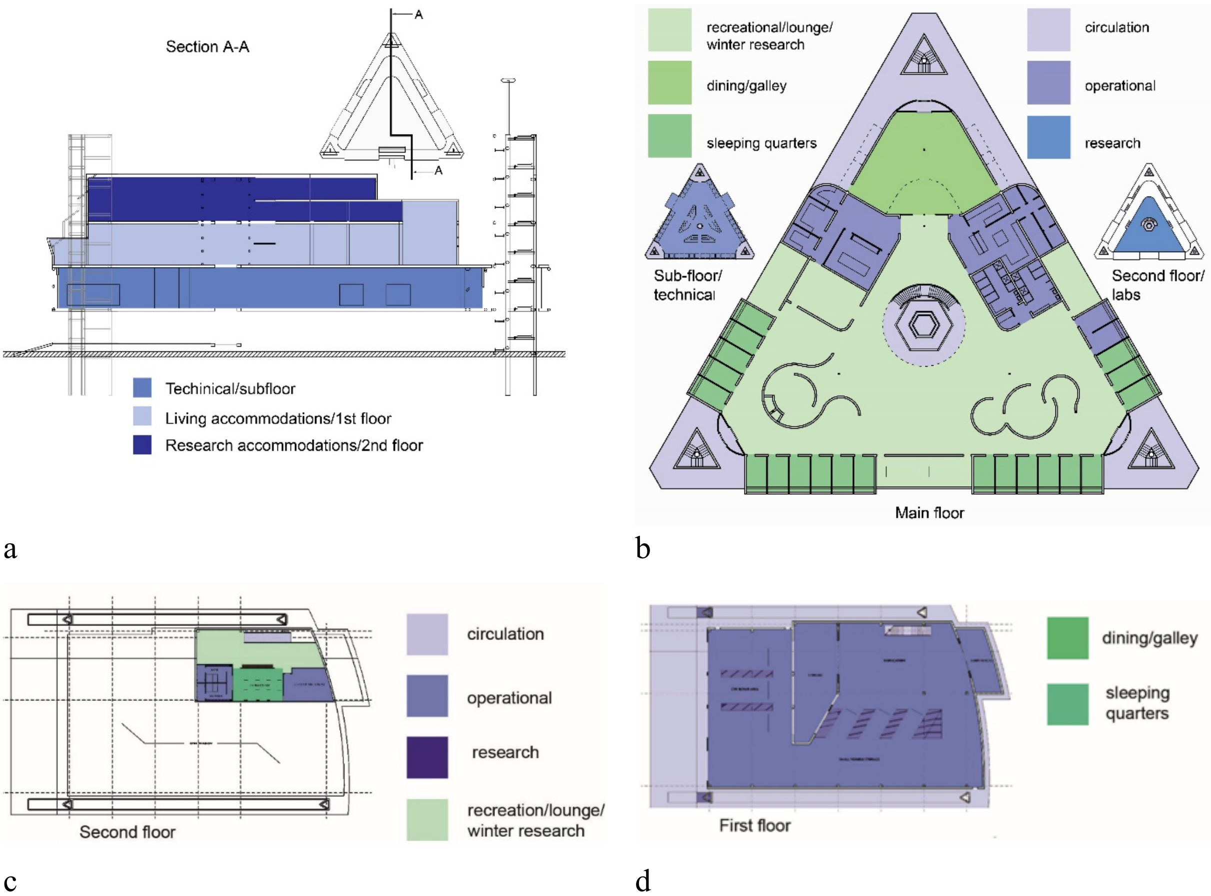

Figure 5.8 Main structure zoning: a - vertical and b - horizontal; c and d - support structure.

In addition to functional zoning between operational and research activities, living accommodations (Figure 5.8 a and b) within the main structure include private (e.g. sleeping), semi-private (e.g. recreation/lounge), and public (e.g. dining) areas. Public areas can also accommodate research needs during the winter. Such zoning approach offers adaptation strategies to psychological and physical requirements of the station population especially during the winter-over time when people are limited in all types of their usual activities and become more sensitive to their living conditions. Living accommodations include:

- Crew quarters
- Cafeteria and kitchen to seat 50 people in shifts with similar menu provisions to space stations.
- Exercise, hygiene and laundry equipment.
- Small health maintenance facility for routine and emergency medical care.
- Research accommodations (Figure 5.8 a and b):
- Facilities for environmental, biological, human, animal and plant life science research.
- Open-plan laboratory space with movable workbenches, experiment racks and storage.
- Maintenance and parts room with basic tools and calibration equipment.
- Wet lab with separate exhaust duct system and temperature control areas.

Support structures (Figure 5.8 c and d) include greenhouse/biosphere for plant growth and hydroponics research, which also plays important role in maintaining station residents' psychological health and morale. Vehicle repair and temporary emergency shelter located in the secondary structure provides protected heated mechanical workshop that can also serve as a temporary housing in case of emergency in the main structure (e.g. fire).

Economic considerations and schedule applied in the project reflected the following:

- Providing well-insulated, tight construction to minimize heat loss.
- Providing economical, nonpolluting energy sources for heating and power systems.
- Sizing and packaging payloads for efficient airplane transport.
- Planning construction delivery schedule according to flight availability from May to August with maximizing number of flights per month during this period.
- Affording construction assembly on a year-round basis.

Construction materials and methods

The initial phase meant to be built by a crew of approximately two dozen people during the Arctic summer and half of the group – through the winter.

Today, steel frames covered with laminated aluminum-fiberglass panels is the most common and economical construction solution in cold climates and it was proposed in the project for walls structures of both facilities.

The materials and methods were studied in the project in light of the following criteria:

- Weight
- Strength and durability
- Economics
- Insulation value
- Ease of fabrication
- Ease of erection/assembly
- Ease of maintenance
- Flexibility
- Deformation under temperature variation
- Availability

Based on the review and evaluation done during the work on the project and by the criteria described above, the following materials are recommended for the uses indicated in Table 5.3.

Material	**Recommended use**
Steel alloy tubing	Structure trusses, framing members and supporting legs
Honeycomb “sandwich” panels with Kevlar reinforced lamination	Modular skin panels
Triple glazed, laminated and coated glass	Windows
Aluminum alloy tubing	Floor structures
Lightweight tubular steel or steel lattice	Wind towers
Laminate flooring system and Mateflex	Floor surfaces
PV PolyCrystalline	Solar panels

Table 5.3 Materials and recommended uses.

Applied Technology: Wind tunnel studies of an active structure

Several tests have been run in the wind tunnel at the EPFL[17] under direction of the IMAC Director, Professor Ian Smith[18], to analyze the effects of snow accumulation under this elevated structure. The most effective way to ensure that excessive snow accumulation is avoided is through the use of aprons that vary their angle according to wind speed and direction. The objectives of this study are to:

- Vary the distance between the glacier and the building to see when snow accumulation disappears
- Determine the influence of fixed aprons on the snow accumulation
- Investigate different angles of the aprons
- Reduce the surface of the aprons to find the most economical solution.

Figure 5.9 a and b show the interior of the wind tunnel and the model used for the studies.

For the design distance between the glacier and the building (4.575 m) different wind directions (0°, 30°, 60°, 90°, 120°, 150°, 180°) were studied. The wind direction of 180° has been found to be the most critical. For this wind direction, snow accumulation under the structure and snow drifting around the columns was observed (Figure 5.10a).

With the critical wind direction, four additional heights (6.86 m, 5.72 m, 2.29 m and 1.14 m) were tested. In the case of 6.86 m the effect of snow accumulation under the building disappeared. Nevertheless, snow drifting around the columns remained. In the case of 1.14 m height, snow accumulation achieved the greatest depth. A phenomenon of snow transport up to the top of the building was also observed. This phenomenon also occurred for a height of 2.29 m. For a height of 5.72 m the effect of snow accumulation was less than for a height of 4.575 m, but more than for a height of 2.29 m. These results lead to the conclusion that the effect of snow accumulation under the elevated structure can be reduced only partially by increasing the distance between the glacier and the building. An increase of the height of the building causes an enhanced and more uniform wind speed under the elevated structure.

In future studies, the influence of fixed aprons on the snow accumulation under the building will be tested. The concept involves transforming the shape of a triangle into a rectangular shape. In a next step aprons at various angles will be tested (Figure 5.10 b). For the real structure, aprons with variable angles would be designed as active structures along the edges of the building.

In addition, future studies include the examination of a reduced surface of the aprons (Figure 5.10 b). The goal is to identify the most economical solution.

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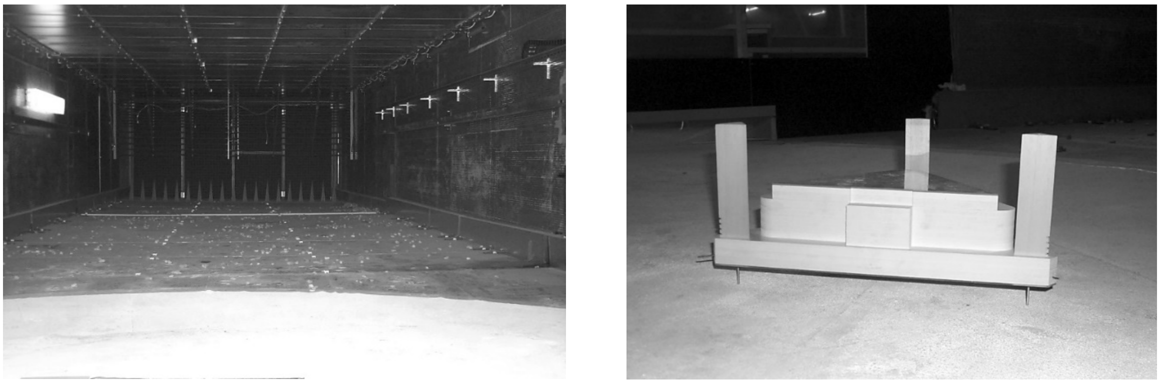
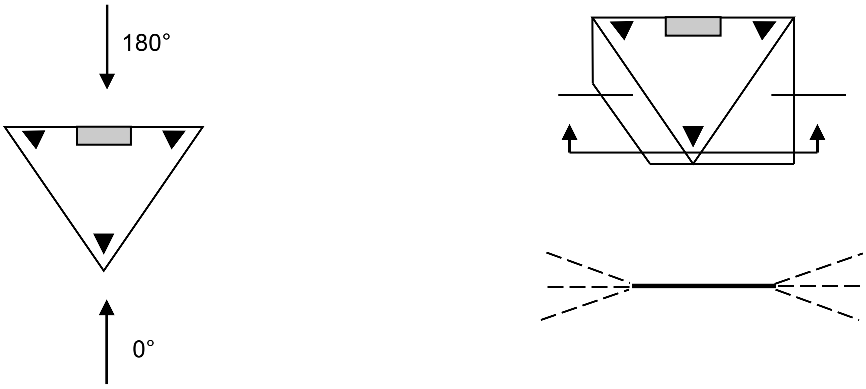
[17] École Polytechnique Fédérale De Lausanne (Lausanne State Polytechnic University, Switzerland)
[18] http://imac.epfl.ch/page-14009-en.html



a b

Figure 5.9 a - Interior of the wind tunnel at EPFL; b - Model used for the wind tunnel studies.



a b

Figure 5.10 a - Definition of the wind direction; b - Aprons with complete and reduced surface that are inclined at various angles according to wind speed and direction.

Case Study I Summary

The research carried out during the work on this project focused on creating an elevated structure with centralized and minimized station operations through building one main facility with dedicated and season-adjustable living, research and operational areas and a secondary structure for a mechanical shop and a temporary shelter for emergency situations.

Summit Science station is an ideal place for scientific activities, especially those related to climate change and snow chemistry research. The Summit facility has to accommodate many users while maintaining a clean sampling environment in order to satisfy a growing demand for scientific research. The year 2007-08 was the second International Polar Year and there was a large number of activities planned for that event. The new advanced Summit Station proposal was a response to increasing research needs in Polar Regions and in the Arctic specifically (GeoSummit Science and Facilities Planning Meeting 2004).

Summit Greenland is a site of expanding scientific interest by both U.S. and European scientists. Research topics of projects include evaluation of characteristics of ice-cores in relation with environmental change, investigation of upper and middle atmosphere phenomena for improving understanding of the global climate system, evaluation of atmospheric conditions in the troposphere and in the boundary layer contacting the Greenland permanent ice sheet and studies of the radiation, energy, and water balances which occur on the ice-pack. In order to provide a high-quality environment for scientific research on a year-round basis, the design process included human factors, psychological, esthetical and social components. Benefits for the international scientific community of building a proposed in the Case Study I project science station in Summit include the following:

- A modular station structure design satisfies C-130 payload restrictions with maximum utilization of payload capacity.
- Use of renewable energy helps minimize operational costs and impact on Greenland's environment.
- Energy accumulation during the summer could lead to an autonomous power supply during winter.
- Adjustable support structure helps maintain the necessary clearance between structure and snow surface and corrects for differential settlement.
- Active structures along the edges of the buildings may minimize snow drifting and erosion around supports, thereby reducing energy requirements for snow removal and simplifying facility operation.
- Technologies developed and tested during construction and operation of the station can spin-off to applications in other Polar Regions.

5.1.2 Case Study II –Muraviovka Park

The goal of the project was to create architecture and the park's master plan that provide spaces for science research and operations, nature protection, environmental education, and friendly settings for promotion of the park's program.

Muraviovka Park for Sustainable Land Use project was focused on creating a development plan for the park that would offer a unique sense of place. One of major goals of the project was enabling sustainable planning and living through a highly natural example.

Design considerations

- Responding to extreme environment challenges with:
  - Building envelope design
  - Building's on-site orientation
- Enhancing economics:
  - Trade with China
  - Locals can benefit from the visitors coming to the park

- Advancing education:
    - Locals from Blagoveshchensk, Heihe, and nearby villages can come for seminars and summer camp
- Expanding reservation:
    - Local citizens can help build the park and with the upkeep.

Geographical location influences.

The park is located in Amur region that abounds in rich natural resources. There are concentrated up to 80% of the hydro resources of the Russian Far East. There are more than 29 thousand rivers over 10 kilometers in length in the Amur region. The Park's location in wetlands of the Amur River offers a unique environment for biodiversity represented by cranes, storks, ducks and other flora and fauna (Figure 5.11).

Figure 5.11 Site proximity to Amur River and Trans-Siberian railroad.

Climate characteristics

All habitable structures need to be designed for extreme continental climate with long and dry winters and average temperatures in January between -26 to -33C°. Peak cold temperatures occasionally may reach -45.4C° and even lower with wind-chill. Prevailing winds in winter are from North and North-West. The permafrost is widely but sporadically distributed through the region. Annual average precipitation is 550mm with up to 70% of atmospheric precipitation drops out in summer; snow deposit in winters is still significant. Summers are very warm and short with highest temperatures sometimes reaching above +42C°.

Park's site planning considered local climate characteristics and geography. That resulted in the following starting design considerations:

- Building orientation – long axis of the building positioned along East-West direction.
- Building position concerning prevailing wind direction (during the winter season).
- Building access and service roads.

Existing problems to address by design

Man-made wild fires mostly caused by the local population are a great threat to cranes and other birds' natural habitat in Amur wetlands. Human agricultural activities in Russia and China are lowering level in Amur River menacing their natural habitats and posing other dangers to the region's wildlife (Bengtsson et al. 2003). A development plan was needed that would incorporate means to preserve and restore existing forestation and marshlands. Smart zoning and operations organized accordingly to the park's long-term mission goals and involving local communities would be a necessary approach to achieve the goals and satisfy the park's requirements.

Short summers constrain construction time and require very structured and tight work schedule and therefore demand minimizing materials delivery time.

One of the biggest challenges the park faces is lack of support from the local government although the park attracts substantial local support on an individual level.

Major design solutions reflected the importance of enabling sustainability in design, planning, economy and social aspects of the park's operations through embracing transdisciplinary agencies in the proposed development plan (Figure 5.12).

Site

Buildings and structures are spread in the park territory and some of them isolated which amplifies operational difficulties, requires individual heating for each building and jeopardizes safety during hazardous weather conditions. There is a mix of summer only operational structures with only a few weatherproof houses.

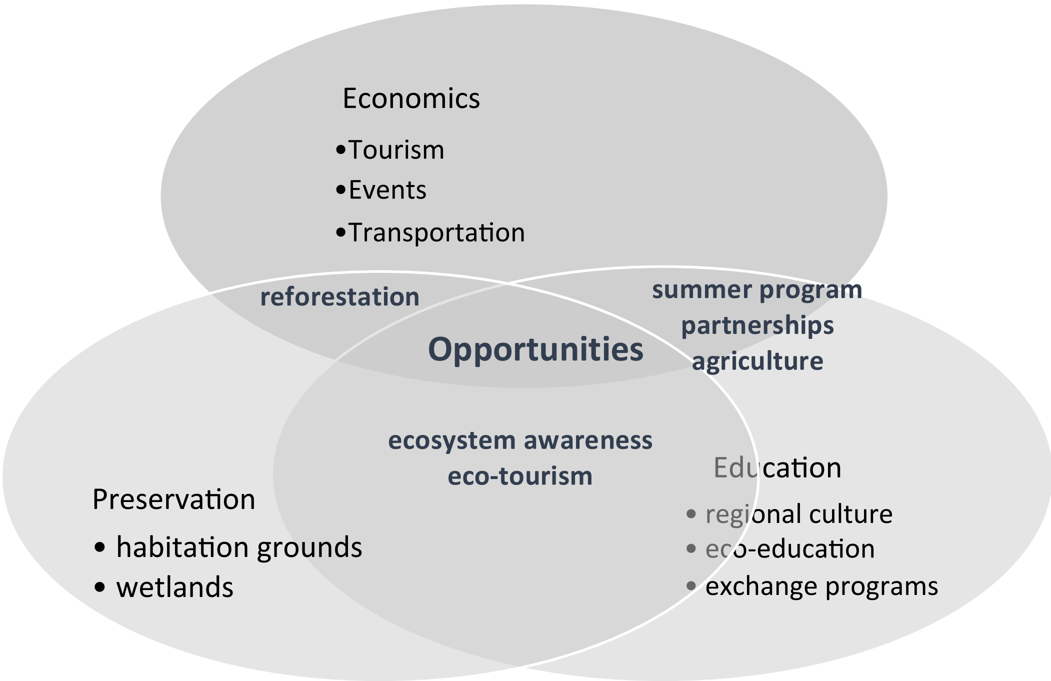


Figure 5.12 Proposed relationships between Muraviovka park activities.

Power

There is a power line connecting the park with the nearby village power station. Additionally one diesel generator provides power in case of a blackout.

Operational capacity/volume

Population of the park dramatically varies between winter and the rest of the year. Lack of housing for permanent personnel complicates and limits research and operational possibilities.

- Requirements for bird habitation
  - Seasonal changes
  - Specific conditions required for different types of birds
- Personnel requirements for living and working in the park
  - Park goals and tasks
  - Number of employees
  - Seasonal changes in work type and quantity of people
- Park development
  - New science projects
  - Tourism
  - Educational and academic programs

Client/user support requirements

Extreme environmental and social activities restrictions affect many aspects of life and work at the park. Important influences are determined by available transportation, differences between summer/winter occupancy, life support needs and emergency plans, including work requirements and conditions.

Infrastructure

Existing infrastructure at the park includes farm roads transportation to Blagoveshchensk that regularly become impassable during the whole year and especially in winter jeopardizing connection between the site and the city. These circumstances negatively affect any type of developments in the park and especially construction-related work. To simplify construction and to make most components of the structure exchangeable, all structural elements, floor and walls details, and utilities runs have to be designed either to fit in a small truck or built using site capacity and resources.

Architectural program

Program specifications and assumptions fall into the following architectural categories:

- Identification of requirements for client/user support
- Major activities and relationships between them
- Site influences
- Facility planning
- Budget and schedule

The new plan accommodates two families of researchers during wintertime and offers housing for at least 15 visiting scientists during summers. The park should also provide living facilities for summer camp and daily housing for tourists. Scientists who come for temporary research projects during the summer occupy any available structure in at the site.

Life support and safety requirements

Apart from periodically difficult weather conditions and fire hazards, connection between the park and Blagoveshchensk are good during the summer. However, there are no regular means of transportation. These conditions present another challenge for the design: the park should be operable autonomously and should provide all necessary support for winter-over personnel for at least 1-month without re-supply. The renewable energy approach meets all power requirements and the excess of the collected energy can be stored in batteries for later utilization. Communication with the closest emergency center should be guaranteed in case of emergency at the park year round.

Safety requirements

- Design structures and select materials to reduce fire hazards.
- Design structures to withstand lateral loads caused by high winds.
- Provide backup power and communication systems.
- Design systems for reliability, easy maintenance and repair.
- Design structures according to emergency evacuation requirements.

Client/user major activities and relationships

Muraviovka Park supports a wide range of scientific research and educational outreach programs on a year-round basis. Represented fields are biology, geology, geography, zoology, and more. This multiplicity of purpose demonstrates the significance of the park as a research and educational outpost and poses certain operational challenges. Sometimes park activities may have contradictory operational requirements that can negatively affect some of the on-going research. There are two fundamental types of activities at Muraviovka: scientific (research) and academic (education) with the third activity required by both – logistic operations (support).

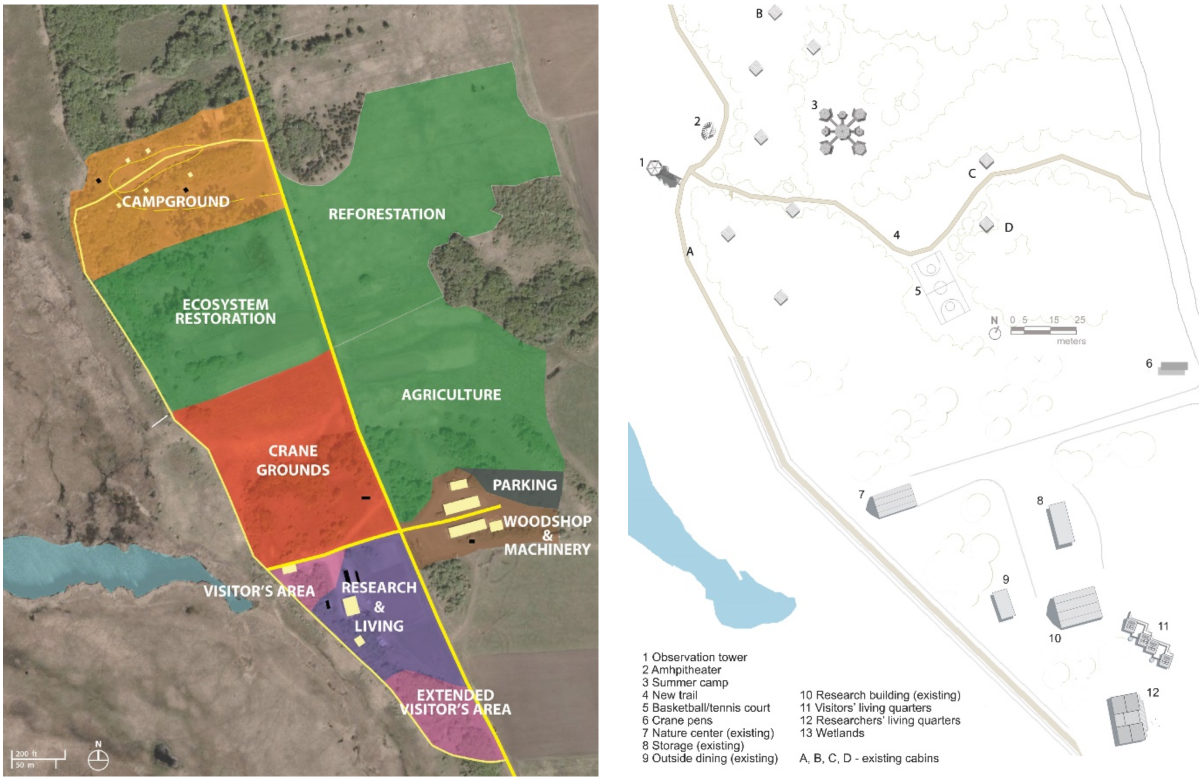
Applied design approach

Analysis of local market conditions verified that locally available construction materials include several types of timber, concrete and metal supplies that can be produced and delivered to the site at low cost. The Amur Region is a multi-wood territory, 56 % of the region is covered with forests. Wood types include larch, pine, spruce, fir, oak, birch, and ash-tree.

Some construction equipment can be delivered from China with favorable conditions as well. Enhancing economical sustainability during construction work was one of the major decision influencing aspects because the region is not currently attractive for external investments. These findings and considerations contributed to park development and growth plan and overall architectural design (Figure 5.13 a, b).

The project proposes recycling and conservation of resources through application of several simple rules and techniques:

- Windows positioning according to inner airflow to be parallel to outside wind conditions
- Indoor airflow traverses interior in non-linear path
- Roof and basement passive ventilation
- Airflow allowance – less than 50% of square footage but more than 2 rooms deep.



a b

Figure 5.13 a - Muraviovka park zoning plan; b – Park site plan

Site influences

Due to extreme continental climate, winters in Amur region are long and dry. Since the sporadic permafrost is widely distributed through the area, the proposed in the project facilities incorporate special foundation construction methods in their design. Due to extreme climate conditions with the coldest days in winter reaching -45.4 °C and hottest days reaching +42 °C in short summers the design of all year-around operational buildings needs to be adaptable and compact. Remoteness of the park especially during the winter requires operational autonomy and resilience of park masterplan and zoning.

Facilities planning and structural considerations (Figure 5.14 a-f)

A proposed site development plan is based on the park specialties and goals. It includes design of 2-apartment housing (duplex) for 2 families of 4 people each for year-round habitation. New structures and facilities included:

- Condominiums for 2 families with 4 people each
- Additional pens
- Amphitheater structure (temporary – possibly tensile, or permanent)
- Water areas for wild life demonstrations

- Dendro-park
- Trails and signs
- 2-storey facility for meetings and gathering with auditorium, dining and observation balcony

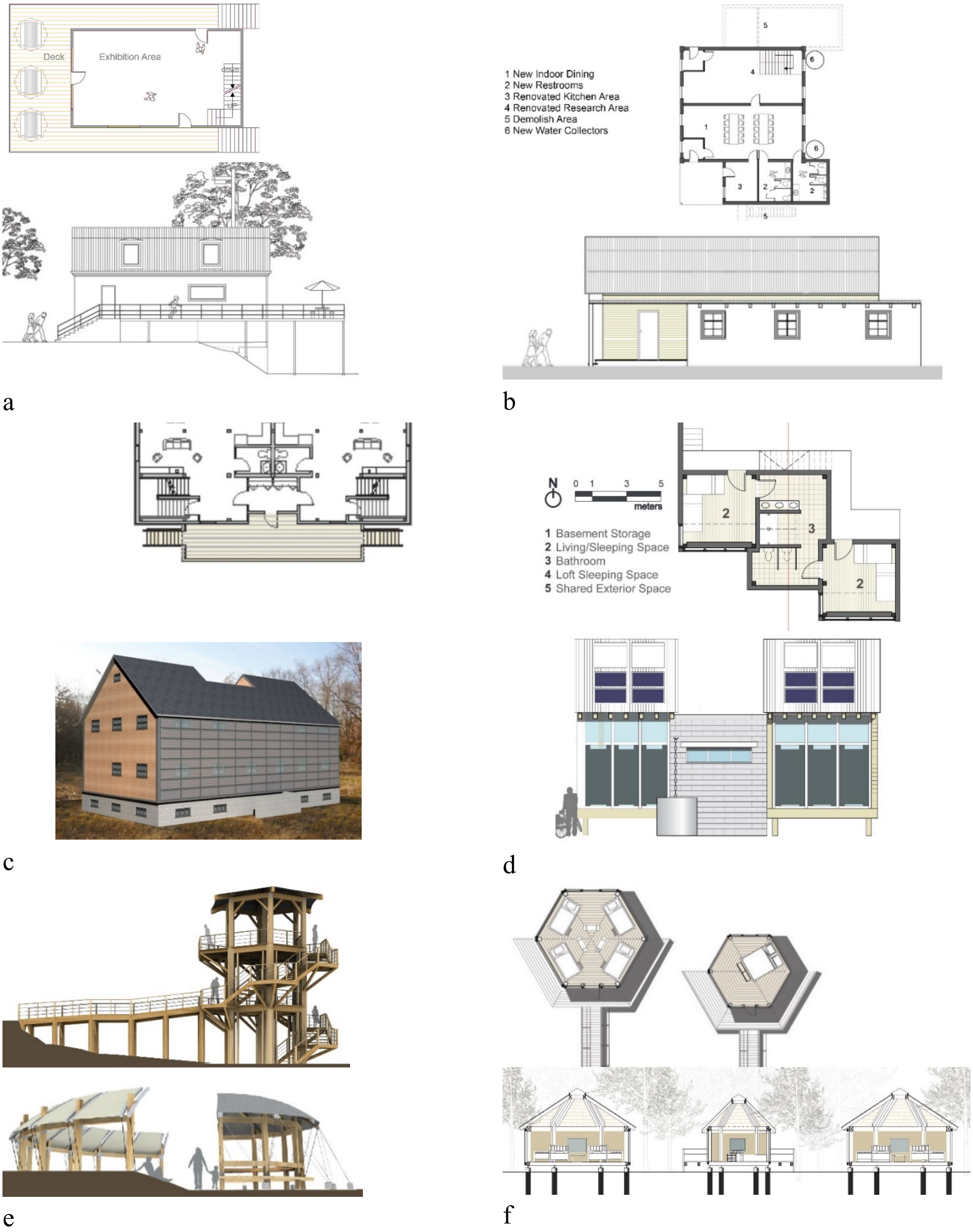


Figure 5.14 a - nature center (renovated); b - research (renovated); c - researchers housing; d - visitors housing; e - park auxiliary structures; f - camp structures

Extreme conditions of the project location, and economical and political complications related to the site determined the following design influencing requirements:

- All elements have to be designed for transport by medium to small-sized trucks to the site.
- System design to avoid the need for very heavy construction and transportation equipment.
- Construction planned to minimize impact on environment.
- Modular interior design to enable easy and versatile expansion, reconfiguration and equipment change outs.
- Design by zones with possibility of temporary seasonal shut downs by sections, reconfiguration and flexibility of interior arrangement.
- Incorporating passive heating systems (e.g. trombe-wall).

Utilities systems proposed in the project aim to facilitate parks operational autonomy through applications and utilization of the following practices:

- Use of renewable energy.
- Modern systems to collect and recycle waste materials.
- Vacuum-assist toilets or smaller toilet tanks
- Optimization of use of "green" or "clean" technologies
- Databases and computing systems to control and monitor diverse experiments.
- Communication and telemetry systems.
- Rainwater collection.
- Graywater collection and recycling.
- Indigenous landscaping.

Photovoltaic (PV) panels incorporated on both structures of the Nature center and on the roofs of living quarters for visitors can accumulate total of 14,400 per day at their maximum capacity (Table 5.4). Although winds are relatively strong in the area, wind turbines could not be considered due to high hazards for birds. The excess of the electricity can be stored for later utilization using lithium-ion batteries or other advanced technologies (Lyons, Gonzalez, Houts , Iannello, Scott, and Surampudi 2010).

	PV Panels (m^2)	PV Panels (KW)
Nature center	15.2	≈11520
Visitors living quarters	5.3	≈2880
Total	20.5	≈14400

Table 5.4 Renewable power need/capacity.

Economic considerations and schedule depend on each other as not meeting schedule goals leads the project to go over budget. The schedule is affected by the extreme environment of the Muraviovka park and its scientific and educational goals demand special design features and approaches:

- Providing well-insulated, tight construction to minimize heat loss.
- Providing economical, nonpolluting energy sources for heating and power systems.
- Sizing and packaging payloads for efficient transportation and maximize use of in situ materials and resources.
- Scheduling construction delivery allowing for weather interruptions.
- Allowing construction assembly on a year-round basis.

Construction materials and methods

The intent of the project to utilize materials and methods, which are most common for the area, recycled from existing structures and can be provided at the site. The materials and methods were studied in light of the following criteria:

- Weight
- Strength and durability
- Economics
- Insulation value
- Ease of fabrication
- Ease of erection/assembly
- Ease of maintenance
- Flexibility
- Deformation under temperature variation
- Availability

Based on the review and evaluation done by described criteria and materials applicability to the site environmental conditions, the following materials are recommended for the applications indicated in the Table 5.5. The materials selection and recommendations are also aligned with sustainable architectural practices.

Material	Recommended use
Local wood/timber	Structure, framing and supporting members
Triple glazed, laminated and coated glass	Windows
Aluminum alloy tubing	Some floor structures
Laminate flooring system and Mateflex	Floor surfaces
PV PolyCrystalline	Solar panels

Table 5.5 Materials and recommended uses.

Applied Technology

As was mentioned, application of some recycling systems and technologies had to be incorporated into design. Passive heating designs were included in permanent housing design solutions. Renewable energy sources included only photovoltaic panels due to the danger windmill power generators pose to birds. PV cells were to be positioned on all new and renewed structures. Design proposal included use of new insulation materials, hot water circulation or hot ventilation to enable minimization of heat loss and heat absorption. Overall park masterplan design centered on sustainable agriculture to provide 100 percent support for park's research, preservation and educational operations.

Case Study II Summary

The research conducted during the work on the Muraviovka park project focused on creating the park's development plan with a new design and adjustment of existing facilities according to park's goals and objectives.

Although enabling better means for sustainable operations of the park, and its educational and international character, were recognized as critical aspects for advancing the park's facilities design and overall planning, transdisciplinary input was not incorporated in the overall project structure. For example, agriculture was and is a crucial component for enabling the park's sustainability. Professional input from practitioners to support an agricultural component, practices and activities, was not included in the project plan, although zones for agriculture were part of the architectural site plan. This resulted in instinctive decisions for crops selection, planting area, harvesting and eventually led to big losses during growing or reaping periods.

In order to provide a high-quality environment for scientific research on a year-round basis, the design process included human factors, psychological, esthetical and social components as it was in the Case Study I, within the particular site. The design reflected some environmental and infrastructural external influences without looking at them in the context of the lifetime of the project and in connection with the other disciplines. Inclusion of those in the process would offer ways for the park's support and growth as an important player of the local community. The final design was summarized with the following benefits:

- Use of renewable energy helps minimize operational costs and impact on park's environment.
- Energy accumulation during the summer and storage of excess of electricity using lithium-ion batteries or other technologies (Oberhofer 2012) (Lyons et al. 2010) could lead to an autonomous power supply during winter.
- Technologies developed and tested during construction and operation of the station can spin-off to applications in other Polar Regions.

5.2 Case Studies I and II analysis

Case Studies analysis acknowledges certain limitations that come from Case Studies projects' two distinct qualities: both of them were strictly academic student projects and both are reviewed in this thesis retrospectively. However, those limitations can be considered less substantial but still informative by active involvement of professionals and scientists in projects' requirements development stage and during and post-projects reviews.

Two studies of completed projects, Summit Science station in Greenland and Muraviovka Park for Sustainable Land Use in Russian Southeastern Siberia, were developed through a common architectural design perspective (Johannes 1992). Usual architectural practice is based on the collection of knowledge about the site and client needs that are summarized in the architectural program under three major areas: site analysis, facility planning considerations, and functional assumptions. In addition, although mockup testing becomes part of the process very rarely, it would be desirable in the case of implementation of new technologies and practices in the design especially in extreme climate conditions of Arctic and Subarctic regions.

Design and planning in both projects required additional attention due to the extreme environment of the Arctic. Summit Station location at altitude of 3200m poses isolation, restricted living conditions, remoteness, and necessity of additional gear for work in extreme temperatures. These aspects influence design decisions and overall project planning. Supporting year-round work at Muraviovka park requires addressing similar human factors-related concerns. Project reviews and discussions with park's leadership Dr. Smirenski made it clear that the park's development and support initiatives would benefit from systematic planning in connection with local multidisciplinary activities.

The data collecting stage and design requirements of both cases share many aspects and create some planning matching patterns. Transportation, power, sustainability, economic expertise and knowledge have to be part of planning and design at earliest stages of a systematic process.

To identify and fully understand what design aspects can be dealt with using a similar approach it is important to analyze and take into consideration some differences in design and planning requirements first. Determination and evaluation of recurrent and specific to the project design aspects is a necessary step of this thesis research process for development of a design and planning methodological approach. In general, structural and infrastructural design solutions always depend on the location of the project. However, they are constantly challenged by extreme conditions in the Arctic and other polar settings and need to be investigated as systems of systems or subsystems of a bigger whole.

5.2.1 Pattern matching

Pattern Matching and Cross-Case Analysis are two analytical techniques used in this thesis (chapter 3). Few design and planning differences in requirements and constraints of Case Studies I and II projects listed in the table 5.6. Although they affected some design solutions, both projects had many similarities especially in planning approaches.

The goal of using the pattern matching technique is to strengthen patterns' internal validity by identifying what patterns correspond with each other and when and how that resemblance occurs.

Those patterns for example, include architectural elements affected by environmental conditions. The affected architectural elements (Figure 5.15) drive selection of requirements specific to the environment at any location but they require extra attention in extreme climates due to delivery and construction difficulties, limited workforce, and construction requirements (Said 2006). Those elements are:

- Building perimeter and shape
- Insulation type
- Walls, roof and floor structure
- Windows and glazing type
- Dimensions and locations of all openings
- Foundation depth and types
- Finishing materials and insulation.

Case Study I	**Case Study II**
Transportation to the site by plane LC 130 only	Transportation to the site only by a farm road
Balanced weight distribution inside the building	Autonomous structures
Incorporating an active structure to minimize snow drift deposition	Incorporating advanced structural and construction technologies

Table 5.6 Case Studies I and II: design and planning requirements.

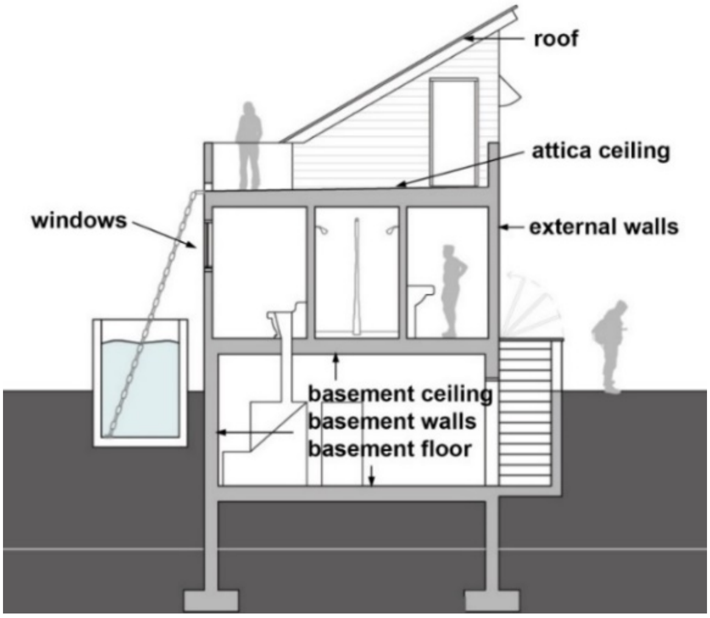


Figure 5.15 Building envelope elements.

These elements require some exceptional attention and design in extreme climates due to logistical difficulties, resources constraints, and human factors challenges that limit selection of design decisions in extreme environments and remote locations. In addition, accommodating building envelope requirements includes providing energy conservation means as part of sustainable design practice. In cold climates, energy conservation for heating is critical and can be achieved by properly selected insulation thickness, minimizing thermal bridges in the building envelope, ventilation with heat recovery, solar heating of domestic hot water and windows with high net energy gain (Svendsen 2005). Avenues to implementation of these practices have to be available for practitioners through design and planning methodologies.

As is discussed in Petersen and Poppel (1999), sustainability needs should be included in project requirements. Successful implementation of sustainable practices in different spheres of human life in extreme environmental conditions depends on many similar factors although they may differ between locations depending on available transportation and resources. Similarities between requirements for sustainable development in Case Studies I and II in the table 5.7 reflect only project-related conditions for enabling sustainability.

Locations	Design and planning	Social	Environmental
Arctic and Subarctic	Depends on availability of local resources and transportation means	Needs professional, personal and group responsibility growth.	Depends on planning process and design adaptability to changes

Table 5.7 Requirements for successful implementation of sustainability in the Arctic and Subarctic settings.

Enabling sustainability in design can seem clear, as it requires implementation of sustainable practices and technologies in design solutions. Yet, in remote locations of the Arctic, it becomes more challenging due to limitations of local resources and availability of transportation. Environmental sustainability depends on adaptability of the design during and after the project's lifetime. It creates additional criteria to the project's requirements, which includes time for changing as a new challenge. Neither case studies projects included analysis of what the project brings to the environment and its settings and what it becomes in its post-operational condition.

Analysis of matching patterns in infrastructure as an important part of architectural planning demonstrated multi-layered and transdisciplinary dependability. Transportation means, on-site existing utilities and available communication connections can dramatically influence site selection, budget and the building design itself. Table 5.8 outlines conditions of infrastructure elements in the Arctic and Subarctic regions based on Case Studies descriptive and explanatory analyses. Communications and transportation can be limited but stable during operational windows (e.g. summer season), some utilities are available but may not be reliable especially during the winter season.

Communications. Establishing a stable communication connection is a priority especially in case of disaster relief operations. Safety, work efficiency, and productivity in any extreme environment also depend on successful communication means. These means have to be restored (disaster response) or established (natural extreme environments) prior to all other developments.

Providing a good means of communication was essential as presented in this thesis Case Studies. Communication issues were included in architectural programming in both cases as a critical element of development plans. Case I had an established satellite communications that had to be upgraded in a new facility (Figure 5.16a) and Case II had a very limited and sporadic connections with nearby villages and urgently needed better communication measures (Figure 5.16b). Because of remoteness of both locations and limitations of transportation, both cases have to provide a certain level of autonomy in their everyday operations and in case of emergencies.

Transportation. Availability of transportation to the site and type of transportation largely depends on site's geographical location and seasonal weather conditions. In Polar Regions in many cases, only air transportation is available which also depends on weather conditions and the time of the year. This leaves only certain types of cargo planes and/or helicopters available and determines payload dimensions and weight allowance. In all cases, time is critical for planning and construction operations and significantly depends on transportation and delivery strategies.

Locations	**Communications**	**Transportation**	**Utilities**
Arctic and Subarctic regions	Limited but stable	Limited but stable (seasonal)	Minimal necessity is available

Table 5.8 Infrastructure elements pre-existing conditions for different extreme settings.

Transportation restrictions in Case Study I (Figure 5.17a) affect design solutions, planning and programming. They also define overall construction schedule and influenced budget allowance. Although in Case Study II (Figure 5.17b) transportation conditions are potentially more flexible but they are highly dependent on weather conditions and availability of required vehicles. Requirements and regulations posed by transportation constraints were primary issues in design and planning proposals in both Case Studies.

Utilities. Sanitary, power and supply utilities usually are almost absent in remote locations, it may take months for establishing support for full operations and temporary measures have to be taken that should become part of overall plan and may be incorporated in planning strategy.

a b

Figure 5.16 a – Summit Station communication dish; b – the only power line connecting Muraviovka park with the nearest village.

a b

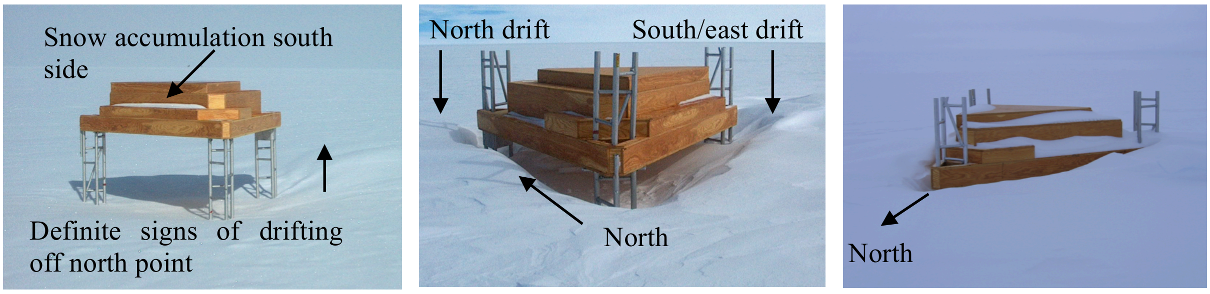
Figure 5.17 a – US Airforce LC130 delivers cargo to the Summit Station; b – a farm road near Muraviovka Park.

5.2.2 Open-ended interviews

<u>**Feedback from scientists and supporting crew**</u>

During two semesters of research and design work on Case Studies I and II projects, regular meetings and reviews with researchers and research supporting crew members were set up to receive up-to-date criticism on a systematic basis (Figure 5.18). Three of the student participants in the Case Study I project and I were invited to the Summit station to give a presentation to the camp personnel after the project was completed and a mock-up installed in its first settings. After the revision of the first stage of mock-up testing, the second stage of testing began in the summer of 2005 (Figure 5.19). The two-staged testing demonstrated key points of the structure that required some design adjustments critical to sustained harsh conditions of the Summit camp. Unfortunately, those adjustments were not implemented into the mock-up and therefore were not tested in real conditions at the Summit camp.

Figure 5.18 Case Study I project presentation at the Summit Science Station in Greenland.



a) Installation at 1’6” height. June 2005.

b) Installation at 10” height. End of July 2005.

c) Installation at 10” height. Sept. 2005.

Figure 5.19 Mock-up testing in Summit camp

Feedback from scientists and the experience gained during the work on the Case Study I project supported the following assumptions:

- Using any possible means to expedite the project to give more time for the architectural design creativity stage rather than spending time on determining what data is needed and how and where it can be collected.
- Project development would benefit from implementing design insights into planning of facilities and operations at every stage of the planning process.
- Methodological approach to planning not only facilitates but also connects design with operational (mission) plan and goals providing opportunities for budget optimization.

The Case Study II project was a result of my close collaboration with the International Crane Foundation and the park's founder and President Dr. Sergei Smirenski. Although the work on the project is over, I continue to have Skype meetings with Dr. Smirenski and occasionally with the park's staff. The project program reflects the fact that a development plan, where attention is equally paid to multiple facets of sustainability, is essential for the park's very survival. Those natural discussions that sometimes assume a form of an open-ended interview contribute important insights on planning aspects in challenging environments:

- A Structured development plan helps to communicate park's goals to local authorities and communities.
- Methodological approach to planning provides opportunities to indicate potential ways for budget optimization.
- Incorporating social and educational goals into design programming is essential for obtaining local support and for overall operational success.
- Creating a stronger bond between facilities design and requirements and the local community's needs and objectives.

5.2.3 Cross-case synthesis

Summarizing and synthesizing the observations collected through descriptive and explanatory Case Studies research reveals dependencies and influences that exist in multidisciplinary design and planning in Arctic and Subarctic regions. Since this research is built on non-experimental methods and qualitative data along with collection of evidence from personal experience, I evaluated those dependencies using the Figures Of Merit (FOM) technique described in the section 3.4.2 of Chapter 3. I qualitatively analyzed the data collected from interviews and questionnaires and included it in the evaluation synthesis. Qualitative methods focus on evidence types and help to identify essential issues that also help to find possible explanations of problems related to planning and design processes in harsh conditions of the Arctic and Subarctic remoteness and environmental challenges.

The issues most influenced by the environment and therefore the most critical physical aspects of design in extreme conditions are structural design elements, infrastructure, and transportation. The criticality of these aspects comes from their influence on fulfilling the project’s goals (in Case Studies I and II – scientific and educational objectives) and human factors. They become principal issues (presented by location) and aspects (presented by project objectives) of the proposed in this thesis planning Matrix. Although some transportation related elements can be considered as part of the infrastructural system, transportation means and requirements have to be evaluated separately because of the complexity of the transportation sub-system.

Case studies and analysis of the collected verbal data outlined basic principles for developing a proposed in this thesis Matrix. Design and planning characteristics described in Chapter 4 projects, identified systems, subsystems and elements that play key roles in the project’s successful development and implementation. These systems, subsystems and elements develop relationships based on levels of dependency from each other and first of all – the environment where they are acting.

Due to the qualitative character of such analysis of dependencies, an appropriate analytical technique has to be applied. Selection of systems and subsystems as Figures Of Merit attributes is based on their qualities and information obtained from evidence sources presented in the case studies descriptive and explanatory components. They provided a foundation for determining and comparing design aspects that are recurrent and specific to already performed projects. That step was necessary for the System Analysis research process and for the logic of a design and planning methodological Matrix.

The Table 5.9 presents FOM for evaluations of dependency levels between Case Studies design planning components and environmental aspects of local settings. For example, both Case Studies project’s structural design depends on environmental conditions at the maximum level due to weather restrictions and unpredictability that is also influencing delivery schedule, transportation availability, and science and educational activities. Contrarily, resources although also dependent on transportation means and availability, depend less on the environment in the Case I than in II due to better and more reliable funding support of scientific and logistical activities.

Table 5.9 compares similarities and differences between cases and helps to visualize and understand the hierarchy of elements from environmental dependency perspective. Evaluation of dependence levels of systems and subsystems is needed for creating hierarchy in the Matrix methodology that is important for successful project implementation.

I compared design and planning patterns of case studies presented in this thesis at element levels as well as at system level when applied to the design and planning processes. Pattern matching is also applied to verbal data analysis that includes structured and semi-structured questionnaires and interviews, and natural conversations about research questions. In addition and in parallel to pattern matching analysis, I applied cross-case synthesis to the collected data in order to summarize the outcome of all types of evidence.

FOM Systems and subsystems	Case Study I	Case Study II
Structural design		
Infrastructure		
Resources		
Transportation		
Sustainability		
Local support		
Science and education		
Social		
Local economy		

The levels are determined as:

Maximum Medium Some Nonexistent or slight

Table 5.9 FOM evaluations of dependency levels.

Application of the pattern matching technique to the case studies also organized corresponded patterns and supported highlighted patterns' essential rationales. First, I extracted patterns of the architectural elements of the projects used in this research as case studies affected by environmental conditions from projects' descriptions. Then I compared patterns found in their architectural programming from the design and planning perspectives. Finally, I concluded with a summary of the collected data that demonstrated reciprocity of design and planning processes in extreme conditions of Arctic and Subarctic regions (Figure 5.20).

Pattern matching logic established relationships between empirically found architectural data with suggested architectural elements or patterns. This approach is applicable for both types of case studies used in this doctoral work; descriptive and explanatory with use of independent changeable patterns. For the descriptive components of the case studies, the projected pattern of specific components such as structural design requirements, were defined before data collection. Related elements are used as patterns for analyzing explanatory components of the case studies.

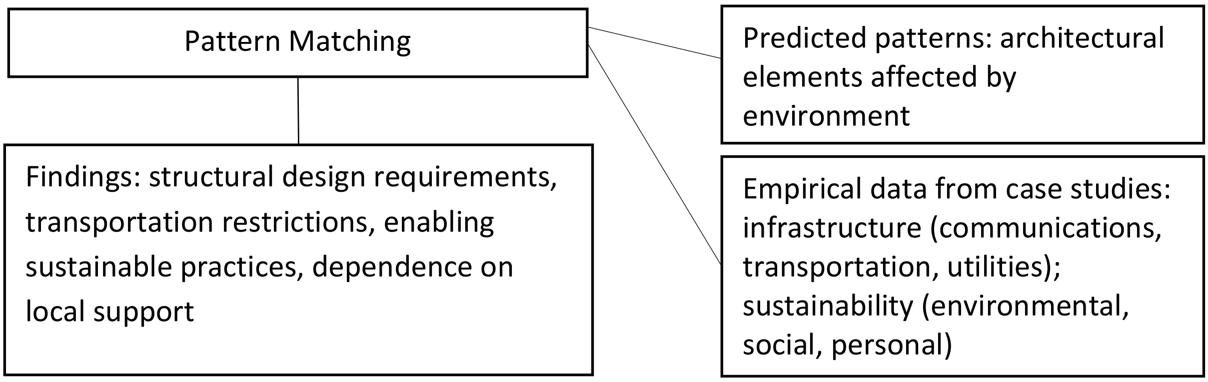


Figure 5.20 Pattern matching analytical technique applied to the case studies research.

Analyzing case studies in order to understand reasons to use the proposed methodology for design and planning processes in case studies regions revealed several gaps in projects development. Understanding those gaps and identifying major principles is critical for creating a design and planning methodology. That step leads to the following stage of research, which investigates possible ways to identify relationships and hierarchy of major aspects of design and planning processes in the extreme environment of the Arctic.

5.3 Evidence explanatory components

Qualitative (non-physical) attributes

Seeing a "big picture" with a Systems Analysis approach (3.3) and treating problems holistically (Nystrom 2002) is important to follow an architectural attitude when handling problems in not strictly architectural areas or disciplines.

A transdisciplinary design approach (Hadorn et al. 2008, Nystrom 2002) that was used for development of this thesis research theory was missing during research and design stages of Case Studies' projects. It is the right platform of knowledge accumulation for complex projects in Arctic and Subarctic conditions that deal with multiple boundaries: environmental, social, technical, professional, and cultural.

Architecture as a collective agency should encourage participants or other agencies to act "otherwise" transferring lines of "agencements" into mapping relationships with time interfering and acting within that web as an additional "agency". If "Consequences of architecture are more important than objects of architecture" (Latour 2004) then connectivity or a "big picture" approach can be an answer to many problems that architectural practice is facing and to overcome difficulties during planning of large-scale developments (Figure 5.21).

Figure 5.21 illustrates the idea how difficulties of dealing with multiple boundaries during planning developments in the Arctic and Subarctic challenging environments transferred into relations as critical elements of a methodological approach. Those relations can make a difference not only in the construction industry but also in society by creating a ripple effect of enabling social and cultural sustainability through personal responsible behavior that enhanced by design and architectural decisions.

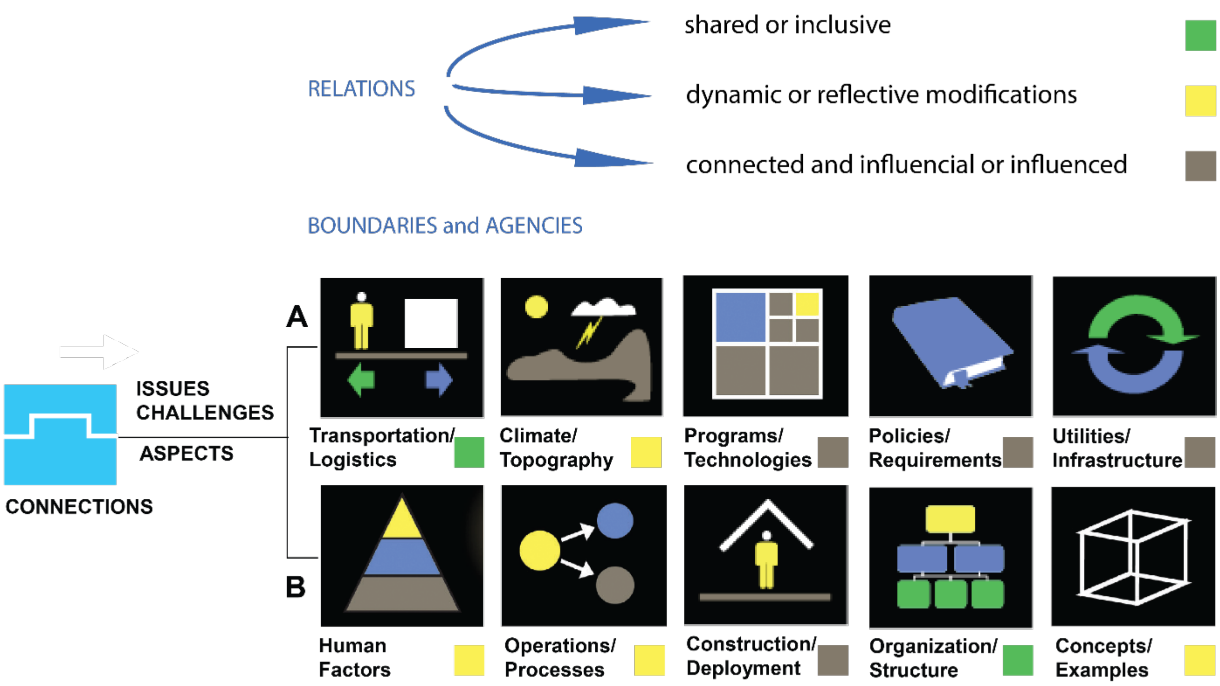


Figure 5.21 Transferring architectural "limitations" into actions through critical architecture and understanding of practice.

Issues or challenges and aspects of planning in the Arctic considered through types of relations they protrude within and outside of their subsystems. In relation to available transportation, they can be shared and inclusive and affected by transportation logistics all at once. Relations can be connected, influential, and influenced at the same time as industry and corporate policies and requirements are influential on project decisions but at the same time, they are influenced by other policies such as local, regional, and state policies and regulations.

Enabling sustainability in all aspects of life, including human factors, economy, society, technology, design, and planning in extreme environments is vital. The technical side of sustainability was partially addressed in the program of the Case Study I project and was one of major objectives in the Case Study II with use of renewable energy sources, energy storage, and recycling systems. The aspects incorporated in the programming of Case Studies I and II projects and proposed for their development plans included:

- Addressing challenges posed by confined conditions
- Optimizing social and private activities in interior planning
- Enhancing quality of life through architectural design, functional and habitable zoning
- Advancing human-machine interactions through ergonomic design solution.

Explanatory components of all the Case Studies include interviews that I conducted with relatively small groups of respondents or individually, with all questions being mostly "open" and respondents were asked to extend their answers. An element of participant observation was also present in the evidence collection that contributed to case studies explanatory components (Figure 5.22). A few interviews were follow-ups to questionnaires distributed to respondents prior to interviewing.

Perhaps the biggest architectural asset is the ability to create an integral view to a problem. Designing a building may seem like the final product of an architect but it is not – a building is much more complex than just a *design*, which is still a key element of the process but not the only one. Understanding of connectivity between design disciplines, involved industries' objectives, user perspectives and functioning of buildings and facilities after construction is over, requires an undivided and connected approach that an architect should be able and can bring to the table. In addition to case studies related interviews and discussions, conversations with Andreas Ruby[19] and Michael Rock[20] during a Communications course (Toorn 2013) organized by ResArc at the School of Architecture in Umea (Sweden), triggered deeper analysis of the role of an architect during planning efforts in Polar Regions and probably other extreme conditions.

Speakers at the panel discussions during the Energy Symposium series at the University of Houston[21] elaborated on many topics that have to become part of planning and design methodology. Kevin Harun, Arctic Program Director at Pacific environment, Jed Hamilton, Senior Arctic Consultant at ExxonMobil Upstream research company, Bob Reiss, American author and consultant on Arctic issues, and Peter Van Tuyn, Managing Partner of Bessenyey and Van Tuyn at Anchorage, Alaska, talked about perspectives of Arctic drilling and exploration, technological and environmental gaps to fulfil and the importance of incorporating knowledge gained from indigenous people of the Arctic.

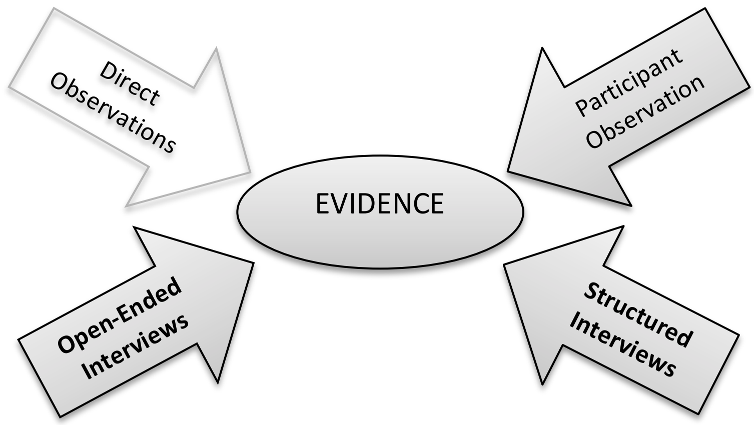


Figure 5.22 Sources of evidence used for case studies explanatory components.

[19] Founder of Ruby Press: books on architecture, art, and other cultural practices engaged in the production of space in contemporary society (Ruby 2008).
[20] Michael Rock is an American graphic designer and recipient of the National Design Award (Cornell University 2010).
[21] Arctic drilling: untapped opportunity or risky business? www.uh.edu/energy

Specifically, Kevin Harum said that “Arctic calls for planning” and that a “more balanced look is needed” there when exploration and even more so, production plans are made. Moreover, with Bering canal becoming next ‘Panama’ canal (as said by Bob Reiss and Jed Hamilton), more activities will be coming to the Arctic and that will intensify logistical problems there even more than it is now (Reiss 2012, Hamilton 2012).

In my after panel interviews with Bob Reiss and Jed Hamilton, they talked about the current practice of rotating working crews every three years, which brings people who are not familiar with this environment and conditions. Non-experienced crew and management make decisions without understanding the real outcomes and consequences of their actions, they do not know what input and proficiencies are needed and what their sources are, and finally, how to communicate their intentions between all involved in the process parties.

5.3.1 Evidence collection from industry and experts

For better understanding of the current situation with energy companies’ exploration plans in polar climates, I reached out to the ConocoPhillips development management in Houston and asked the company’s professionals to answer a questionnaire about their work in extreme environments. I interviewed three ConocoPhillips managers after they answered the questionnaire to summarize and validate the knowledge and the proposed in this thesis methodology. In parallel with questioning ConocoPhillips managers, I used an open-structured approach when interviewing professionals from Fluor[22] engineering company and Shell oil and gas company – Moscow office[23], I also discussed my research and Matrix and asked them to evaluate the need for such a tool for scientists who conduct research in polar Arctic regions and geophysicists who worked on research and recommendations for Arctic Consul (US National Research Council of the National Academies 2014). There is a distinct difference between exploration and production work development and facilitation including planning and preparation work, rigs and site maintenance, and crew rotations. Nevertheless, general logistics, technology and human factors requirements mostly remain the same.

Planning considerations

- In general, an exploration rig can be operated by around 50 people, while production rigs crew size depends on the scale of the project.
- Maintenance and repairing operations in extreme environmental conditions require larger numbers of people involved in fixing a problem in a shorter period of time due to the weather window that is available for operations.
- Only iced roads are used in North Slope for site access for protection of the tundra environment, which also causes strict limitations on transportation requirements (in the case of alpine facility, access is available only during two-month periods).

[22] Fluor – Global Engineering Construction Company, www.fluor.com
[23] www.shell.com.ru

- Crew rotation schedule is based on two weeks on and two weeks off routine that presents additional transportation complications for coordination of different activities (people, supplies, and construction logistics, local communities' demands etc.) and especially in case of emergency situations.
- Planning involves many levels of professionals from different disciplines and multi-number of employees from different contractors and sub-contractors, which creates a higher risk of human error situations.
- Political complications are related to the fact that more restrictions and regulations exist on the Federal level, while the state level authorities are more concerned about revenue for the state and they are more up-to-date with current needs of the state.

Geographical locations of discussed projects

The locations of discussed projects included offshore platforms, Alaska North Slope developments (Figure 5.23), Gulf of Mexico (deep-water), Russian Arctic region, and Northern Alberta County in Canada (Table 5.10). Although the topic of this thesis is planning in Arctic and Subarctic regions, for the fairness of representation of discussions with ConocoPhillips professionals all referenced projects are presented in the table.

Figure 5.23 Trans Alaska Pipeline System (ConocoPhillips).

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

Table 5.10 Discussed ConocoPhillips projects.

Projects' drivers and problems

The schedule was the main driver for all these projects as well as cost and safety for operational projects. All of them were challenged with similar problems: remoteness, logistics problems at different degrees, and communication issues between involved parties including contractors, local authorities, workforce, and the project management.

Existing world tendency of business globalization and at the same time localization of on-site developments including construction work, workforce deployment, supplies delivery, and other support operations, leads to a lack of understanding between the partners involved in the project and creates problems especially at last stages of project execution. For example, according to state rules, 70% of on-site work in Russia has to be delegated to local companies. Those companies enter the project at the final stage of its development and bring new sets of standards and checklists. Similar rules are applied to foreign businesses in other countries.

Challenge

Most operations started in the 1980s, the lifespan of structures was planned for 25 years but it has been expanded beyond that with new discoveries in the region, development of new technologies that allow them now to reach oil and gas resources that were not available before.

Because facilities are used longer than expected and new technology can be re-applied to existing sites, more workforce is required resulting in using the same facilities and structures but with double or triple occupancy.

Although all mentioned ConocoPhillips projects were denoted as successful, the corporate criteria for "success" or "failure" is only based on safety and execution within a given timeframe and budget (ConocoPhillips 2006). 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 might sometimes jeopardize the project flow.

The survey contributors from ConocoPhillips pointed out independently that effective and timely *communications* 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 be necessarily 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.

Although these impacting aspects of success may be applied to projects in any location, the gravity of their impact is tightly related to remoteness of geographical locations, climate, and physical conditions of the site. Tools to address these aspects and issues that result in problems and lead to possible failures should be implemented in design and planning processes through a systematic architectural approach. "*The (architectural) philosophy is centered on what architecture and design* do *over time, rather than what they* are" (M. Nystrom 2002).

5.3.2 Evaluation of related to ConocoPhillips projects standards and regulations

To understand all influencing factors on the existing approach to planning exploration, production and related to them activities in the Arctic, I researched what current standards and check lists are used by energy and other companies there. The projects had to comply with multi-level system of codes and regulations.

On a global level according to Peter Van Tuyn[24], governmental regulations did not improve spill prevention much during the last decades, nor did the Sea treaty help to manage the Arctic offshore developments globally as not all the Arctic countries signed the document. Most developments in the region are managed through international, state, regional, local, corporate and professional codes and standards.

Overview of existing standards and codes used in Alaskan projects

International Standards have to be formulated by an internationally recognized Standards Development Organization (SDO). Standards related to the petroleum and natural gas industries are prepared by the International Organization for Standardization (ISO) and the International Electro-technical Commission (IEC). The standards include regulations for materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries (OGP Standards Committee 2012). The standards also list fire safety, basics for design of structures, and most equipment items that may be used by oil and gas industries and contractors. Those checklists are specific to a particular element and address only technical characteristics of the equipment used aiming to satisfy requirements for performance, quality and application safety.

[24] Managing Partner of Bessenyey & Van Tuyn at Anchorage, Alaska.

Several state and federal organizations provide standards for oil and gas industries in the United States including Occupational Safety and Health Administration (OSHA) of the US Department of Labor and the US Environmental Protection Agency (EPA). Both organizations have lists of requirements that companies have to comply with during exploration, production and utilization stages of development. They list certain activities and operational conditions when those activities are performed. For example, 29 CFR 1926 regulation covers site preparation for oil and gas well drilling and servicing operations including site leveling, trenching, and excavation (Appendix). 29 CFR 1910 covers all other aspects of drilling and servicing operations, and if serious hazards are present at the workplace that are not addressed by a specific OSHA standard, Section 5(a)(l) ("General Duty Clause") of the OSH Act would apply (Fairfax 2015).

Regions develop their regulatory documents as well. Alaskan project of the ConocoPhillips projects had to comply with State Statutes and Regulations Related to Oil and Gas of the Department of Natural Resources, Division of Oil and Gas.[25] As it was stated during interviews with Conoco Phillips project managers, very often local authorities are concerned about profit that the region may receive rather than effective and positive outlook of the project for the local environment and society.

Corporate codes of business ethics and conduct address all business developments without specifying any environment where they apply. The following list of several corporate codes by the company presents general regulations that are exercised cross-environmentally:

- ConocoPhillips
    - Code of business ethics and conduct
    - Health, safety, and environment policy
    - Substance abuse policy
    - Political support policy and procedures
- Shell
    - HSSE and social performance – standards and manuals
    - Impact assessment of company activities
    - CODE of conduct
- Fluor
    - Ethics and compliance
    - Code of business conduct and ethics
    - Political activities policy

[25] http://dog.dnr.alaska.gov/AboutUs/OGStatutes.htm

- Exxon Mobil
    - Ethics
    - Business conduct

Internal and public reports reflect the lack of a multidisciplinary approach. For example, ConocoPhillips company's internal overview of Alaskan assets (ConocoPhillips 2015) identifies that significant engineering, technical, regulatory, fiscal, commercial and permitting issues would need to be resolved prior to a final investment decision on the potential $45 billion to $65 billion (gross) project of Alaska LNG (Liquefied Natural Gas). An attempt to solve those issues through following a checklist approach will be a challenge in spite of a State participation roadmap signed by Heads of Agreement (HOA) in January 2014. ConocoPhillips' Report to the Alaskans (ConocoPhillips 2013) is an effort to outline and explain their corporate position to local communities from multiple perspectives. Acceptance that some of the specific to environmental issues should be emphasized as essential aspects to consider in planning is important but no unified methodology how to achieve that proposed.

Professional or disciplinary codes also cover mostly cross-environmental types of professional work with some standards specifically targeting technical complications of specific subsystems and elements. Examples of professional codes and standards applied for construction in general conditions and in cold climates such as ConocoPhillips projects are:

- American Society of Civil Engineers (ASCE)
    - Design and construction of frost-protected shallow foundations
    - Preparation of construction specifications for civil projects
- American National Standards Institute/American Society of Safety Engineers
    - Safety Requirements for Confined Spaces
    - Safety Requirements for Personal Fall Arrest Systems, Subsystems and Components
- National Fire Protection Association
    - Fire Code
    - Life Safety Code
- American Institute of Architects (AIA)
    - International Code Council (I-Codes)
    - State codes

International, state, regional standards	Corporate and professional codes
Safety	Corporate ethics
Applications	Safety
Technical characteristics of tools, equipment, supplies	Specifications and characteristics of structural elements for conditions

Table 5.11 Current standards and codes.

The overview of international, state, and regional standards, regulations and codes confirmed the fact that they are targeting very specific and limited to certain operation, equipment or procedure. Compliance with them while providing some assurance of safety for people and/or environment does not ensure that all involved in the project parties will communicate and adjust their decisions with each other on time. In the case of corporate and professional codes, they are addressing generic issues without differential considerations to conditions of the project location (Table 5.11).

Following checklists' standards does not guarantee project's success or human error mitigation, nor do they provide a good platform for multidisciplinary collaboration during project preparation, design, planning and implementation. In fact, as all interview respondents acknowledged, that following established procedures and filling in regulatory checklists do not necessarily lead to success unless good and effective communication procedures are available for all parties involved in the project. A new methodology for decision based design approach is needed to enhance communication while providing real-time feedback on already applied decisions.

5.4 Chapter Summary: Analyzing case studies applied strategies

The lessons learned summarized in the end of the case studies chapter include parallels between case studies aspects and issues within their environmental boundaries that include correlations in human factors and activities, and building and utility systems. To develop the design methodology, identified case studies projects similarities are used for outlining core elements and defined by them subsystems in the table 5.12.

Case Studies design solutions included accommodation of special structures (e.g. trombe wall structure in Case Study II), solar panels and battery storages, electric and solar water heating, baseboard heating system (Appendix). Building systems similarities between case studies include:

- Avoid heavy construction (I, II and ConocoPhillips projects)
- Minimize impact on environment (I and II)
- Enable modularity in building and system design (I and II)

- Apply proper zoning based on functions allocation and activities(I, II and ConocoPhillips projects)
- Pay equal attention to design of living accommodations, research facilities and support structures (I and II)

Utility systems and support structures also share similar requirements and considerations:

- Facilitate emergency care (I, II and ConocoPhillips projects)
- Maximize renewable energy utilization (I and II)
- Apply advance systems for collection and recycling waste materials (I and II)
- Provide close proximity between critical structures and functions (I, II and ConocoPhillips projects)

Environmental and geological similarities	**Personnel profiles and activities correlations**
Temperatures are as low as –50°C during the wintertime (in some locations the temperature drops to the minimum occasionally).	Researchers and crews are typically well educated and motivated with high devotion to mission and research goals.
Wind range can reach 21 meters per second. Snowstorms in these locations create similar snow drifting difficulties.	Crew who are cut off from outside resources and services for long periods of time are forced to adapt and become self-reliant. They must confront difficult problems with determination, innovation and teamwork.
Arctic and Subarctic locations experience seasonal long days and nights, thereby affecting surface operations. The Arctic has almost 5 months of darkness and extreme cold.	Remoteness imposes restrictions on living and work facilities, amenities and operations. Construction activities, for example, are constrained by seasonal weather conditions, limited available equipment and small labor crews.
The permafrost environment in Greenland is similar to surface conditions in some Subarctic areas.	Environmental safety and conservation is a high priority in Greenland and in privately operated park for sustainable land use.

Table 5.12 Case Studies I II and ConocoPhillips projects similarities.

Following the identification stage of correlated aspects and issues or challenges between projects, the next stage of the research combines discussed in the chapter 4 concepts with case studies results. That will become a foundation for the Matrix methodology itself. The example of the case II project when agricultural input from related disciplines and specialists was not sought during the project development illustrated how the need of an interdisciplinary input was missing during research and design stages of Case Studies' projects. The work on the case studies projects was conducted following strictly architectural or engineering design organizational approaches that did not engage in the process inputs from other disciplines and practices.

Retrospective reviews of two finished student projects are examined in this thesis to find out if there would be differences in the final product without and with application of the proposed Matrix (Figure 5.24a). As a result, connectivity of several sub-elements that were not present during the conducting of the projects emphasized and analyzed how their absence affected the final design solutions. Those missing components are not considered to be additional components but rather prerequisites and/or requirements that would help with identifying the next steps of design and planning process and making design decisions. Similarly to Case I, the Case Study II project, although the park enthusiastically involves the public in its activities, it did not rely or did not take into consideration connections to local communities as part of new developments, until after the project was conducted. Eventually, with legal controversies and social discrepancies, the park's development plan can be used as a communication means between different social and professional groups and parties. During the work on Case Studies I and II projects, designs and planning processes were based strictly on an architectural approach. In spite of the fact that scientists and logistics company representatives participated in projects discussions, the design process did not anticipate involvement of local communities, including policy makers for existing and future region development, adaptability of the project design during and after project timeline. Missing sub-elements of the design process were determined through discussions with I and II Case Studies projects' operation managers, logistic workers and researchers and includes:

- Local needs and requirements beyond project lifetime
- Social connectivity beyond project limits through conjoint learning and problem solving
- Interdisciplinary collaboration

ConocoPhillips projects developments were taken following commonly used, corporate and professional checklists. That resulted in not integrating even more important sub-elements of design process and obviously handicapping human factors related design aspects (Figure 5.24b).

Missing sub-elements of the design process in ConocoPhillips projects include:

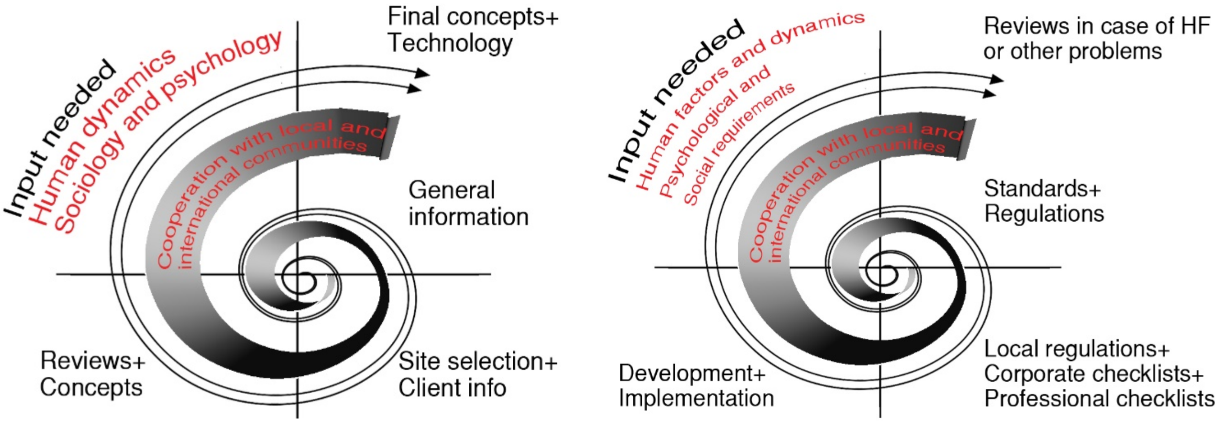
- Architectural factors and considerations, including adaptability of the design as a project criteria
- Psychological aspects influencing design and planning

- Social requirements and tendencies beyond project limits through conjoint learning and problem solving
- Interdisciplinary collaboration

In contrary to Case Studies I and II, ConocoPhillips projects were planned and developed based on the company's standards and by-laws and without architectural involvement or approach to design process. As a result, projects' development missed human factors psychological aspects, potential for participatory design, social and human-centered design collaborations and contributions.

During the work on ConocoPhillips projects, managers and engineers followed common engineering planning practices that were based strictly on satisfaction of accepted and required regulations. Although there are new tendencies to maximally incorporate sustainable and environmentally friendly technologies during preparation and execution of projects in the Arctic and Subarctic regions, that scientists and logistics company representatives participated in projects discussions, the planning process did not anticipate involvement of transdisciplinary input from local communities, including policy makers for existing and future region development.

Missing sub-elements in all Case Studies can be indicators that planning and design processes are not balanced. They should have been considered to be 'red flags' indicating that certain input from suggested resources had to be sought and project development cannot proceed without it.



a Architectural design process:
Case Studies I and II: Summit station
and Muraviovka Park.

b Corporate project development process:
ConocoPhillips exploration and
production sites in Arctic and Subarctic regions

Figure 5.24 Design process divergences in case of Matrix application: a – Case Studies I and II; b – ConocoPhillips projects.

6 Modeling the Matrix

To this point, this work has been built upon research steps to progressively increase the integrity of the Matrix methodology. Beginning from the understanding of case studies components and their analysis, the research continued with summarizing human factors and extreme environment influences, conceptualized ways to enable sustainability into practices and understanding of real outcomes of all efforts. These issues need proper addressing in all extreme environments as they characterize the following planning and design factors that drive or significantly influence option requirements and assessments:

- *International factors* encompass considerations associated with program participation involving multiple nations, including policy and law implications, cooperative relations, contributing assets and capabilities, and potential benefits and risks.
- *Human factors* address ways that mission planning influences such priorities as crew/workforce selection and training, habitat design, and health maintenance and safety.
- *Environmental factors* examine ways that environmental conditions will affect human and equipment operations, including special influences and hazards.
- *Geographical factors* address correlations between the site location and various project or mission goals including international science and local resources utilization opportunities, delivery and surface transportation options, habitation, and operational support requirements.

The final step is to develop a systematic approach and methodology Matrix that would enhance planning of construction developments in extreme conditions. Its effectiveness can only be confirmed with time and through new projects applications; but methodology validity can be achieved through application of validation elements presented in the section 6.4. The research problems were investigated through exploration of measures that are needed to improve the current situation in planning and designing for extreme environments and particularly in the Arctic and Subarctic regions. The proposed methodology also frames organizational relationships between systems and subsystems elements and phases at any stage of the planning process in extreme Arctic conditions and includes implementation of sustainable practices. Maintaining proper hierarchy of elements, subsystems and overall systems is important for survivability of complex systems such as environmental systems and societal organizations. The Matrix takes into account hierarchal requirements and includes them into its logical path.

The planning Matrix idea is significantly based on the necessity of applying transdisciplinary and participatory design (Nicolescu 2010, McGregor 2004), and “systems of systems” approaches to design and planning processes (Chang 2011). Matrix logic comes from understanding the elements of design and planning processes connections and relationships along with suggesting corresponding modes between various spheres of human activities in the Arctic.

The planning Matrix applied to a transdisciplinary design process brings a resilient aspect into a newly developed system making a pre-existing system easier to adapt to new conditions while letting new components adjust to existing conditions. *"Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist"* (Holling 1973, p. 14).

The Matrix therefore has to offer a logical means to address:

- Design stages and involvement of essential disciplines at every stage of the planning process
- Scale and intensity of involvement of all included disciplines
- Input and evaluation methods
- Output handling and integration
- Lessons learned to apply and re-apply in design and planning developments and in further advancement and optimization of the process

Research presented in this thesis has resulted in identification of specific issues present in extreme environments of Arctic and Subarctic regions. This chapter demonstrates how the Matrix summarizes, categorizes and organizes planning and design aspects caused and produced by related issues.

6.1 Influences and correlations

Analysis of Case Studies and collected verbal data (chapter 5) demonstrated a certain correlation between recurrent design aspects that can be addressed in the design process in a similar way. In general, correlations exist between variable aspects when they are related to each other in a certain way. Structure-related aspects for example, include approach to structural elements and technologies selection, requirements for overall structural integrity, and payload adjustments to available types of transportation to the site.

Shared outlook on the problem solving process between architectural, engineering, environmental, and social professions has to become a part of a common methodology for planning, design and other developments in the Arctic and other extreme environments. The table below summarizes structural and infrastructural recurrent and specific to case design aspects (Table 6.1).

	Structure	Infrastructure
Recurrent aspects	Avoid heavy construction needs; Interior zoning; Use of renewable energy; Use of recycling systems; Apply tight building envelop; Optimize elements packaging for efficient transportation.	Plan for restricted transportation windows; Site zoning; Minimize environmental impact.
Unique aspects		
Case Study I	Strict limitations applied to mass and dimensions of structural elements; Structurally balance weight distribution; Incorporate automatic and robotic systems.	Year-around assembly operations are possible; Limited transportation means are available (only by LC-130 planes from Kangerlussuaq air force base)
Case Study II	Constrained construction and assembly time; Many transportation means are available but limited for economic reasons.	Few transportation means may be available (by train, airplanes and Amur river to Blagoveshchensk and by car to the site) but limited due to economic and weather conditions. Need for economic and social sustainability

Table 6.1 Recurrent and unique physical design aspects.

Other recurrent influencing aspects are associated with human factors (chapter 4). They are combined under non-structural, human dynamics category of systems where psychological, societal, cultural, and mental challenges demonstrate comparable levels of stress and other risk factors (Table 6.2).

Refinement of design requirements based on the summary of design aspects presented in Tables 6.1 and 6.2 is discussed in subchapters 6.2 and 6.3. A set of requirements composed in accordance with recurrent design aspects is a key element of the proposed planning Matrix.

A transdisciplinary, comprehensive approach includes highlighting influences upon general habitat requirements, constraints upon delivery and construction, and special provisions for safety and hazard interventions (Mode 2). Recurrent and diverse design influences 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)

	Individual	Group
Recurrent aspects	Psychological: motivation for excellence in performance; Acceptance of some hardships and challenges. Physical: regular exercising, demand for personal spaces.	Social and cultural tolerance; Educational outreach programs for local communities and visitors; Staff seasonal rotations.
Unique aspects		
Case Study I	Total isolation during winterover operations	Lack of social or other group activities other than scientific researchers visiting.
Case Study II	Partial isolation during winter months; very limited transportation means are available.	Involvement of local communities in some activities and being involved in local events.

Table 6.2 Human dynamics recurrent and specific aspects influencing design.

Analysis of human error contributing factors and possibilities of incorporating preventive measures into the design and planning process is based on discussions with industrial engineering specialists at the University of Houston and professionals from NASA JSC (Johnson Space Center) who are involved in a collaborative effort in occupational error and fatigue factors research. This thesis incorporates part of the Energy and Natural Resources Research Cluster's[26] work that responds to demand from oil and gas companies to research human factors influences and human error preventive measures not only in the Arctic and Subarctic regions but within the energy industry in general. The industry's goal is to receive a better methodology that addresses human factors and human error issues during planning and coordinating work in challenging conditions.

The research findings of this doctoral work and the logic behind them are proposed to be organized into a programmatic tool after more data is collected from application of the Matrix logic to large-scale projects in the Arctic. Operational data for that purpose has to be listed in a form of tables (Helmers 2010) with attributes and features linked to suggested information resources. The subchapter 6.2 depicts this logic in hierarchy diagrams based on relationships between the planning matrix as an overall system, its subsystems, connecting elements and elements.

[26] Energy and Natural Resources Research Cluster is one of the six University of Houston's research clusters that concentrates on environmental issues, such as ecology and conservation, through discovery and recovery of fuels and alternative fuels and through particle physics and space radiation.
http://www.uh.edu/research/about/clusters/energy-nr/

6.2 Connections and relationships

The first stage towards an integrative methodology creation is establishing priority and hierarchy of subsystems and elements to organize the data received from different sources properly. Subsystems and elements connected when they have dependencies one on another, their connections become relationships when subsystems and elements begin sharing some activities and requiring responses. Preliminary assumptions of design Matrix elements and their relationships are depicted in the Figure 6.1. The first level of relationships focusses on issues affecting design and aspects of life that may also be affected by design solutions. Aspects and Issues are subsystems and include other subsystems accordingly. Each subsystem identified by relationships between its subordinate subsystems and elements. The second level of relationships narrows down influencing issues and affected aspects of the planning system (Figure 6.2). The Matrix evolves and expands from the basic or preliminary assumptions to subsequent levels of relationships through application of transitional connecting elements. For example, functions and operations of the 'Aspects' subsystem develop and narrow down to project sub-elements requiring input from diverse disciplines that are specific to the project's essentials. Human dynamics connecting elements require input from resources and professionals from sociology and psychology and provide a linkage to local cultures and societies, while human factors connecting functional and operational aspects to working and living planning requirements with the help of an architectural discipline.

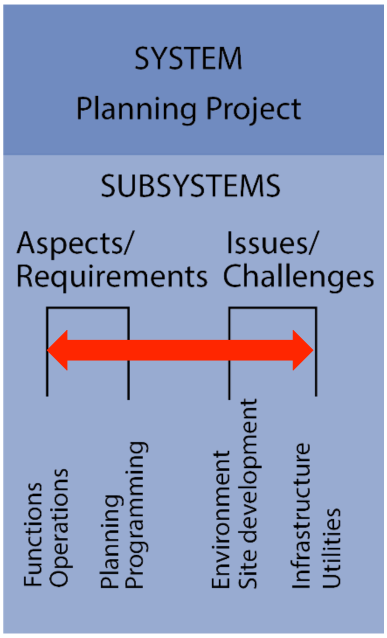


Figure 6.1 General assumptions of planning Matrix elements.

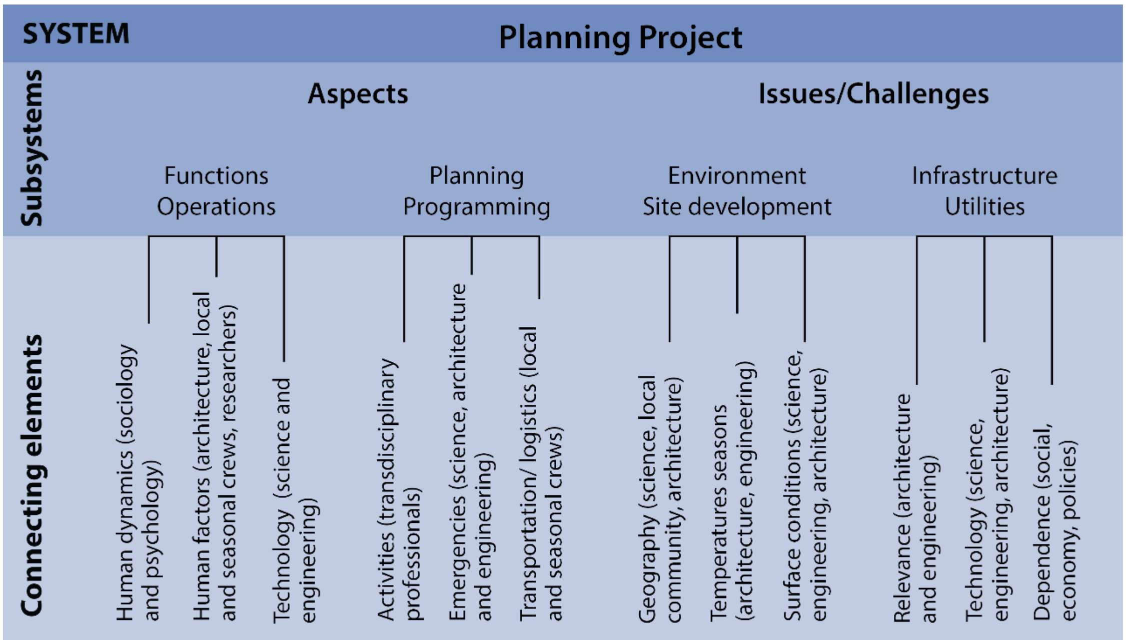


Figure 6.2 Planning project subsystems.

Subsystems of Issues/Challenges also consist of a number of narrower subsystems and elements. For example, the Planning and Programming subsystem can include site development activities with requirements in surface preparation, power and sanitation, core facilities and support equipment. Design considerations for those requirements are elements of the Planning and Programming sub-system.

These diagrams do not represent a sequence of events during the planning and design processes but present a "systems of systems" logic of the planning matrix. Therefore, connecting and sub-elements have to be present throughout the whole process and every stage of the development of the project and its implementation.

6.3 Applying systematic approach logic

A Systematic approach aims to generate an optimized planning tool that will assist planning and design practices in demanding conditions of extreme climates. Retrospectively applying it to case studies and analyzing how they were conducted allows it to identify 'red flags' of non-considered factors during design and project development. In addition, the model presents general characteristics of a successful planning tool (Assar 2012) that include:

1. *Reducing uncertainty*. Unforeseen situations are very common in extreme environments including Arctic and Subarctic conditions due to weather, geographical and geological conditions, policies and social challenges (subchapters 4.2 and 4.3). Some unforeseen problems can be at least partially predicted through implementation of a systematic approach. A comprehensive planning tool helps to plan for complications that may be also caused by changes in technology, social structures, government regulations and requirements.

2. *Resources utilization optimization*. Resources, materials, and infrastructures are very limited in Arctic regions as it was discussed in case studies of Greenland Summit Science Station and Muraviovka Park for Sustainable Land Use projects (subchapter 5.1). Proper planning offers effective and accurate utilization of available resources. Including identification of resources needed for reaching developments towards the project's goals and the ways to achieve them.

3. *Increasing of organizational effectiveness*. Extreme conditions impose constraints for deployment, construction, and maintenance operations (subchapter 4.2). Planning insures maximization of overall organizational effectiveness at every stage of planned developments

4. *Reduction of development and maintenance costs*. Development and maintenance costs can be significantly reduced by effective application of time, resources and materials in accordance with an associated project stage(s) (subchapters 4.2 and 4.4).

5. *Proper coordination of efforts*. Complexity of planning for extreme conditions requires a high level of coordination of all involved in work development disciplines with a systems analysis approach (subchapter 3.3).

Since planning is *"a process, a collection of tasks and activities that leads to a desired result"* (Helmers 2010) its logic has to be analyzed and synthesized as a hierarchy of systems, subsystems and elements.

To provide computational parameters for the Matrix connections between subsystems and elements and between elements within subsystems, Boolean operators will be used to help automate the decision Matrix process: in case of high dependence of elements, the Boolean operators will qualify one of the elements to be present only when it accompanies another. Another operator will be implemented when elements can be used instead of each other or when one of them can be disregarded. Such logic is usually referred to as Decision Tree Analysis (DTA) (Schluyler 2001) and is applied when multiple factors have to be considered and evaluated. The DTA has to be included in the planning Matrix but it does not define it, there are many Matrix elements that are irreplaceable although they may have different characteristics.

Computational configuration of the proposed Matrix enables its organizational structure to have integrative and interactive qualities. It belongs to the Mode 1 of the platform of knowledge, enables data collection from the Matrix during the application process, and after the planning Matrix was applied (Figure 6.3).

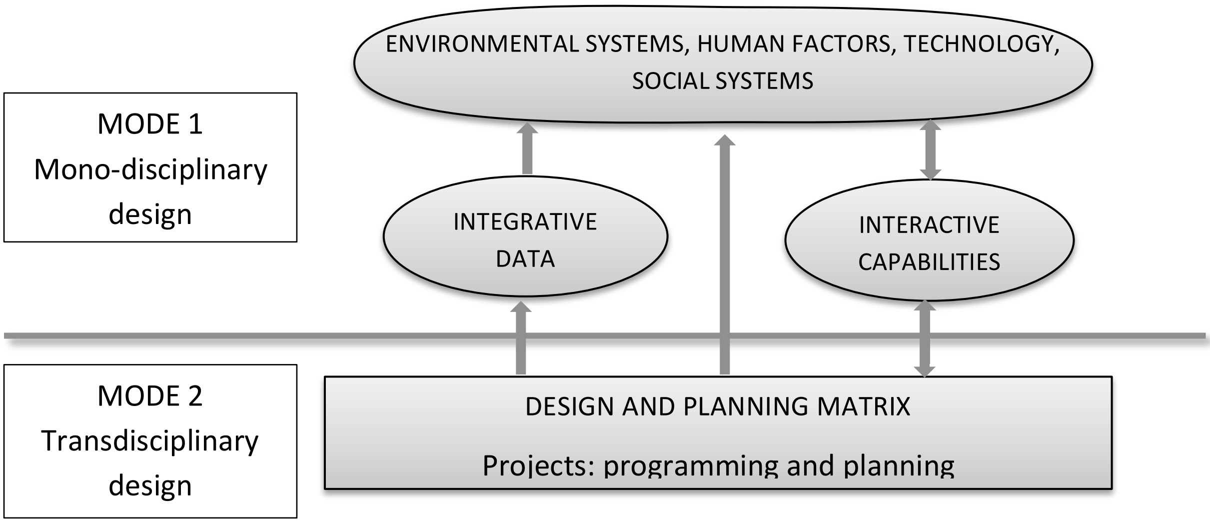


Figure 6.3 Mode 1 with testing capabilities for the planning Matrix.

Integrative qualities of the Matrix organizational structure include collecting multidisciplinary data and professional expertise for transdisciplinary design and planning in Mode 2 and transferring proposed solutions to validate in Mode 1. After the validating stage, the results have to be relayed into the Matrix tool using *interactive capabilities*. Integrative qualities of the data characterized by integration of the data that comes from different sources (subsystems), bringing them together and making sure they are properly related. The difference between integration and interaction is that integration is meant to bring together different systems and subsystems, including people and their activities physically or functionally and to provide proper conditions for such connections. While interaction is a kind of action that occurs between two or more systems or subsystems, or people and system(s) affecting one another.

Geographic Information System (GIS) has also interactive and integrating qualities that "allows to view, understand, question, interpret, and visualize the world in ways that reveal relationships, patterns, and trends…"[27] The Matrix can offer the same potentials while including human factors and behavioural components along with an architectural approach to design and planning. That allows simultaneously work on several interrelated issues such as, human factors, transportation, environmental responsibility, and technology readiness (Figure 6.4).

[27] http://www.esri.com/what-is-gis/howgisworks

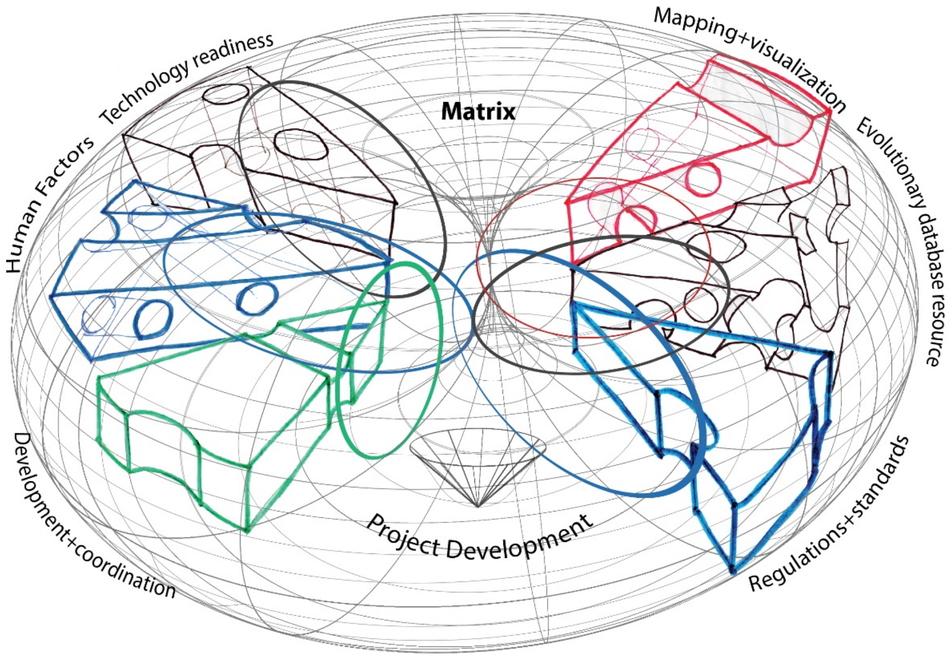


Figure 6.4 Visualization of interconnected project components.

Built upon figure 4.2 from the chapter 4, figure 6.4 advances the idea of a multi-dimensional diagram where direct dependences and influences and indirect connectors represent conditional and permanent relationships between project components. The integrative nature of the Matrix methodology serves and facilitates communications between them. Following GIS approach it becomes a multi-functional tool (Table 6.3).

6.3.1 Matrix modeling

Matrix' subsystems can be combined into three Matrix' major systems: project requirements (programming with descriptions of operations and functions), environment-related challenges, and site-related pre-existing and current issues. Every element of the Matrix therefore has three categorizing qualities. Hierarchy of the subsystems within systems is subject to their level of dependency and importance (Figure 6.5). While environmental challenges and site-related issues hierarchies remain the same, project requirements order may change depending on project objectives and scale and with evolution of the project. That is explained through an example of an on-going ConocoPhillips project in North Slope Alaska, Greater Mooses Tooth 1 (GMT1) drilling site, which is an expansion of recently completed Colville Delta site CD5.

The schedule of the GMT1 project follows a strictly linear engineering process that is monodisciplinary with occasional multidisciplinary inputs requested by the engineering team from other than engineering fields (e.g. law or economics) (Figure 6.3).

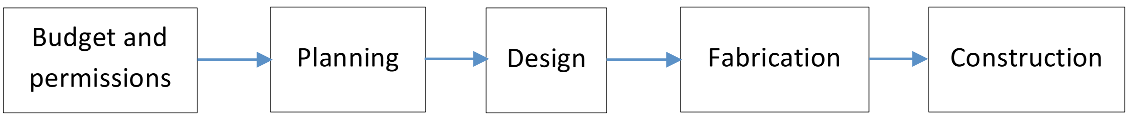


Figure 6.5 Engineering process applied for GMT1 project.

Elements	Characteristics
Human Factors and dynamics	Offers a dynamic information system correlating diverse issues and options. Identifies specific issue-driven risks, opportunities and requirements. Supports establishment and tracking of performance criteria.
Development/ Coordination	Facilitates conceptualization and monitoring of complex, multi-track program activities. Promotes participant awareness of ways their contributions influence the total program. Affords a platform to introduce and integrate diverse outlooks into planning/decision processes.
Technology readiness	Sets testing objectives. Provides disciplinary components for testing purposes. Combines results for further analysis.
Mapping/Visualization	Highlights interconnected issues, requirements and considerations. Presents on-demand system and process examples along with referenced information sources. Provides information on a need-to-know basis with on-demand amplification of details.
Evolutionary Database Resource	Affords an expandable platform and format for continuous knowledge upgrades. Facilitates discovery of information gaps warranting priority attention. Encourages cooperative targeting of planning and investigation resources upon vital topics.
Regulations/Standards	Categorizes international, state and local regulations. Distributes awareness of existing requirements in relation to project specific needs. Identifies stages of project development when certain input is necessary for advancement.

Table 6.3 Characteristics of Matrix elements.

ConocoPhillips engages local stakeholders in projects by using local companies' services to support company's (ConocoPhillips) activities. A number of ASRC (Arctic Slope Regional Corporation) providers, organizations and groups benefit from such engagement in the North Slope including ASRC Energy Services, ASRC Federal, ASRC Construction Holding Company, Petrostar, Alaska Growth Capital, and Little Red Services[28]. All these companies serve as CP contractors and subcontractors and depend on the company's support and approval.

Gradually, since the Trans-Alaska Pipeline System (TAPS) was opened in 1977, several programs have been created to oversee developments in the North Slope counties. Currently, National Petroleum Reserve-Alaska (NPR-A) Impact Grant Program serves to provide grants to eligible municipalities to overcome negative impact on the environment and people of the North Slope caused by the oil and gas production. The impacts considered by the program include those related to: population, employment, finances, social and cultural values, air and water quality, fish and wildlife habitats, and the ability to provide essential public services (health care, public safety, education, transportation, utilities and government administration). The process of establishing connectivity between 'new comers' of energy companies in Alaska took many years but in spite of the gained experience, there are still occasions of miscommunications and misunderstanding resulting in costly later adjustments of project decisions. Those occasions were brought up during post-questionnaire interviews with ConocoPhillips managers. More so, associated with such problems, challenges are more dramatic at not so well explored locations such as Alaska sites.

The purpose of the Matrix methodology applied to the GMT1 project development is to demonstrate how the transdisciplinary logic of the Matrix methodology can identify most critical points (informing elements) of the project development. Figure 6.6 includes systems that need attention in any planning process and with reference to the Arctic conditions: project requirements, environmental challenges, and present situation of conditions and physical structures at the project location.

[28] https://www.asrc.com

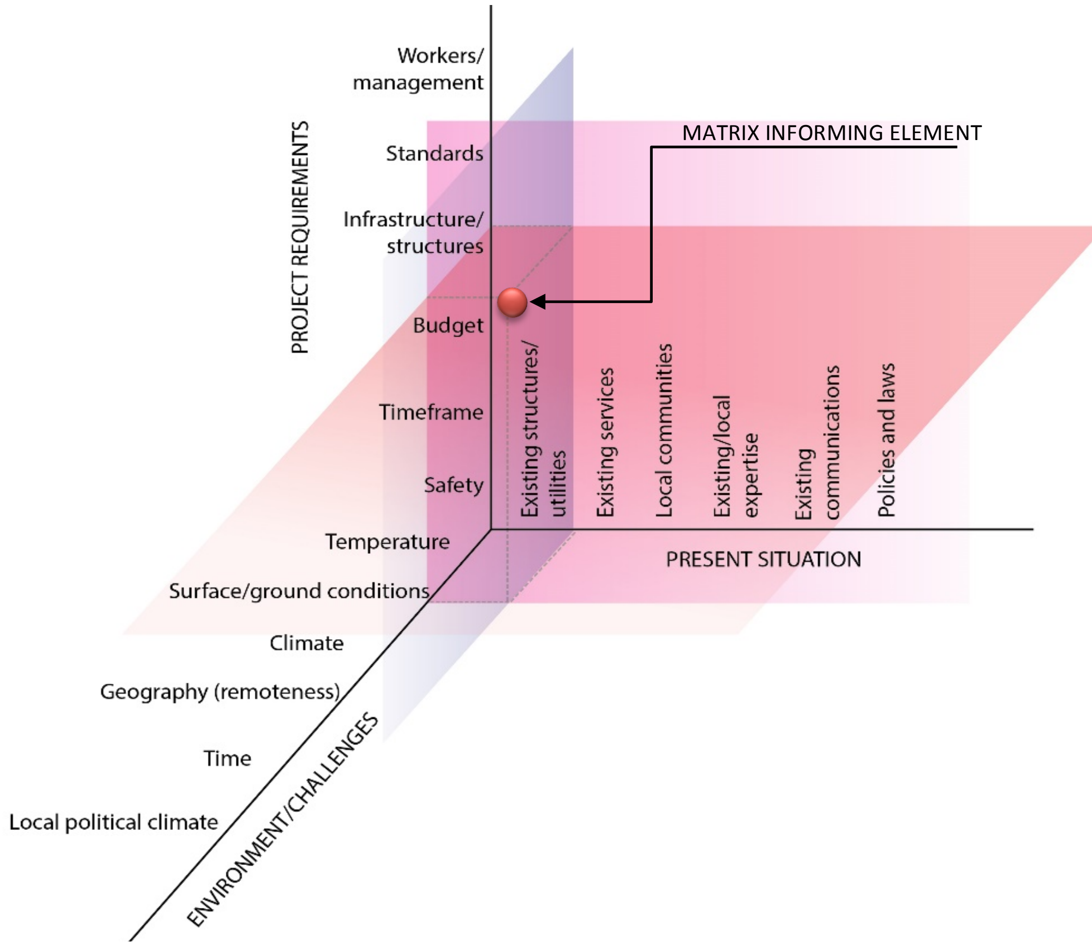
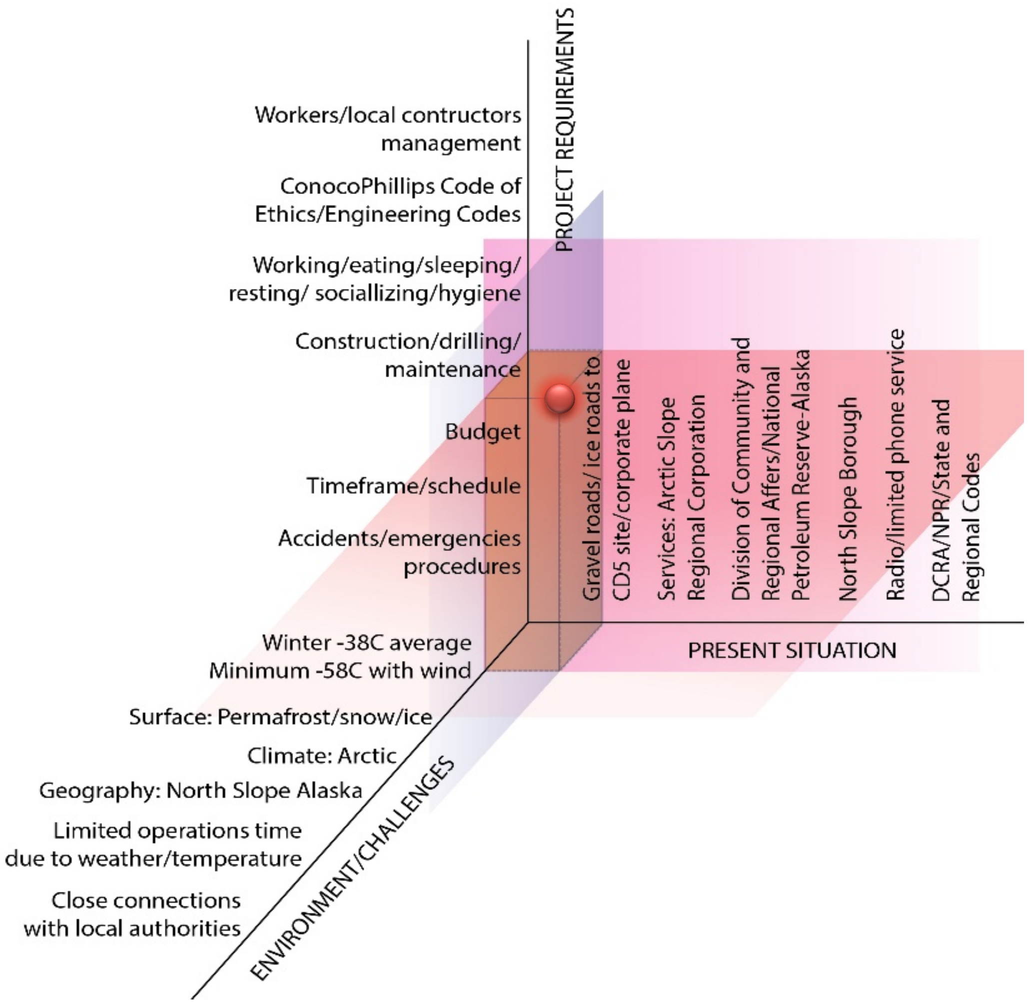


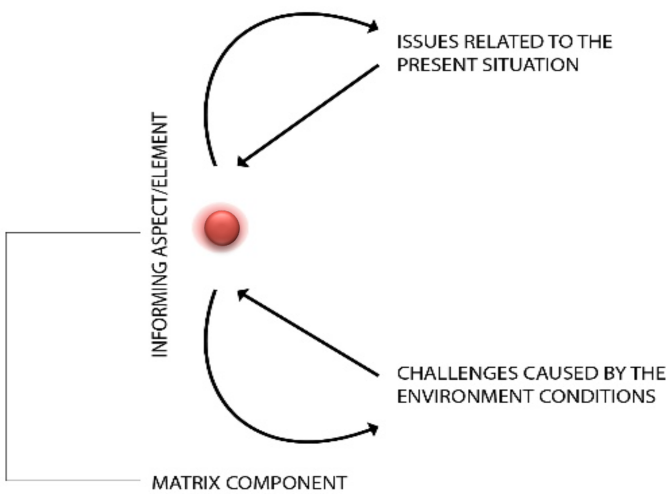
Figure 6.6 Subsystems and elements to consider during a planning process.

The figure illustrates how elements of the Matrix methodology are created. The points of value (Figures Of Merit) of each system 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 strongly on the temperature conditions and availability of existing structures and utilities at the location. Intersection of these systems creates a Matrix informing element. In the Figure 6.7 the systems are broken into subsystems according to the selected simulation project: GMT1. The project requirements for construction, drilling and maintenance operations are challenged by the temperature conditions, and availability and conditions of the roads at the site.

Closer to the axes intersection point the informing elements represent the correlated and most critical components of the Matrix. The hierarchy of subsystems here is defined based on the analysis of the case studies along with the literature overview of projects conducted in the Antarctic, Arctic and Subarctic regions. Such intersections can happen from connections of every project requirement with issues and challenges associated with the site or may become weaker as a result of advanced site conditions and availability of services. For example, GMT1 site is an extension of the CD5 drilling site that has already gravel and ice roads therefore only extra 6 miles (9.65 km) needed to be built for the construction of GMT1 site.



a



b

Figure 6.7 a **-** GMT1 project planning subsystems; b – Matrix methodology component.

The Matrix logic defines the most critical for the realization of the project aspects of the planning process. They help to recognize resources and expertise to be included in the planning before the planning process begins at earliest stages of the process. The pattern of the critical aspects may change depending on a project mostly because of the present site conditions. For example, in the case of the GMT1 project site conditions have advantages of the previous work done by the company in its vicinity.

Informing aspects/elements create sets categorized by their urgency to the project's successful implementation and close correlations with subsystems (Figure 6.8). In the GMT1 example more critical informing elements identified with emergencies procedures affected by the site geography and infrastructure conditions, project timeline influenced by weather conditions and local services and workforce, crew living and working needs challenged by the site geography and conditions. Less critical or urgent elements are associated with living conditions of local workforce under influences of regional groups and communities that may be less concerned with site remoteness. That translates into a certain hierarchy of the aspects/elements sets. Subjectivity of this process opens the possibility of failure but inclusiveness of the process lowers that risk. Aspects sets instigate new project criteria: project adaptability to the environment during and after its timeline. That criteria needs expertise to draw scenarios about the future of the region from economics, demographics, climate scientists, geologists and more.

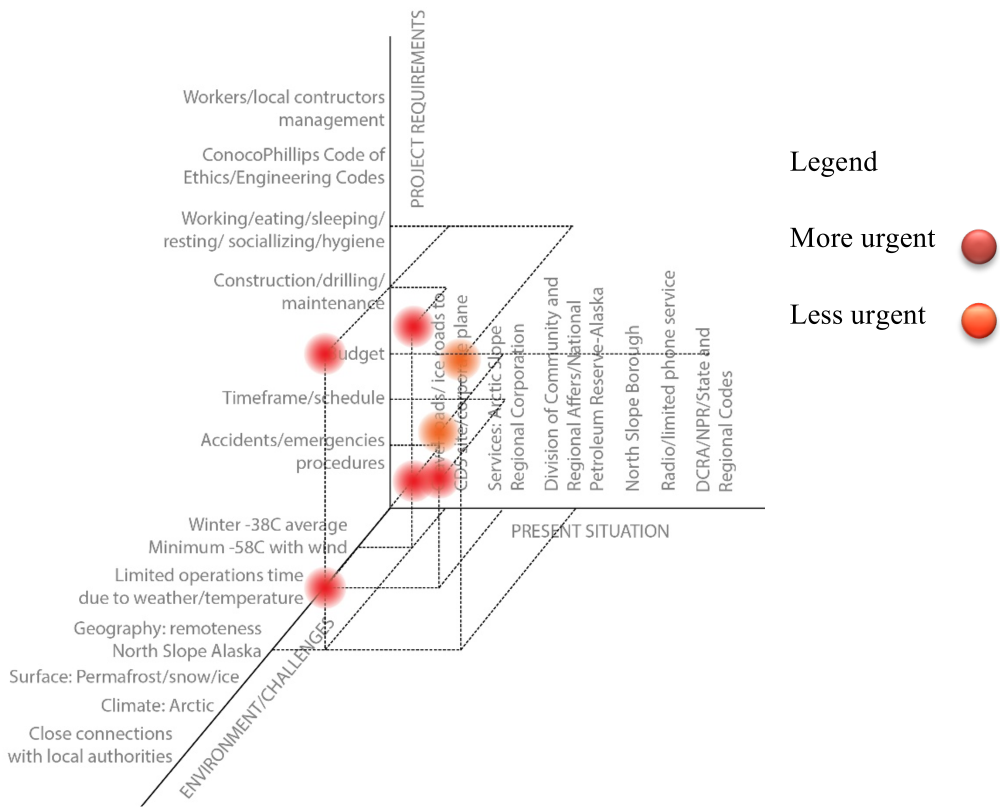


Figure 6.8 Matrix logic applied to the GMT1 project and site conditions and environment.

6.3.2 Matrix methodology simulation

The Matrix methodology needs to be utilized concurrently when a decision to start a large-scale project development in the Arctic is made and confirmed. Applying the multilayered spiral model presented in the chapter 3.3, the steps of project development include additional inputs from selected multidisciplinary sources and can be identified as the following: initiation, integration, interaction, and inversion. The application steps refer to two major stages of the project development process: starting the project and after that, work on the project. Matrix components inform what participation is required for the planning of the project from the beginning and throughout the process.

Project description: Alpine satellite CD-5 (Colville Delta) consists of a production drill site approximately 6 miles west of the Alpine field (Figure 6.7). The site can be accessed via a gravel road from the Alpine road system. The production from CD5 is transported with flow lines to Alpine for processing. During the construction, materials are moved over ice roads to Alpine and staged for installation during the winter.

Drill sites Greater Mooses Tooth 1 (GMT1) and Greater Mooses Tooth 2 (GMT2) are extensions of the Alpine Drilling Site CD5 project completed in 2015 (Figure 6.10). GMT1 construction is planned to begin in 2016 and to be completed in 2018, GMT2 development depends on the GMT1 schedule. The GMT1 project is selected for Matrix methodology simulation for the following reasons: it is a new project, it is connected to the recently finished CD5 drilling site, the project is funded and has to be finished within the budget and timeframe. The engineering stage of the project is under development right now and scheduled for completion in 2016 with construction phase to begin in 2016, and first production is expected in December 2018 (Figures 6.9 and 6.10). The peak employment during the construction stage of the project is estimated to reach approximately 700 people. The fabrication will be mostly done in Anchorage and transported to the site after construction of the roads.

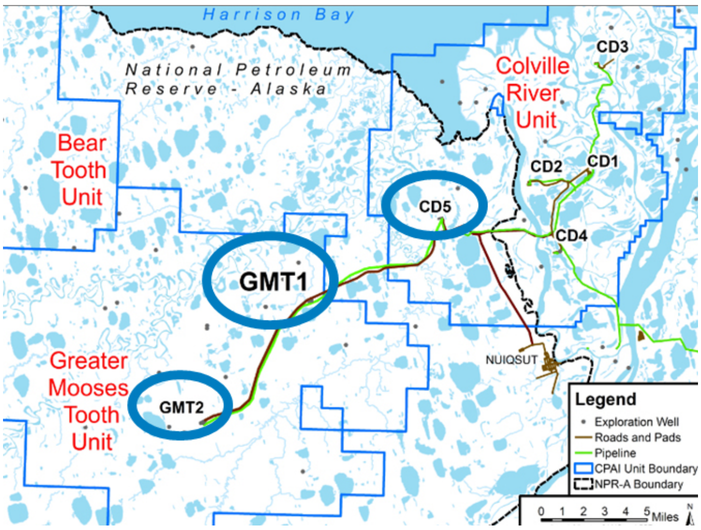


Figure 6.9 Drilling site CD5 with extensions GMT1 and GMT2 (ConocoPhillips).

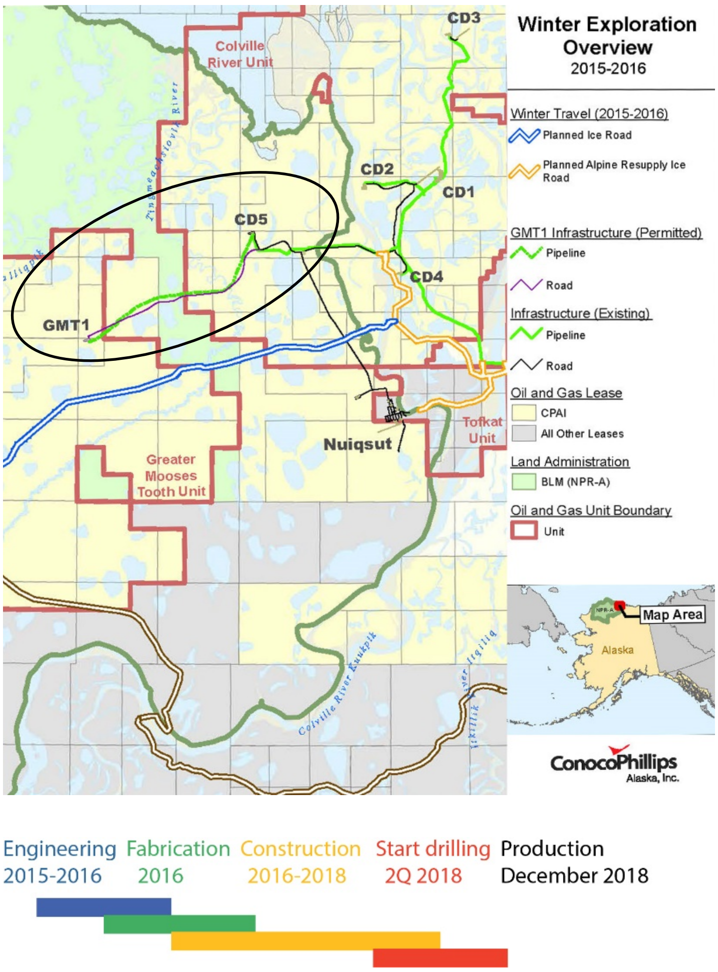


Figure 6.10 CD5 and GMT1 sites and project development schedule (ConocoPhillips).

The first step (Initiation) is similar to any project development and requires collection of the initial data: location – North Slope Alaska, GMT1, anticipated date of completion – 2018, type of development – drilling site, scale and type of workforce needed – peak employment reaching approximately 700 during the construction and includes construction workers and management, drilling engineers and technicians, and rig personnel. The data are incorporated into the Matrix using Matrix integrative tools. Based on the integrated data the Matrix helps to identify required participants of the project who are outside of the company's specialties and proficiencies. Including are North Slope communities, K-12[29] and higher education, science and research groups, architects and human factors specialists (Figure 6.11). At this step, the Matrix gets access to the North Slope local and Alaska state databases. The planning process of the GMT1 project at this point links human dynamics of GMT1 planning and operational management, transferred to the site workforce and local multidisciplinary groups.

[29] Elementary, middle and high schools in the USA

The second step (Integration) makes the project system with all the attached subsystems and elements available to all participants identified in the **first step**. It is important to note that the initiator of the project or the client (in this simulation – ConocoPhillips) **does not select** those involved in the project parties and representative project participants. They are selected by the Matrix and resulted from the initial project core data and Alaskan and North Slope area databases. Simultaneously with ConocoPhillips specialists, identifying project objectives and related problems, local architectural, Alaska's Native communities (e.g. North Slope Borough Autaagtuq Fund), and academic professionals and representatives recognize project's environmental, transportation, social, and technological boundaries and associated to them problems. These become Matrix' subsystems and connecting elements that belong to diverse fields of knowledge collected from practitioners, scientific disciplines, and social and cultural groups. Subsystems include functions, operations, planning, and programming (Figure 6.12).

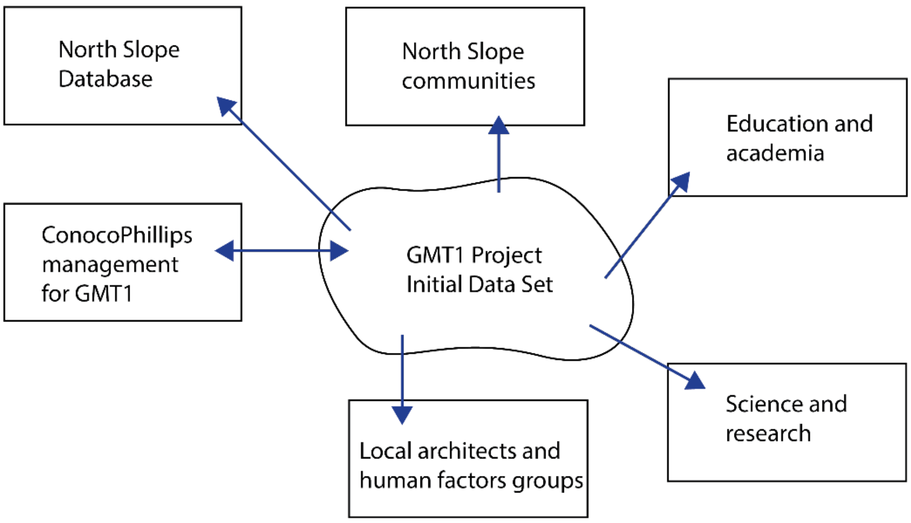


Figure 6.11 The first step of the simulation: Initiation.

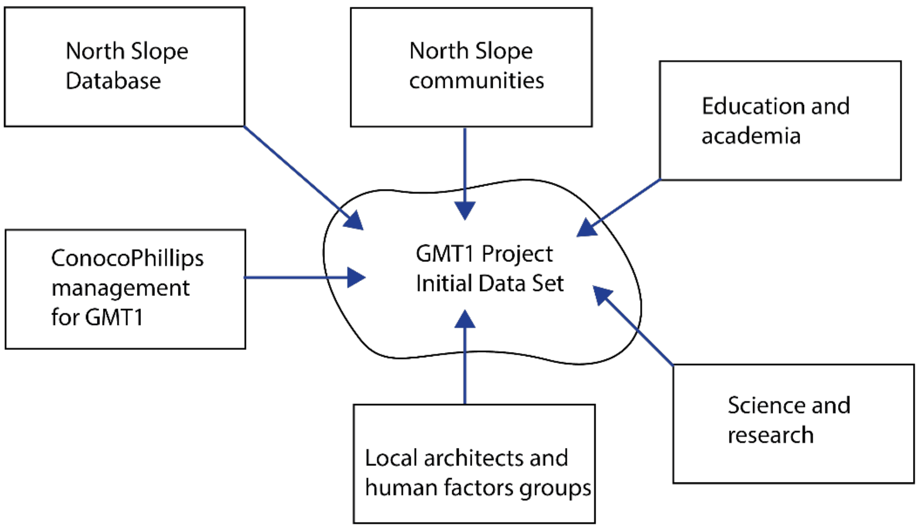


Figure 6.12 The second step of the simulation – Integration.

The third step (Interaction) consists of several cycles using Matrix integrative and interactive capabilities stimulates transdisciplinary information sharing and exchange. At this stage, the Matrix begins utilizing both integrative and interactive capabilities that correspond with GIS database integrative and interactive qualities. In a similar way, operators can see and influence the process. Project's subsystems, connecting elements and elements interact with each other on a permanent basis and project participants are well aware of each other actions and demands. The Matrix now enables cooperation and active communications between ConocoPhillips project management, North Slope architects, and local educational entities and groups (Figure 6.13). Selected local architects work with the coming to the GMT1 workforce as a client and user. Together with other disciplines, architects create new ways of cross-learning and problem solving within the project boundaries. Post-production scenarios of the GTM1 site are analyzed during the third step of the Matrix application simulation. Data Tree logic is used at this step to minimize system error and failure possibility.

The fourth step (Inversion) results from Matrix integrative and interactive cycles. This is the final step of the process that has to be within the project timeframe by the end of 2016 – beginning of 2017. At this stage company's requirements will be satisfied and the GMT1 project aspects will be well integrated into the North Slope communal needs and activities. Certainly, the project will be in accordance with the state of Alaska, ConocoPhillips' company, and professional codes and standards. New forms of learning and problem solving are returned to the ConocoPhillips for project implementation. Although the planning stage is finished by this step, participation of all identifies in the first step groups is not finished and they continue monitoring, validating and integrating their ideas during construction and even production stages (Figure 6.14).

During the fourth step, implementation of all subsystems and elements becomes a cohesive and simultaneous process of the project development. Arrowed lines in the figure 6.12 represent transdisciplinary engagement of all participating in project and otherwise aware in the project actors. The project continues utilizing the Matrix during its development until the project's completion, the Matrix methodology can begin being used for project maintenance stage as well.

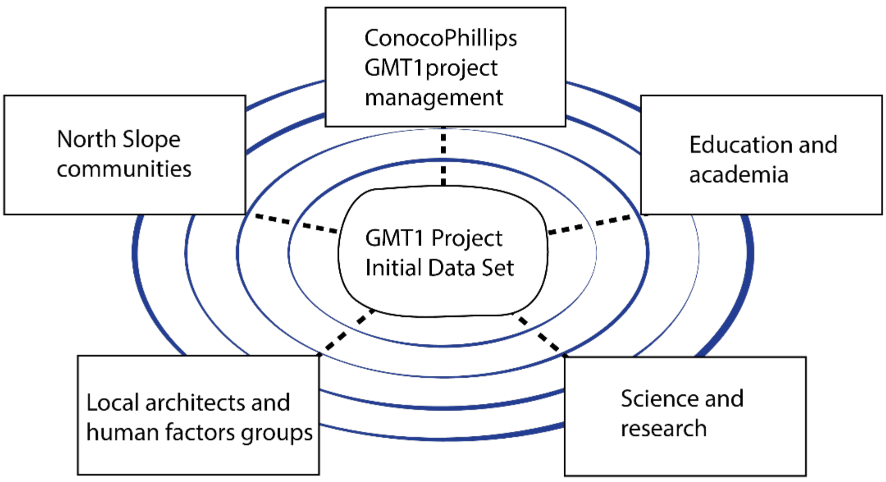


Figure 6.13 The third step of the simulation – Interaction.

Comparing the proposed steps of the application of the Matrix through the GMT1 simulation with the process usually employed by the company to projects in the North Slope Alaska presented in the table 6.4. Overall, company's declarations as they appear in the NPR update by the VP of North Slope Operations and Development Nick Olds, are not project-specific but rather generalized statements of common conduct.

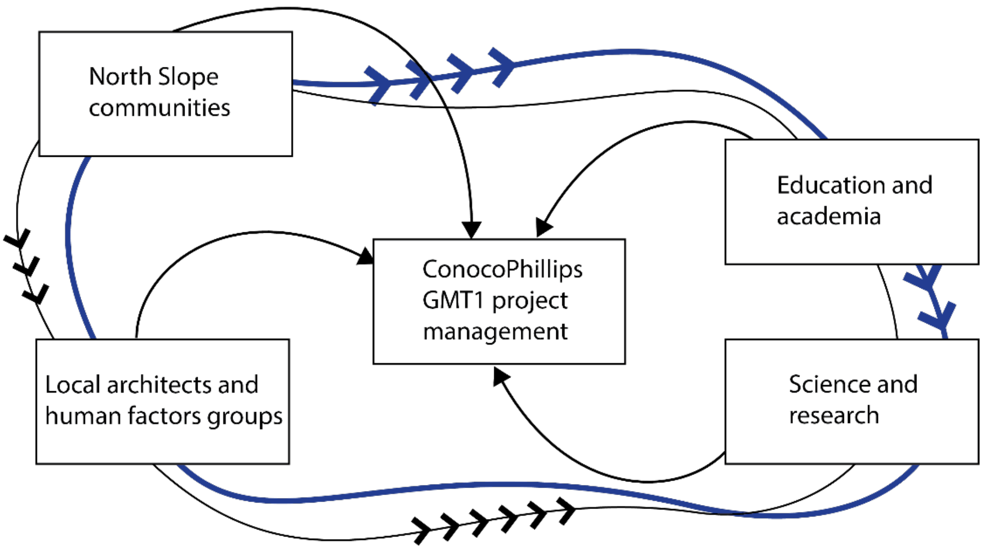


Figure 6.14 The fourth step of the simulation – Inversion.

Improvements through Matrix application	**ConocoPhillips outreach and engagement in North Slope Alaska characteristics**
Create awareness of project requirements ensuring multi-way communication	General: Honest and respectful relationships with North Slope communities.
Ensuring that all participants associated with environmental and situational challenges of the project integrate and interact with the project and each other directly.	Monetary (inside and outside of the project): Support community projects and economic opportunities including subsistence support, and education and workforce development programs.
Participants and contributors of the project interactions result in constant down-up integration of knowledge that happens not upon managerial requests but due urgency of the issues.	Top down (outside of the project): frequent communication to balance needs of subsistence users with development through obtaining feedback on operations, and gathering local and traditional knowledge to help protect subsistence resources.

Table 6.4 Company's common conduct and enhancements associated with Matrix application.

6.4 Matrix validation

Given that the Matrix idea was created after research and architectural projects of Case Studies I and II were completed, application of a theoretical validation becomes reasonable. Projects of the Case Studies I and II that are described and analyzed in Chapter 5, were conducted before this doctoral work was launched. The work on those projects acted as a trigger, which stimulated conceiving the idea that materialized into the Matrix methodology in this research. The fact that projects were developed earlier presents certain difficulties in identifying proper validation approaches. Therefore, after analyzing validation theories described in the subchapter 4.4 and identifying the Matrix as a prescriptive model type, I applied a relativist validation approach. According to the relativist approach, I organized the validation process to encapsulate four stages:

- Case studies design processes critically analyzed emphasizing what was missed during its course;
- Projections are made what would be done differently if the Matrix was applied;
- Discussions with professionals from industries and scientific community evaluating usefulness of the Matrix approach;
- Summary of results from applied validation approach.

Following Olewnik and Lewis definition of validation (Olewnik and Lewis 2005) Matrix validation has three key elements: *1) maintain concurrence with the logic of the proposed tool, 2) relying upon meaningful and reliable information, and 3) letting Matrix users set design preferences as needed*. While the first two elements require conducting at least some test cases, all of the validation components are done through the most current literature and media sources (news broadcasts, TV documentary and interviews), public and scientific lectures, and obtaining professional opinions regarding the proposed in this thesis Matrix.

Validation Element 1: Be logical

Elements of the Matrix can vary while they continue to belong to established hierarchy of subsystems following the same logic. As Olewnik and Lewis pointed out, testing for this is not easy and can be done through test cases for "*which results are intuitive and checking if the model results agree with intuition*." Keith F., manager and advisor of ConocoPhillips, stated in his interview to me that it is critical for project success to minimize changes along the way but be flexible and competent enough to manage changes that do occur without major disruption of overall goals and objectives of the project.

Such influences and relationships between systems, subsystems and elements are illustrated through review of Case Studies projects, planning, and design processes applied to them, and their critical analysis. The tables 6.5 and 6.6 are examples driven from reviewing design processes of the Case Studies I and II projects. Although subsystems are comparable and are permanent parts of planning, their elements vary and are not always required or present during project execution. Sub-elements in red identify that they were missed during design processes when Studies I and II were conducted. Using the Matrix would raise ‘red’ flags during the design process before moving to the next stage of the design, minimizing chances for errors.

For example, the missed connecting elements of Human Dynamics and Human Factors in Case Study I resulted in weakening a Functions and Operations subsystem they all belong to (Table 6.5). Dr. Smirenski, the President of Muraviovka Park for Sustainable Land Use, the Case Study II project (Table 6.6), disclosed in multiple personal conversations that in order to move forward with the proposed development plan, working with local authorities and organizations, implementation of sustainable living practices and advanced technologies had to be simultaneously addressed in the park’s development plan. Dr. Smirenski’s observations confirmed that such mishaps would not occur if the Matrix was used during the project elaboration and all needed sources of information and implementation collaborators could correspond using the same communication and reference model.

Subsystems	**Missing Connecting Elements**	**Not Implemented (Used) Sources**
Functions/ Operations	Enabling functional and operational support	Collaboration with local communities (critical for the Case Study II project success)
	Enabling means for sustainable functionality including provisions for safety and support	Implementation of sustainable living and working practices
	Enabling sustainable construction and operations practices	Identifying local providers
Planning/ Programming	Medical, occupational, site-related emergencies	Operation and Human Error related

Table 6.5 Elements and sources not utilized in Case Study I project that affected their subsystems.

Subsystems	Missing Connecting Elements	Not Implemented (Used) Sources
Functions/ Operations	Securing park's functional and operational support	Identification of non-governmental organizations to work with local authorities
	Enabling means for sustainable functionality including provisions for staff and visitors safety and support	Housing design, sustainable living practices implementation
	Medical, occupational, site-related emergencies	Advanced techniques based on local resources
Planning/ Programming	Education, research, ecotourism	Year-round research and educational activities

Table 6.6 Elements and sources not utilized in Case Study II project that affected their subsystems.

Validation Element 2: Use meaningful and reliable information

Design solutions in general can be physically tested through living and functioning experience and only with time. Therefore finding an effective way to test and evaluate design in constraint timeframe is a challenge. Although testing with a large-scale on-going project through all stages of its development could be immensely useful, it requires earlier and in-depth involvement in the project, which could not be accomplished within this thesis research. As a result, other sources of information were used in this work including current periodic and proven media sources, as well as reviews from professionals from the industry and scientific community who have the experience of working in the Arctic or on Arctic projects. The reviews were obtained during personal interviews and discussions and at Earth and Space: Engineering for Extreme Environments, ASCE conference in St. Louis, MI on October 27, 2014 (Bannova and Nystrom 2014).

The information about design strategy used during ConocoPhillips projects development was provided by people who executed the projects and their opinions about usefulness of the Matrix methodology and reasoning for it were based on their professional experience and knowledge.

After reviewing projects of reference (North Slope Alaska, Gulf of Mexico, and Russian Arctic), the respondents identified several existing challenges in project development that the Matrix is designed to address:

- "Design while built" strategy leads to fixing mistakes in the field – and as a result, drives the overall cost up.
- Low level of design completion prior to sanctioning increases a possibility of human error occurrence.
- Schedule, cost and quality are major drivers but in some locations, native employment and profitability for local partners are also important.

- Knowledge and experience to bear to define what needs to be included in the infrastructure and the project.
- Identifying the risks involved and establishing mitigation plans to address risks.
- Alignment of major objectives with partners from the start is important in order to avoid delays during project development.

The respondents stated that – "*Adequate front end engineering and planning are absolute keys to successful projects in any environment, but especially in extreme and remote environments*." – Keith F., Project Engineer, Technical Advisor, ConocoPhillips. Communication is the key to manage such challenges.

Validation Element 3: No bias designer

Although some predictions have been made during the descriptive part of the study, design and planning preferences and hierarchy of elements and their relationships in the Matrix can be adjusted according to current goals and based on the up-to-date information. Planning should also include providing means that are necessary for timely execution of mitigation plans for possible risks.

As it was stated in discussions that followed the questionnaire, with more complex technological operations and in challenging environments, more workforce is needed now to safely execute and operate facilities in remote locations, which creates a shortage of living accommodations forcing people to live in temporary structures. These accommodations lack safety and comfort and therefore may increase possibility of stress and stress-related risks. Harsh environmental conditions and remoteness of sites intensify such risks (Maria A., Ted W. and Keith F., ConocoPhillips, Olga I., Fluor Corporation). Olga I., manager from Fluor Corporation[30], reviewed the Matrix tool from that perspective and importance of incorporating architectural approach in commonly engineering-oriented practice.

Addressing human dynamics through enabling functional and operational support from social and psychology experts should have been utilized in Case Studies I and II projects at all design and planning stages, and in parallel and in conjunction with specialists from other fields. In spite of substantial international science community participation in research at Summit, the Case Study I design project did not consider active participation from local professionals and society. In Case Study II, scientific international collaboration in research did not provide input for project development, perhaps for certain political and related to them social reasons, which also affected the *Infrastructure* sub-system of the Matrix. Science and engineering inputs for applications of new and already proven technologies and professional collaboration for applying them to Case Studies I and II projects was only partially utilized at the latest stages of both projects and had to be integrated into already accepted designs.

[30] Full names of respondents are not disclosed to protect their privacy.

Solitary application of a common architectural procedure in Case Studies I and II projects resulted in all three connecting elements missing at least one of their sub-elements and therefore not fulfilling information needed in the related to them subsystems. *Functions and Operations* as well as *Planning and Programming* subsystems lacked information from two out of three suggested in the Matrix connecting elements that could have been provided by available but not implemented sources (disciplines).

The Planning and programming sub-system also missed two out of three suggested in the Matrix' connecting elements at projects' initial stages, those inputs had to be sought later in Case Studies I and II design processes and were partially integrated in designs and planning later. Activities data from clients, users, and communities was not analyzed through multidisciplinary sources; same conclusion applies to analytical data about possible causes of emergencies and design enhanced preventive methods.

Even though environmental, site development, infrastructural and utilities challenges affecting projects' design and planning processes in Case Studies I and II were understood and comprehended, *Dependence* in context of local policies, economies and social aspects was not implemented in both projects.

In addition, as it was acknowledged multiple times during my interviews and conversations, safety has been always a major driver for operated projects and therefore related aspects should become an important component of the Matrix logic. Other project's drivers are connected to challenges already described and include completing a project within the timeframe, under the budget and with secure technology implementation after field experts' inspections.

6.5 Chapter Summary: Finalizing research

This thesis research confirmed the need for the application of a systematic approach to planning in Arctic and Subarctic regions. The research led to the Matrix concept and proposed validation methods. This is summed up in the synopsis of reviews presented in the table 6.6. Geologist Sullivan resonated on the importance of the potential use of the Matrix methodology when we discussed her work on the geospatial analysis of Arctic Ocean hydrocarbon resources (Long et al. 2008). She pointed out that based on her research and analysis of the Arctic conditions "*logistics may control areas of exploration more than hydrocarbon potential*" (p. 4.1). Ecological and environmental issues along with social and geopolitical regional aspects need to become part of engineering and architectural planning for future developments there.

The table 6.6 summarizes Matrix methodology reviews categorized by Matrix aspects. Matrix aspects were identified through respondents' answers to the questionnaire described and discussed in the Chapter 5. Their reviews were collected during follow up phone interviews, personal open interviews and discussions.

Matrix aspects	Reviewers' statements
Technology	Nowadays more resources become reachable from the same location because of technological advancements. That leads to expanding of lifespans of existing facilities more than it was initially expected. Facilities built in late 1970s were planned for 25 years in operation but are still in use and have to be adapted to new technological processes and larger number of personnel. A methodology that can address it in new and upgrading projects is needed.
Facilities and infrastructure	Remoteness and lack of existing infrastructure are obviously related problems and common for most northern locations. They drive overall cost of projects up proportionally to degrees of their intensity. Even if the current infrastructure is established, future infrastructure is partly controlled by geopolitics and governmental decisions, making it difficult to predict. The most significant areas for future exploration are those with both highest hydrocarbon potential and the best current and planned infrastructure. The proposed Matrix deals with and correlates potential changes with associated sub-elements.
Transportation	Transportation windows in most Polar Regions are limited to few months of a short polar summer, although in some locations (North Slope Alaska) ice roads are constructed during the winter and operations are cut off regular supplies during summer time. Transportation issues as connecting elements determine if the design and planning processes comply with payload and timeframe restrictions.
Governing	Federal and state governments often have different objectives. Their agendas and cultural, social and political aspects connected to them drive the overall cost up and influence management decisions. Planning ahead for such issues will help mutual understanding at upper management and local government levels. Including them in the loop of participatory design process provides foundation for their understanding and support of project objectives.
Human factors and possible risks	Safety is always a major driver for operated projects. Remoteness has to be addressed prior to project initiation leading to additional time and budget requirements. Remoteness also affects psychological climate and may influence personnel motivation and performance. Identification of the magnitude of possible risks and using methodology (Matrix) that incorporates appropriate mitigation plans into planning strategy is very important. Planning should also include providing means that are necessary for timely execution of mitigation plans when needed.

Table 6.7 Matrix aspects and reviews. Continued on next page.

Matrix aspects	Reviewers' statements[31]
Workforce	More workforce is needed now to safely execute and operate facilities in remote locations, which creates a shortage of living accommodations forcing people to live in temporary structures. These accommodations lack safety and comfort and therefore may increase possibility of stress and stress-related risks. Harsh environmental conditions and remoteness of sites intensify such risks. Architectural mentality that is implemented in the Matrix methodology ensures that dealing with those issues is a part of the planning process.
Accommodations	In many locations, accommodations are facing the same challenges as technology and facilities that were built in late 1970s but were planned for 25 years in operation. They have to be adapted to new technological processes and large number of personnel. Companies have different employees' rotating schedules and availability of housing. In remote and harsh locations, living requirements should be given equal priority as safety, budget and schedule. It is more achievable with a methodology at hand that implements such mentality.
Collaborations and partnership	Alignment of major objectives with partners from the start is important in order to avoid delays during project development. Appropriate levels of knowledge and experience have to be identified first in order to have sufficient owner and contractor work force to execute the project. These should be initial or sub-elements of the Matrix and the methodology application has to prevent the project from moving forward unless these issues are addressed.
Communications	Effective communication strategies are critical to avoid time delays and operational mistakes, to respond to emergencies quickly and efficiently, to establish positive and constructive relationships with local communities and authorities. These strategies should be a core of planning approaches in extreme environments. The Matrix is proposed to serve also as a communication tool between everybody involved in the project at different stages of work in progress.

Table 6.7 Matrix aspects and reviews, continued.

[31] Experts, managers, engineers from ConocoPhillips, Fluor Corp., Shell (Moscow office), ExxonMobil

A critical interpretation of social, economic and environmental sustainability of contemporary design processes, moving towards a changing professional role and discourse within and between disciplines has to become a regular practice in the professional world of architects, engineers, and planners. A timely introduction of collaborative processes that promotes critical reflection is vital to applying sustainable practices to everyday life style. There is however, a lack of effective communication between 'users' (and/or clients) and 'professionals' (designers and/or planners). Shaping those links by providing research in design and learning through building opportunities, along with creating new advanced outreach prospects for designers, are key steps towards new sustainable professional practices. In addition, applications analysis should be performed not only as a result of the process but in the context of the whole process and with an emphasis on human factors, systems and elements' relationships and trans-dependability. Based on the knowledge gained, a design and planning process can optimize sustainability approaches implementation into practice through incorporating testing and evaluating stages into the design process.

7 Summary and Discussion

This thesis research is built upon my personal and academic work experience, 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. I recognize this research has limitations that come from Case Studies projects' specific qualities: both projects were earlier performed student projects and both are retrospectively reviewed. Other limitations come from inadequate number of existing records about a process of planning large-scale projects in the Arctic (Nuttall 2005, Expert Group on Ecosystem-Based Management 2013). Nevertheless, understanding that these limitations open possibilities for failure of the proposed concept lead 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 ConocoPhillips current project GMT-1. Matrix' application steps do not necessarily match its organization because Matrix subsystems include many variables defined by a specific project. However, relations between planning and design processes remain present in any type of project.

The methods used in this thesis included retrospective review of case studies projects, case analysis, cross-case synthesis, pattern matching, Figures Of Merit comparisons, systems synthesis and three-element validation process. The validation findings supported the Matrix concept through reviewers' statements. The discussion suggests opportunities for research by design and learning through building, to test the Matrix methodology.

7.1 Conclusions: Polar and cold climate applications

This thesis investigated influences of driving forces of existing and emerging problems in extreme environments, specifically in the Arctic and Subarctic regions with concentration on design and planning aspects of those problems. The research resulted in proposing the Matrix that can be used to help architects, engineers and planners work together on projects for cold climates and potentially in other extreme environments. Throughout the work on my thesis research, my questions evolved, leading to the merging of the first two questions[32] together as they refer to the same sources of evidence in a similar way. A combined version of questions 1 and 2 evolved into a new question: what is not satisfactory in the existing construction and planning procedures in the Arctic? A new methodology that addresses key aspects of developments in Arctic and Subarctic regions emerged to answer that question.

The analysis of the case studies exposed elements of subsystems that were missing during the work on the case studies projects, revealing what was missing during design work on Case Studies I and II projects (research question 3: What was missing when conducting Case Studies projects and what are the consequences? What approach can improve the situation?) And how to organize and validate a new Matrix methodology (research question 4: How to

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[32] Q 1. How the construction projects and other developments in extreme environments have been planned and managed up-to-now?
Q 2. Are the current planning procedures and approaches effective enough in the Arctic?

organize a new methodology (Matrix) and validate it?). It also showed which sources of information and inputs require attention and correlation during the entire process of project development. The discovered results led to the conclusion that multidisciplinary Matrix methodology needs an architectural human-centered *designerly* way to become an equal partner of transdisciplinary efforts of the overall planning, constructing and maintaining processes of projects in Arctic and Subarctic locations.

Validation of the Matrix presented in the subchapter 6.4 supports the idea that the Matrix model can assist in advancing design, planning and the organizational process by offering a consistent approach to planning and by optimizing integrative processes between disciplines and areas of expertise involved. It is important to note that the goal of it is not to 'control' complexity of a design process that would prevent possibility for change (Doucet and Janssens 2011) but to activate all necessary information from related disciplines and sources and provide means for an effective conversation among them. Such conversation is not controlled by one participant but introduces possibilities and options to all involved in the process actors.

Although an architectural process includes research and programming stages as the foundation to conceive a design concept, it also includes creative and esthetical aspects that cannot be standardized and therefore included in the Matrix as subsystems. Nevertheless, application of the Matrix allows better implementation of programming into overall planning and project execution where creative design is recognized as a necessary attribute of the project. In addition, the Matrix allows expediting 'routine' or standardized design processes (Gero 2000) and facilitating creative designing with implementation of computational support.

Case studies analyses demonstrated several major similarities in projects design processes that included environmental and transportation issues, and operational and functional aspects. Although not all design and planning solutions were similar, the process of identification of issues or problems and then suggesting how they can be resolved were the same in both cases. The Matrix is not an approach to offer standard solutions but rather a model for finding unique for each project design and planning elements within an integrated process system. It helps to establish and facilitate connectivity between aspects of the planning process (Figure 7.1).

It also has to be recognized that Arctic and Subarctic regions including wetlands of rivers and lakes there, are particularly vulnerable to climate change, economic developments and human activity in general (Minayeva and Sirin 2009). The biggest challenge that all parties engaged in the Arctic face is finding ways how to protect nature while developing the environment, always respect the indigenous peoples who live there, and at the same time considering the needs of the increasing numbers of diverse immigration as they become new people of the North (Malaurie 2009).

Figure 7.1 Contributors to planning processes in Polar Regions (author's photos and a map of disputed areas in Arctic (Cowling 2011))

Since carbon resources is one of the biggest driving forces of bringing newcomers into the Arctic and close to Arctic regions, oil and gas industries have to consider all potential advantages and complications of developments in extreme conditions of the cold region of the Arctic. David Parkinson[33] says,

> *The Arctic should not be considered a single frontier for the oil and gas industry. Each area will have a unique set of challenges that require unique solutions. It will continue to be a difficult environment for oil and gas companies to prosper. However, understanding the differences across the Arctic basins will allow companies to take advantage of its resource potential* (Smith 2007, 22).

Other permanent and temporary immigration includes seasonal workers, fishing and marine transportation crews and researchers. Every category of newcomers has some specific requirements that correlated with other project subsystems through the Matrix.

On the other hand, although technological advances in the Arctic and other naturally extreme environments may create environmental threat, they can and already do provide more efficient and cost-effective energy solutions, better waste management and smart building design (Sachs 2015). Science and academia of local communities in extreme environments can also benefit and contribute to new technological advancements to make their surroundings and neighborhoods safe and resilient places (Vergragt 2006, Bannova and Kristiansen 2014). Hybrid or active structural systems, computation-based design solutions, advanced insulation materials and overall smart and effective building envelop and city planning – design solutions that would not be possible without new technologies and knowledge (Said 2006).

Combination and synthesis of discussed in this thesis theories and concepts adopt multidisciplinary and systems of systems approaches into building a methodology, the Matrix,

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[33] Vice President, Upstream Consulting at Wood Mackenzie.

where informing elements of project planning handled appropriately to levels of importance and subsystems relationships.

7.2 Discussion

Applications of the proposed Matrix beyond Polar Regions requires additional case studies investigations and analysis. Still, some highlighted correlations between researched in this thesis cases and other extreme conditions and environments are based on my work, research experience and literature overview.

Discussing if the proposed Matrix can be useful for planning in other extreme environments including space led to the overview of the special characteristics of those conditions. Experiences on space stations, underwater vessels and facilities, and polar stations have revealed a variety of common human factors, psychological and physical health and behavioral issues that are related to habitable environment and design approaches (Leon, Sandal and Larsen 2011) (Figure 7.2):

- Cut off from "the outside", crews must learn to be resourceful, and to depend upon one another.
- They must work to help crewmates deal with psychological and physical stresses.
- They are required to adapt to limited comfort and recreational amenities.
- They must be prepared for fatiguing work overloads and stimuli deprivations.
- They must be trained and equipped to deal with equipment malfunctions.

Figure 7.2 Space: International Space Station (NASA), Arctic: DYE-2 science camp (author's photo), underwater: Aquarius station (NASA NEEMO)

Other cross-environmental conditions associated with common types of constraints that place stringent requirements and severe restrictions on habitat design and operations:

- Limited internal volumes constrain storage and human activities.
- Limitations on equipment, labor and processes constrain structure assembly/deployment procedures.
- Limitations on maintenance and repairs (people, tools/ spares and methods) constrain maintenance and repair options.
- Safety and operations under harsh environmental conditions and demanding mission schedules pose safety and operational challenges.

Recent naturally caused catastrophic events in the United States and natural and technological disasters in other countries exposed that even advanced communities with developed emergency response plans may not be fully prepared for disasters and face multiple challenges. A proactive response strategy is vital and as Colonel Cassie Barlow, 88th Air Base Wing commander at Wright Patterson Air Force Base (Dayton, Ohio), commented: "*we can't wait for emergencies to happen before we respond*" (Badiru and Racz 2014). Stronger connections and better understanding of actions between business, industry, other agencies, and the community have to be required in response programs for emergencies that can also be considered extreme environments.

The Matrix methodology addresses these urgencies and caused by them challenges, and may be applicable to many locations with extreme conditions such as disaster and technological catastrophes response zones, deserts, outer space and surfaces of other planets. In all those locations similar issues characterize planning and design factors that drive or significantly influence option requirements and assessments.

Furthermore, in space exploration circumstances, the Matrix methodology may enable mission planners and spacecraft designers to incorporate human aspect to the whole design process to provide stimulating and optimized living and working environment for the crew along with helping to establish effective relationships between humans and their environment.

7.3 Future research

The Matrix is a methodology and a foundation for developing an interactive software program. Further research should aim to finalize computational modeling for the Matrix and its adjustments for different extreme environments conditions. *Microsoft Visio* software was the first considered computer aid for the planning model, other options have to be reviewed and evaluated using Figures Of Merit (FOM) approach. Applications have to be tested by real time projects to collect data of application reliability and applicability to specific conditions.

Computational capabilities of the Matrix methodology can be initiated with simpler than GIS software applications. For example, *Microsoft Visio and SharePoint* can enable creating network and data center diagrams, sub-processes and validation of flowcharts with multiple validation rules. This can provide an affordable platform for implementing Matrix logic into a programming tool containing controls that can offer diagrams in the framework of software-based collaboration activities. Matrix diagrams put in Visio and SharePoint fit into collaboration scenarios because they clearly represent the required data to those involved in the planning processes groups and can be simultaneously and dynamically updated from group actions. These capabilities provide enhanced mechanisms for more effective planning, collaboration and communication. In addition to diagrammatic tool, the Web Part can be used to inform team members about project status, represent real time access to enterprise data, reallocate scarce resources, communicate changes to key business processes or keep senior management informed of key milestones and performance metrics. Using the Matrix with the aid of software all members of the project team can understand their tasks and operations in relation to other parts of the project development process and can correlate their efforts in time and location.

Efficiency and optimization of best sustainable practices has to be observed and tested in real life conditions and with extended time. For example, projects similar to Living Lab design and built environment can provide data from environmental systems, human factors, technology and social systems. Environmental sensors and other devices usage, building layout and structure, and socially responsive architecture, enable sustainability into living practices. The Matrix can be also applied in classes for academic purposes creating interdisciplinary student projects where different parts of research and design project are distributed between groups of students with different background (Figure 7.3).

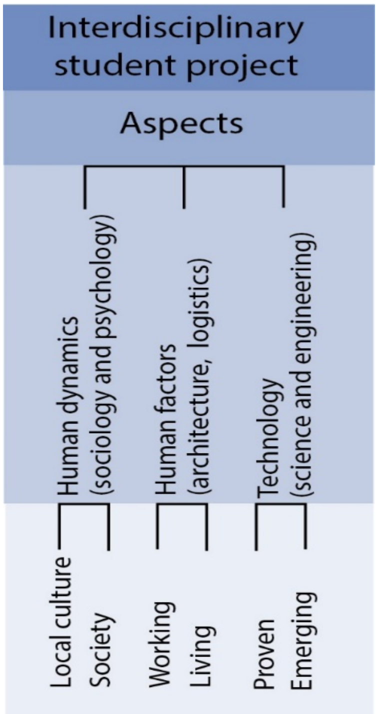

Figure 7.3 Interdisciplinary student project components.

Projects like the ‘HSB Sustainable Living Lab’, a collaborative effort between the largest Swedish co-operative housing association, HSB, and Johanneberg Science Park, is a perfect candidate not only as a verification avenue for the Matrix testing but also as a tool for applying Matrix to creating interdisciplinary student projects within it (Baedeker et al. 2014, Bannova et al. 2014).

The building is currently under construction as a student housing, located on Chalmers main campus. Its location offers a unique opportunity to merge research, education and outreach. For example, architectural and industrial design studios students can design and build several units within the structure and several of the students may be offered to rent built-by-themselves rooms for a semester to test their own design solutions. They would document their experience, positive and negative reflections for next semester students to reflect in their design-built studio experience. The same process can be applied in students’ projects from other disciplines. Students may form interdisciplinary design-built teams following the same procedure. Although coordinating efforts within a new academic entity may seem as not a challenging task, it may be used as a hands-on opportunity for students to learn transdisciplinary skills for professional life preparedness.

In order to educate professionals from a wide range of disciplines and to secure implementation of the architectural approach into strategic planning using the Matrix methodology, it needs to be tested in the academic environment first. A timely introduction of collaborative practices to future practitioners promotes critical thinking, communicating of ideas, and participatory design training. All these elements are vital components of the Matrix and of applying sustainable practices into design, planning, and everyday life style. Hands-on learning of new and advanced possibilities for designers as key steps towards new sustainable professional practices ensures effective support for enabling sustainability in many facets of human life. With the help of the Matrix as a communicative tool, critical interpretation of social, economic and environmental sustainability of contemporary design processes moves towards shaping its role within disciplines, which has to become a regular practice in professional world of architects, engineers, and planners.

In addition, a combination of an academic component with real-life experience and application of their skills into practice together with professionals from construction companies can serve as an innovation incubator for start-up businesses and professional practices. Using a Matrix methodology adds transparency and easy collaboration platform for implementation of innovative ideas from technological, human factors, scientific, architectural and other disciplines.

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Appendix

The materials collected in the Appendix that are related to the Case Study I differ from the Case Study II project materials due to limited on-site availability of resources for conducting project-related work and logistical complications. Mock-up installation, along with long-term data collection and observation was not possible at the Muraviovka Park although the project would benefit from such efforts.

On-site testing has to be a required component of projects that involve building and constructing any types of facilities for extreme environments of Polar Regions including Arctic and sub-Arctic locations.

Students participating in the Case Study I project were Spencer Howard, Clay Richards, Brian Swartz, Veronica Honstein, Mayur Patel, Brian Malone and Andre Thompson.

Students participating in the Case Study II project were Tressa Powell, Erick Diaz, Barry Tse, Nancy Johnson, and Candice See.

Abstracts and synopses of related papers

Paper I: Experiments in mapping human factors for sustainable design and living

Paper presented at IAPS International Network Symposium in June 2013, peer-reviewed post-conference paper published as a book article in: Urban Sustainability: innovative space, vulnerabilities and opportunities, edited by Ricardo Garcia Mira and Adina Dumitru.

Bannova, O., Hagbert, P., Department of Architecture, Chalmers University of Technology.

This paper reflected investigations on forming sustainable behavior and architectural practice through design. The paper was based on the data collected from two students' surveys and one workshop from the School of Architecture of Chalmers University of Technology and the College of Architecture of the University of Houston, was analyzed and summarized for further research.

Abstract

This paper addresses architectural and design considerations regarding challenges of sustainable living in extreme environments, in relation to a design research methodology applied in an on-going Sustainable Living Lab reference project. The outlined research addresses the need to radically reduce residential energy and resource consumption, through a proposed studio intervention, as part of student housing currently under development at Chalmers University of Technology, Sweden. In addition to a theoretical and methodological background to this reference project, results from initial studies revolving around user perceptions and ideation are presented. The paper also discusses future developments and suggests how derived design strategies can be applied to everyday life and in other regions around the world.

The research outlined here investigates multiple aspects of sustainability and possible applications of lessons learned in future design practices. Investigating essential human needs and how those needs can be addressed in design and planning is a relevant challenge. The reference project discussed in this paper particularly revolves around developing user-centered design research methodologies and practices, studying how sustainable innovations are applied and perceived in everyday life and living environments. By gaining insights into the usability and acceptance of sustainable strategies and processes regarding both spatial and material properties, the objective is to create an environment that stimulates living practices related to a radically reduced energy and resource consumption and conscious social and personal behavior. The paper is concluded with focus points for further investigations.

Paper II: Testing and Evaluating Sustainable Design Practices

Peer-reviewed paper presented at ARCC in February 2014 and published in the ARCC database.

Bannova, O., Nystrom M., Femenias P., Hagbert P., Toups L., Department of Architecture, Chalmers University of Technology.

This paper studies a proposed Habitation Lab studio as a testing and evaluating tool for sustainable design practices. Such a new design approach is investigated where students will be designers, clients and users in simultaneous and homogeneous process experiencing all stages of designing, building and living practices. The on-going Living Lab project on Chalmers university campus is considered an initiation point of the research and design and a foundation of further studio developments.

Abstract

This paper presents an in-progress design research conducted by teachers and students of Chalmers University of Technology (Sweden) and the University of Houston (USA), in the form of a Habitation Laboratory (HabLab) (Nystrom et al. 2010) design studio and in connection with a Sustainable Living Lab project.

The 'HSB Sustainable Living Lab', is a collaborative effort between the largest Swedish co-operative housing association, HSB, and Johanneberg Science Park, and will be built in 2014 as a student housing, located on Chalmers main campus[34]. Its location offers a unique opportunity to merge research, education and outreach.

A 400 m2 three-story building will accommodate 25-30 students and guest researchers. Student units are designed to be flexible and adaptable to possible layout adjustments and changes throughout a ten-year building permit timeframe. The structure will also include additional facilities such as an exhibition area, a common laundry room and various meeting zones.

The paper identifies and investigates experiments in sustainable design education through the use of a design studio as the first stage within the larger "Sustainable Living Lab" research and building environment project. The goal of the educational initiative is implementing practice and construction experience into the learning process by combining hands-on approaches with theoretical development in trans-disciplinary real-life contexts, where design serves as a link between practices and disciplines. This is argued to be essential in the shaping of future responsible architectural practices.

Possible applications of lessons learned for the design of future environments is a key inquiry. The project objectives are: developing participatory and user-centered design research methodologies and measures, as well as studying how sustainable innovations are applied and perceived in the living environments of everyday life.

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[34] http://suslab.eu/partners/chalmers-th/hsb-living-lab/

Paper III: Architectural Engineering Approach to Developing a Matrix for Planning in Extreme Environments

Peer-reviewed paper presented at the ASCE Earth and Space 2014: Engineering for Extreme Environments conference in October 2014 and published in the ASCE online library.

Bannova, O., Nystrom M., Department of Architecture, Chalmers University of Technology.

The paper introduced the concept of the planning Matrix proposed in this thesis to engineering audience at the American Society of Civil Engineering (ASCE) conference. The conference focused on extreme environments including space and specialists from diverse engineering backgrounds participated in the discussion of the planning Matrix idea. The discussion validated applicability of such approach to planning for extreme environments and helped to expand on engineering-related complexities of planning for extreme environment conditions.

Abstract

Extreme environments on Earth share similar facilities and operations, design and planning challenges. Each environment presents special lessons regarding housing design, crew/staff operations and training, and equipment and logistical requirements for human activities. The paper discusses these challenges and lessons. Recurrent and specific to environment and conditions events are outlined and categorized based on case studies reviews and literature summary. Understanding of relationships and influences between different facets of human society and architecture can help to find a design approach, which would optimize needs and requirements for various types of people living in different environments, societies and cultures. Environmental conditions affecting architectural requirements include form developing factors, site orientation and circulation, and budget considerations. They have to be addressed at the programming design stage in order to avoid costly adjustments at later development stages. It is even more critical in case of designing for challenging environments.

Paper IV: Extreme environments - Design and human factors considerations.

Licentiate thesis, Chalmers University of Technology, December 2014
Bannova, O., Department of Architecture, Chalmers University of Technology.

This thesis explores what aspects and issues of design and planning processes in extreme environments have to be addressed in a similar way and therefore may be used as a basis for further work toward PhD thesis to develop a methodological planning tool or matrix. This work investigates both sides of any activity's planning process for Polar Regions: physical conditions and human factors and as an important part of the latter – possible human error complications.

Abstract

The starting point of this research is based on my experience at SICSA performing research and design for extreme environments, including orbital and lunar planetary facilities, disaster shelters, polar stations and offshore surface and submersible habitats. That "tool" will be proposed for the purpose of facilitating a dialogue between all parties involved during developments in extreme conditions of Polar Regions. The complexity of the problem calls for a multi-disciplinary approach where the many facets of sustainability have to be also addressed. Dealing with the difficulty of combining multiple components is a role for an architect as a facilitator for a dialogue between all actors involved in development activities in extreme environments. Although requirements and hardships specific to diverse extreme environments are outlined at the beginning of the text, the study is later more focused on polar and boreal sites and based on two case studies located there. The text is also based on an overview of related to research problem technical papers, discussions with professionals about their work experience with projects in extreme conditions, and students' workshops debating strategies to form sustainable behavior and design practices.

This study finds that an interdisciplinary, comprehensive approach includes highlighting influences upon general habitat requirements, and constraints upon delivery, construction, and special provisions for safety and hazard intervention. Optimization of such design requirements based on a summary of design considerations will be a key element for future development of systematic planning approach. In summary, the next steps of the research advancement are outlined; emphasizing the importance of equal attention to all elements of the project development, including human factors and psychological aspects, in design and planning processes. Such an approach is essential to enable successful sustainable development and maintenance practices.

Paper V: Architectural approach to planning in the extreme Arctic environment.

Peer-reviewed paper, archiDOCT: Transformable Architecture, Vol. 4, ISSN 2309-0103, ENHSA (European Network of Heads of Schools of Architecture), July 2016
Bannova, O., Department of Architecture, Chalmers University of Technology.

This conceptual paper introduces an idea of a new interdisciplinary and comprehensive approach that includes highlighting extreme environment influences upon 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.

Abstract

Extreme environments in Polar Regions share similar facilities and operations, design and planning challenges: extreme cold temperatures, structural problems, high standards for materials, resources 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 criticality of addressing such impacts at the programming design stage especially in challenging environments, in order to avoid costly adjustments at later development stages.

The paper argues that integrating an architectural approach into planning of construction and related to it 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 follow strictly 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.

This paper outlines and categorizes recurrent and specific to extreme environment and conditions events based on select research methods that include verbal data collection and case studies analysis. Figures Of Merit method employed for identification of important lessons that can be applied across different settings; and the 'HSB Sustainable Living Lab'[35] project is suggested for effectiveness and verification purposes.

[35] http://suslab.eu/partners/chalmers-th/hsb-living-lab/

Understanding of relationships and influences between different facets of human society and architecture can help to find a design approach and optimize needs and requirements for various types of people living and working in extreme environments of Polar Regions, their societies and cultures.

List of sources used in the thesis research

Source	Date	Type	Notes
Discussions	2005-2015, multiple occasions	Open-ended, private, group and personal	Personal discussions with professionals, researchers, workers
Case Studies Projects overview	2006-2012	Structured	Data collected before, during and after Case Studies projects execution
Questionnaire	November 2012	Structured	Graduate students of the University of Houston’s College of Architecture described and compared their habits, social and cultural aspects of student living, studying, working and relaxing.
Workshops and surveys	May 2013	Structured	Undergraduate students of the Chalmers University’s Department of Architecture responded and discussed important aspects of students’ sustainable living, behavior and design.
Questionnaire	January 2012 – February 2013	Semi-structured	ConocoPhillips, Shell management and engineers’ responses related to their experience working on projects in extreme environments.
Interviews	2013, 2014, 2015 multiple occasions	Structured, semi-structured, open ended	Shell, Flour, ExxonMobil, geophysicists, environmental scientists discussed important issues and their perspectives on development processes in the Arctic and Subarctic regions.
Media	August 2015 (Russian TV news), 2012-2015	Television programs, newscast, internet open sources, newsletters	Russian – liquid gas production infrastructure development in the Arctic (LNG factory and port on shore of Northern sea, Russia, TV documentary), US TV news programs, Public Broadcast, documentary series, professional societies newsletters (ASCE, AIA).

Continued on next page

List of sources used in the thesis research, continued

Lectures, conferences, workshops	February 8, 2011, October 2014, September 2015	Public and specialized	ATC 2011, Houston, ASCE Earth&Space 2014, Missouri University, University of Houston's Energy Lectures Series: Arctic drilling: Untapped opportunity or risky business?
Post-lecture interviews	September 2015	Open-ended	Bob Reiss, American author and consultant on Arctic issues;
Post-lecture interviews	September 2015	Open-ended	Jed Hamilton, Senior Arctic consultant, ExxonMobil Upstrem Research Company

Case Study I support materials

Existing structures and facilities:

- Living quarters with kitchen and dining areas
- Center's main building with auditorium and observation balcony
- Storage
- Light structure: mechanical workshop
- Summer living quarters for visitors
- 1 outhouse

Client/site requirements:

- Design elements to fit into payload of ski equipped LC -130 airplane.
- Avoid the need for very heavy construction and transportation equipment.
- Construction planned to minimize impact on environment.
- Balanced weight distribution to avoid differential settlement.
- Modular interior design for easy and versatile expansion and reconfiguration.
- Possibility of temporary seasonal shut downs and interior flexibility arrangement.
- Incorporating an active structure into the main facility platform to minimize snowdrift around the facility.

RECOMMENDED MATERIALS

Material	Recommended use
Steel alloy tubing	Structure trusses, framing members and supporting legs
Honeycomb “sandwich” panels with Kevlar reinforced lamination	Modular skin panels
Triple glazed, laminated and coated glass	Windows
Aluminum alloy tubing	Floor structures
Lightweight tubular steel or steel lattice	Wind towers
Laminate flooring system and Mateflex	Floor surfaces
PV PolyCrystalline	Solar panels

STATION/CLIENT FUNCTION(S)

- Client/facilities relationships
  - Research personnel and logistical support
  - Type of science/work performing
  - Work organization
  - Habitable conditions

- Station goals
  - Research fields and objectives
  - Life cycles of research projects
  - Minimizing work and living associated pollution
  - Implementing closed-loop systems

Budget

- Minimizing construction costs by optimization of LC-130 payload capabilities and modularity of construction elements
- Minimizing life costs
  - Optimization new economical technologies
  - Design and construction according possible station objectives for better and faster future adjustments

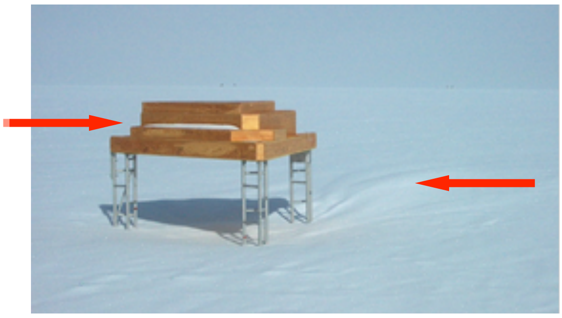
Mock-up installation

Location: N 72deg 35.947' W 038deg 23.150'. Installed: April 26th 2005

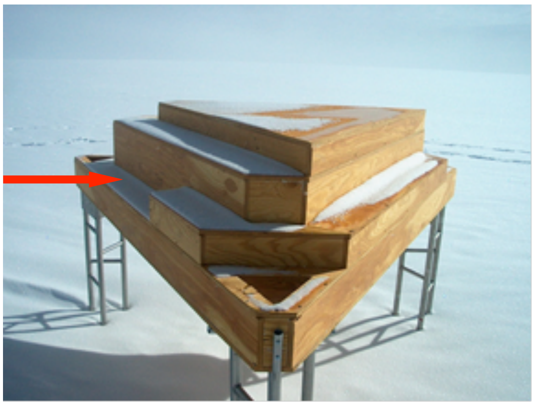
April 26th

May 13th (after 35 knot winds)

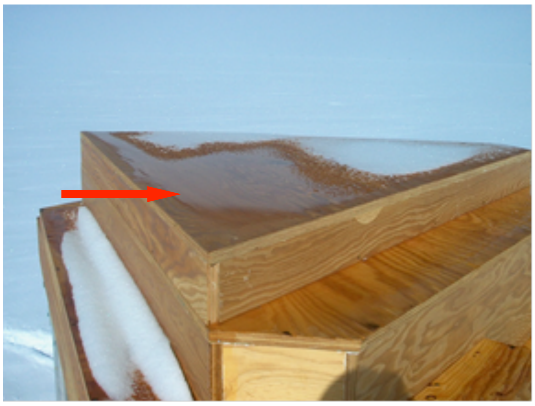
Snow accumulation south side



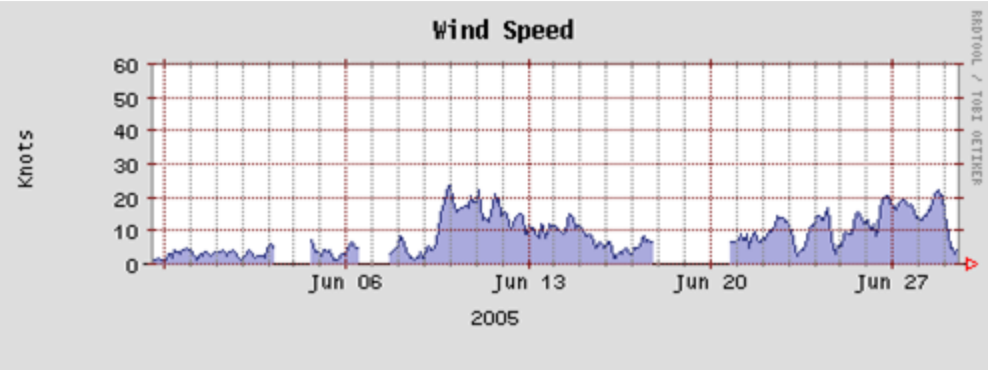
Definite signs of drifting off north point

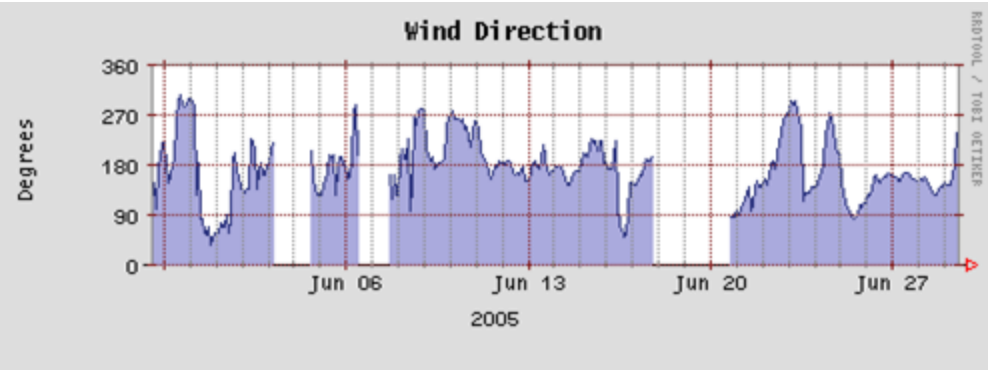


Snow accumulation (June 29, 2005)



Melting, mostly on south sides (June 29, 2005)

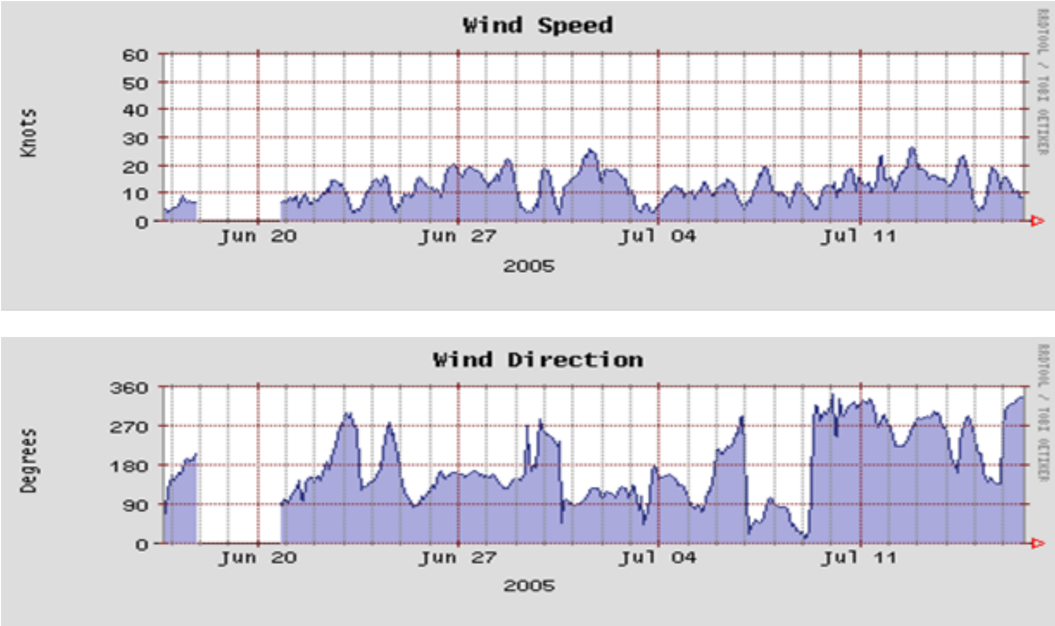




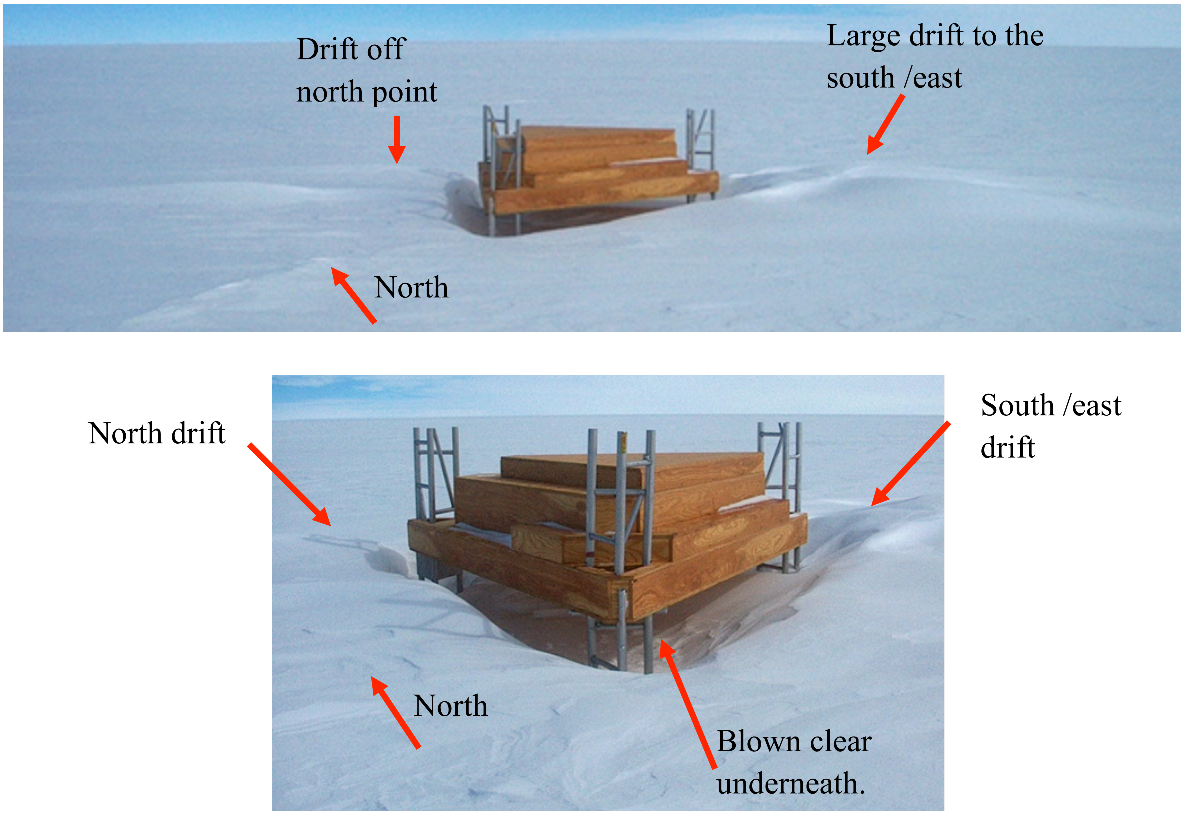
Wind speed and direction during initial installation set up.

Testing Results:

- On June 29, 2005 there were definite signs of drifting snow off the north point of the structure.
- Snow seamed to accumulate on all roof in all areas.
- There was definite melting snow on south sides of structure.
- Construction crew awaiting instructions on the height of proposed legs on top of structure, as well as what height the structure should remain at for the winter season.
- The structure was solid and not in need of securing, but will be secured if directed.
- The mock-up was reset at 15” clearance from the bottom of the model to the surface on July 16th 2005.



Wind speed and direction during second installation set up.



Installation second set up pictures.

Case Study II support materials

Existing structures

- Living quarters with kitchen and dining
- Center's main building with auditorium and observation balcony
- Storage
- Workshop
- Solar kiln
- 3 large pens with pools for birds
- Garage
- Sauna and 2 showers
- 2 outhouses
- Outdoor dining
- Summer camp
  - 7 houses for 12 people each
  - Kitchen with dining
  - 2 outhouses
  - Storage
  - 2 Showers

Client/Site Requirements:

Propose a site development plan based on the park specialty and goals and design new structures and facilities for year-round habitation and operations. New structures and facilities include:

1. Condominiums for 2 families of 4 people each
2. Additional pens
3. Amphitheater structure (temporary – possibly tensile, or permanent)
4. Water areas for wild life demonstrations
5. Dendro-park
6. Trails and signs
7. 2-storey facility for meetings and gathering with auditorium, dining and observation balcony

RECOMMENDED MATERIALS

Material	Recommended use
Utilization of local materials	Windows, floor structures and surfaces
Proper sizing of all building systems	Structure trusses and framing members
Use of reclaimed or recycled materials and components	Modular skin panels
Use of non-conventional building materials	Not-permanently occupied structures
Material-conserving design and construction	All buildings and structures
Use of new economical materials	All buildings and structures
PV PolyC rystalline	Solar panels

PARK/CLIENT FUNCTION(S)

- Client/facilities relationships
    - Park personnel and their families
    - Type of science/work performing
    - Work organization
    - Habitable conditions
- Park goals
    - Park inhabitants
    - Their life cycles
    - Ecosystems co-existence and creating new systems
    - Creating new educational and academic programs

BUDGET

- Minimizing construction costs by using local materials
- Minimizing life costs

    Optimization new economical technologies

    Design and construction according possible future park development for better and faster future adjustments

Student workshops and surveys

In preparation to the studies, empirical data on students' daily living activities has been collected and analyzed through a series of workshops and surveys in the form of activity diaries at the Architectural department of Chalmers University of Technology and the College of Architecture of the University of Houston (overall n=19). Preliminary data from student diaries at both universities were collected in December 2012 followed by workshops organized at Chalmers University in December 2012 and May 2013. Collected data on students' needs, activities and energy and resources requirements have been cross-analyzed in regards to both current functional understanding and in a modified and/or extreme situation. Classification of functions and activities based on personal preferences in sharing spaces while performing them (personal perception depends on geographical locations, cultural and religious beliefs, age and social status; and those conditions may alter the results) are presented in the table "Basic functions and activities related to acceptance of sharing.

They further demonstrated differential understanding and presumptions of collective and private values. For example, even though students belonged to same age groups and had relatively similar disciplinary background, their demand for privacy diverged, most likely based on cultural and social specifics and housing situation. This was further underpinned at two workshops held with respondents at Chalmers only.

Collected data are not quantitative but rather based on students' qualitative impressions and recognition. It resulted in the functional breakdown of student housing according to: 1) Grouping of activities and human functions; 2) Levels of private or shared use of space and resources 3) Defined or perceived corresponding spatial, energy and resource requirements.

Data were furthermore analyzed in order to establish a pattern of compatibility, with a focus on spatial composition, functional relationship and possibilities for enabling sustainable lifestyles and responsible individual behavior.

BASIC FUNCTIONS AND ACTIVITIES RELATED TO ACCEPTANCE OF SHARING

Activity Sharing	Sleeping	Eating	Housekeeping/ cooking	Studying	Hygiene	Recreation
Collective (sharing activity and resources)	No	Yes	Yes	Yes	Not likely	Yes
Individual/ sharing resources	Maybe	Maybe	Maybe	Yes	Not likely	Maybe
Private/ not sharing at all	Yes	Not likely	Maybe	Not likely	Yes	Not likely

Questionnaire and interviews

Introduction

This research aims to test the hypothesis that a systematic design process strategy would help to organize planning and design activities for extreme environments[36] projects in a more time and resources effective way. The goal of such approach is to provide better planning which would include: sustainable systems and operations, up-to-day and cutting-edge building technologies and construction methods, and implementing those design approaches and considerations from the beginning of the planning process.

Instructions for participant: select a specific project in answering the following questions. Participants can answer the set of question for multiple projects. Please provide examples or references for your answers if possible.

Note: Questionnaire was distributed and answered by management and engineering employees of ConocoPhillips, other discussions include participants from: Shell Moscow office, Fluor Corporation (engineering and construction), scientific consultants for US Department of Energy.

[36] Extreme environments referred here share such conditions as remote locations, undeveloped infrastructure, and harsh climate.

Questionnaire Summary (combined)

What was your role on the project?

Project manager (KF);

Project engineer/technical advisor (MA) (planned and scheduled project, coordinated contractor's work, oversaw execution activities, provided technical expertise);

Offshore Construction Manager (TW)

Some projects with environmental challenges include:

North Slope Alaska

Deep-water offshore

Gulf of Mexico deep-water from concept engineering pre-sanction thru start of production.

Russian Arctic from concept engineering to sanction. Project now in operation.

Northern Alberta Canada from concept screening thru concept selection. Project still in preliminary engineering pre-sanction.

Was the project success or a failure?

North Slope Alaska project considered successful: project was executed safely, just under budget, and new technology was implemented and vetted by experts in field.

Deep-water offshore project was started-up on time and on budget with a >95% uptime from day one: success

GOM project successful: Good safety performance, fast track schedule, high uptime, good profitability, very experienced PMT and good contractor performance.

Russian Arctic project partially successful: Reasonable safety performance, good schedule, but operability issues, high cost overruns and low profitability. Owners not aligned on major drivers.

Canadian project too early to judge success/failure. Project challenged with low forecast profitability. Schedule challenged with regulatory constraints (HSE and sustainability issues wildlife and weather seasonal interruptions). **Logistics challenged with remoteness, lack of infrastructure and harsh environment. Execution efficiency challenged with number and quality of personnel with required skills.**

How do you define success and failure?

Success means projects meet goals of low safety incident rates, low environmental impact, target capital cost and schedule and high quality resulting in good reliability and uptime.

Success = safe execution (no injuries or incidents), on time and budget, project objectives met (achieve most value for the company).

Failure = Injuries and/or incidents occur, late completion, over budget (or drastically under), project is not value adding to company.

In addition: Human Factors contributing to both success and failure.

What was the design strategy employed?

The most common strategy is **design while built** with modifications specific to the site and/or other related to the location conditions

North Slope Alaska project. In-house design contractor coordinating with various contractors, field personnel and project team. Small scope and in-house team allowed for quick design modifications. Implementation of new technology facilitated by lab testing, process hazard analysis, and conservative schedule.

GOM project. Design was awarded to different contractors for the major components of topsides, hull, well systems and rig. Philosophy was to design while build to meet schedule. Large strong operator project management teams were used in contractor's shops to oversee and drive the work.

Russian project. A conceptual design was submitted to the government for approval which was based on preliminary subsurface data. The design was issued to a general contractor to implement. The design was based on very dated Russian philosophy and technology. The general contractor subcontracted much of the design. There was **little or no oversight of the subcontractors. Mistakes had to be fixed in the field – that usually drives the overall cost up.**

Canadian project. Too early in the project to comment on design strategy.

How much of the design was complete prior to sanction of the project?

North Slope Alaska project: Most conceptual engineering was complete, very simple scope so there was little risk of significant changes after sanction. The "design" was redone a couple times after sanction, before execution, using the same "parts" (i.e. long lead items we had already procured).

Deep-water offshore project: 60% to 70%

GOM project was sanctioned before the end of conceptual engineering. The hull type was not selected.

Russian project was sanctioned with **very little engineering complete.** Only a conceptual development scheme was submitted to the Russian authorities and that submittal was issued to a general contractor who completed the work of design thru start-up.

Canadian project not yet sanctioned. Presently in pre-FEED.

In summary: a lower level of design completion prior to project sanctioning **increases a possibility of human error occurrence.**

What were the major project drivers? (Cost vs. schedule)

For operated projects safety is always the first driver.

In addition, the following are usual major drivers: maximizing value for company, cost and schedule.

Costs on the North Slope of Alaska are significantly higher than many locations (such as the Lower 48).

Deep-water offshore: schedule was the major driver

GOM project: schedule, quality and cost in that order

Russian project: schedule, quality and cost in that order

Russian priorities were annual cash flow and local employment and other partners wanted **good profitability**.

Canadian project: cost, quality, schedule (at this time)

North Slope Alaska location specifics: With a long history of projects in this environment, the costs can be estimated pretty accurately. Schedule is always a constraint, mainly **due to weather windows**. For this project a "warm" weather was essential and it was only approximately a 3 month timeframe to execute the work, which requires a significant amount of planning to get everything done in time. Most work on the North Slope is done during the winter, when an ice road is constructed to reach the work site. Again, there is a limited window of time to execute the work before the road melts. There are typically weather delays due to extremely harsh conditions and **operations have to be planned for these in their schedules**. Large projects are completed over multiple winter seasons.

What are the major challenges in planning operations in extreme remote locations?

North Slope Alaska: Availability of **resources and maintenance** of them (people need housing, food, and to be kept happy and equipment needs storage and maintenance shelters, spare parts, mechanics, fuel, etc.), **access to site** (ice road, plane, barge, etc.) has limitations (**weather window, size, weight**, etc.), costly and time consuming (business objective must be able to support higher costs and additional time)

Deep-water offshore project: The platform was set during hurricane season **with a tight weather window**. Material logistics are always a challenge. Housing of construction staff on remote platforms and floating hotels causes productivity issues**. A very small laydown area forces just in time material and equipment deliveries.**

General thoughts on major challenges:

Little or no infrastructure exists in extreme remote locations, so the infrastructure has to be brought to the location to execute the project

Bringing sufficient owner and contractor work force **knowledge and experience to bear to define what needs to be included in the infrastructure and the project.**

Taking sufficient time to define the work in sufficient detail to be able to effectively plan the work in the most effective work sequence.

Identifying the risks involved and establishing mitigation plans to address risks.

Identifying and mobilizing a work force to do the work. Keeping the work force working in a productive manner.

Establishing a communication plan to keep the work force informed and aligned to execute the work efficiently.

Managing change so it does not derail the work plan.

In summary: Pick the right people, **identify the issues**, plan the work and work the plan. Always complete sufficient work to be ready to proceed to the next phase of the project. Minimize changes along the way, but be flexible and competent enough to manage changes that do occur without major disruption to the overall goals and objectives of the project. **Communicate, communicate, communicate…………**

What are the major risks?

Not establishing aligned project objectives first between different owners and between owners and contractors

Not having the right critical mass of owner PMT personnel

Not having sufficient numbers of skilled contractor personnel

Insufficient front end work

Trying to go too fast

Allowing **significant scope changes after concept selection**

Incomplete work carried from one phase to the next in the project without a plan to effectively handle the additional work in the subsequent phase

Cost/schedule overruns, health and safety concerns (for example if injured person can't get medical support in timely manner)

Materials not being on location when they are needed and weather limiting the ability to get the construction staff to or from the platform in a timely manner.

What are the gaps in planning and designing specific for extreme environments?

Gaps result from **inadequate actions to mitigate the major risks**. Usually risks are identified and mitigation plans are developed and documented. Failure occurs due to not actually executing the mitigation plans.

In "new" extreme environments the **timing requirement for new technology development and vetting is many times understated and not well planned/thought through**. If a Project requires new technology to be implemented, the execution planning and engineering design need to account for this (it is not a small task!).

Reliable and consistent materials tracking and forecasting of pending weather conditions

Would applying a design and planning methodology enhance strategic development in extreme conditions?

Adequate front end engineering and planning are absolute keys to successful projects in any environment, but especially in extreme and remote environments.

It would definitely help from the materials perspective.

What are the most challenging locations you worked on?

North Slope of Alaska: Here is a publication (slightly dated) on the oil and gas industry in Alaska:
http://alaska.conocophillips.com/EN/about/publications/Documents/ArcticEnergy.pdf

Deepwater offshore is the most challenging because of its remote nature and distance from existing supply infrastructure. If you need a key piece of material and you can't get it for days because of your remote location or because of bad weather, your entire operation could be shut down.

Please provide examples or references for your answers if possible.

Above referenced project was a small pipeline rehabilitation project on the North Slope employing internal coating technology new to the company and region. The results of this project were so favorable that 2 additional similar projects have been completed since.

Qs: How much autonomy was given to local contractors sub-contractors?

New locations – using existing scheme and starting from "scratch" every time?

Maintenance? Is maintenance operations part of strategic planning before the project executed?

Yes, equipment related mostly

North Slope, Alaska

Exploration rig can be around 50 people, production depends on the scale of the project. Maintenance and repairing: more people involved in fixing a problem in a shorter period of time because of weather window available for operations. Only iced roads used for access. Crew rotations: 2 weeks on 2 weeks off (think about emergency situations)

Planning involves many levels of professionals from different disciplines and multi-number of employees from different contractors and sub-contractors which creates a higher risk of human error situations.

Alpine facility: access is available only during 2 months period.

Political issues:

More restrictions and regulations on Federal level, state level more concerned about revenue for the state and more up-to-date with current needs of the state etc.

Challenge:

Most operations started in 1980s and lifespan of structures was planned for 25 years but it has been expanded beyond that with new discoveries in the region, development of new technologies that allow now to reach oil and gas resources that weren't available before.

Because facilities are used longer than expected and new technology can be re-applied to existing sites, more workforce is required resulting using the same facilities and structures but with double or triple occupancy.

Comments and discussions

Challenges

1. Remoteness,
2. Lack of infrastructure,
3. Weather conditions,
4. Transportation windows,
5. Local cultural and political habits and practices,
6. Technology upgrades.
    A. Remoteness and lack of existing infrastructure are obviously related problems and common for most northern locations. They drive overall cost of projects up proportionally to degrees of their intensity. Remoteness also affects psychological climate and may influence personnel motivation and performance.
    B. Related to #1 and has to be addressed prior to project initiation leading to additional time and budget requirements.
    C. Unpredictable weather conditions are very common for extreme environment locations and require certain preparedness level for all parties involved in development of the project. They also pose special constraints for physical structures, roads and other infrastructure. Harsh weather conditions also demand more precise and effective safety operations routines. It also requires developments to be accomplished in a short period of time and with larger number of workers.
    D. Transportation windows in most Polar Regions are limited to few months of a short polar summer, although in some locations (North Slope Alaska) ice roads are constructed during the winter in order to prevent damage to vulnerable tundra environment. This means that operations there are cut off regular supplies during summer time.
    E. Federal and state government have different objectives pretty often. For example, federal government has more restrictions on environmental issues while state is more concerned about getting money back. In different countries local government has different agendas and planning for it is important for successful developments. Those agendas and cultural, social and political aspects connected to them, drive the overall cost up.
    F. Nowadays more resources become reachable from the same location because of technological advancements. That leads to expanding of lifespans of existing facilities more than it was initially expected. Facilities built in late 1970s were planned for 25 years in operation but are still in use and have to be adapted to new technological processes and larger number of personnel.

Human Factors related issues

1. Project success or failure major drivers
2. Risks assessments and analyses
3. Workforce/personnel
4. Local and company management, local contractors and HQ
    A. Safety is always a major driver for operated projects. Other drivers are connected to challenges described above and include: completing a project within the timeframe, under the budget and with secure technology implementation after field experts' inspections.
    B. Identification of the magnitude of possible risks and incorporating appropriate mitigation plans into planning strategy is very important. Planning should also include providing means that are necessary for timely execution of mitigation plans when needed.
    C. In connection to the Challenges' item 6, more workforce is needed now to safely execute and operate facilities in remote locations, which creates a shortage of living accommodations forcing people to live in temporary structures. These accommodations lack safety and comfort and therefore may increase possibility of stress and stress-related risks. Harsh environmental conditions and remoteness of sites intensify such risks.
    D. Alignment of major objectives with partners from the start is important in order to avoid delays during project development. Appropriate levels of knowledge and experience have to be identified first in order to have sufficient owner and contractor work force to execute the project. Effective communication strategies are critical to avoid time delays and operational mistakes, to respond to emergency situations quick and efficiently, to establish positive and constructive relationships with local communities and authorities. These strategies should be a core of planning approaches in extreme environments.