THESIS FOR THE DEGREE OF LICENTIATE OF ARCHITECTURE

Extreme environments - Design and human factors considerations

OLGA BANNOVA

Department of Architecture
CHALMERS UNIVERSITY OF TECHNOLOGY
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OLGA BANNOVA

Department of Architecture
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone +46 (0)31-772 1000

Cover:
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ABSTRACT

The starting point of this research is based on my experience at SICSA[1] performing research and design for extreme environments, including orbital and lunar planetary facilities, disaster shelters, polar stations and offshore surface and submersible habitats. 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. That "tool" will be proposed for the purpose of facilitating a dialogue between all parties involved during developments in extreme conditions of Polar Regions.

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. 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.

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

[1] Sasakawa International Center for Space Architecture, Gerald D. Hines College of Architecture, University of Houston, Houston, TX, USA

List of publications

This licentiate thesis is based on the work comprised in the papers listed below and referenced in the text by Roman numerals:

Paper I: Autonomous Architecture Proposal for Summit Science Station in Greenland. (2005)
Peer-reviewed conference paper presented at ICES-05 in July 2005.
Authors: Bannova, O., College of Architecture, University of Houston, Smith, I. & Landschulz, A., École Polytechnique Fédérale de Lausanne.

Paper II: Can We Test Design for Coming Interplanetary Expeditions in the Arctic? (2006)
Conference paper presented at AIAA Space 2006 in September 2006.
Authors: Bannova, O., College of Architecture, University of Houston & Jorgensen, J., SpaceArch, Copenhagen.

Paper III: Terrestrial Analog Selection Considerations for Planetary Surface Facility Planning and Operations. (2010)
Book chapter 28 in: Lunar Settlements. Edited by H. Benaroya.
Author: Bannova, O., College of Architecture, University of Houston.

Paper IV: Experiments in mapping human factors for sustainable design and living. (2013)
Paper presented at the IAPS International Network Symposium in June 2013. Peer reviewed paper accepted for publication.
Authors: Bannova, O. & Hagbert, P., Department of Architecture, Chalmers University of Technology.

Paper V: Testing and Evaluating Sustainable Design Practices. (2014)
Peer reviewed paper presented at ARCC/EAAE in February 2014.
Authors: Bannova, O., Nystrom M., Femenias P., Hagbert P., Toups L., Department of Architecture, Chalmers University of Technology.

Table of Contents

1. Introduction

Although existing methods applied to planning and design for remote and extreme environments address some environment-specific challenges they usually do not cover or include a systematic approach to the design process from preliminary design phase to construction stage and are usually conducted on a case-by-case basis (Nielsen 1999). Sometimes some previous experiences are used in new conditions but without comprehensive arrangements and systematic methodology it may be misleading and resulting in misusing and waste of resources and time delays.

Despite the fact that there are federal laws, standards and regulations generated by companies, local authorities, developers and other entrepreneurships, they are disconnected at many levels and usually have different objectives which consequently lead to unbalanced design and planning resulting in failure in one or several areas of development (Bell 2014). This is also critical for creating sustainable environmental and social systems (Rasmussen 1999). Social systems in extreme environments are much more vulnerable and sensitive to changing conditions in any of their subsystems, such as cultural, political, ecological, technological, societal (Rasmussen 1999). A malfunction in one of those subsystems may very easily make the whole system dysfunctional and handicapped (Nuttall 2005).

Efforts in fixing not properly addressed problems later in the development process are very costly, time consuming and sometimes too late to be corrected (Reason, Human error: models and management 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. This path or integrative model is to be based on analysis of two case studies: a Summit science station in Greenland and Muraviovka Park for Sustainable Land Use. The Licentiate study presented in this report is focused 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 shall serve as a design and development planning tool development of which will be the subject of doctoral studies (Figure 1).

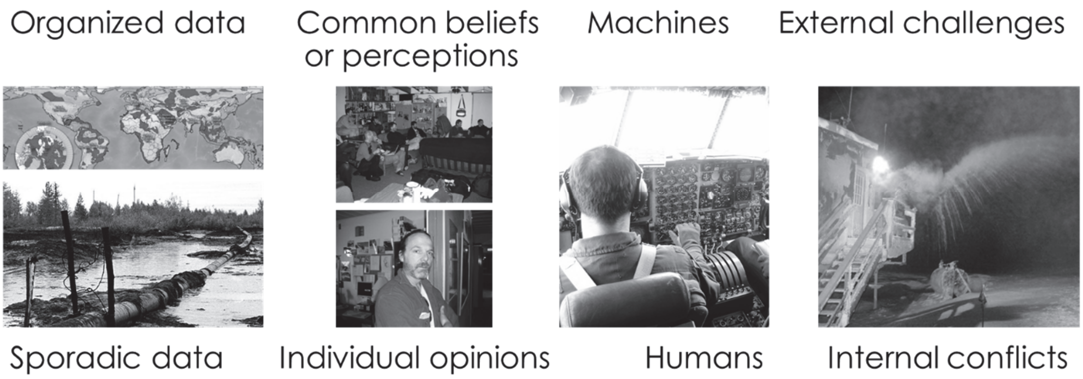


Figure 1. Issues and aspects for the proposed dialogue tool. *Source: O. Bannova.*

My Licentiate and following it PhD research is aiming at arctic and permafrost areas where regular construction methods cannot be applied, transportation is severely restricted and safety requirements are very strict and critical. Figure 2 presents a combined map of potential and existing fossil fuels fields and permafrost zones in Polar Regions. Those areas of development will require construction of facilities, infrastructures and accommodations for workers, supporting and logistics crews, storage capabilities, optimization of local resources and more. All of those structures will have to be constructed within a very tight timeframe of a short polar summer and by using limited transportation means.

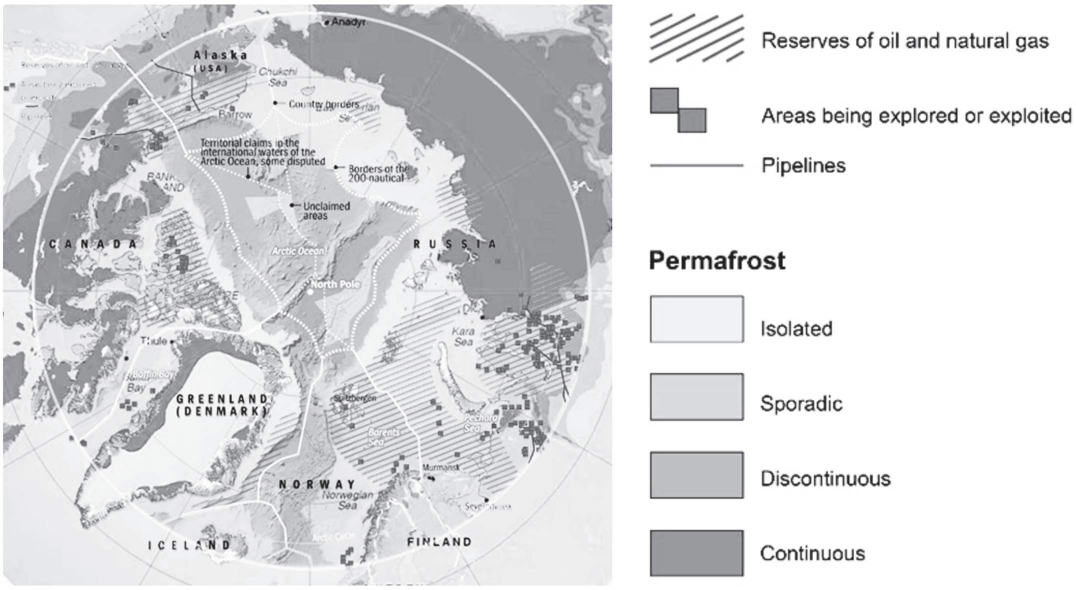


Figure 2. Map of permafrost regions combined with oil and natural gas reserves in Arctic. *Sources: International Permafrost Association, 1998. Circumpolar Active-Layer Permafrost System (CAPS), version 1.0* (Ahlenius, Johnsen and Nellemann 2005)*; and Grid-Arendal, ACIA, AMAP, GAZ de France, East European Gas Analysis, NSIDC, United States Geological Survey.*

1.1. Thesis structure

The text is based on research conducted at the Sasakawa International Center for Space Architecture (SICSA) of the University of Houston and Architectural department of Chalmers University of Technology, the research was reflected in technical papers written and presented at different international conferences. The present thesis includes 10 chapters with sub-sections, references and appendix (Figure 3).

Chapter 1 introduces the subject of research, existing situation and concerns in studied environments and locations and combination of factors that affect areas of study.

Chapter 2 explains roots of the research problem, the goal of the study as well as research questions.

Chapter 3 talks about initiation points of this research and interests laying in the foundation of the investigation process. The sub-sections 3.1 and 3.2 of this chapter explain two major definitions that refer to the roots of the research problem: what conditions characterize extreme environments and interpretation of “human factors” terminology.

Chapter 4 begins with a summary of first three papers used in this thesis and continues with outlines of case study and research presented in those papers emphasizing connectivity between them and the theme of the thesis work (sub-sections 4.1, 4.2 and 4.3).

Chapter 5 presents papers I, II and III abstracts with a synopsis for each of them.

Chapter 6 moves on with discussion about research methods considered for this work and applied in the study. It brings up the second case study to illustrate a trans-disciplinary design approach that was used during research and design stages of the project.

Chapter 7 elaborates on attributes that help to form an architectural attitude. It examines the philosophical aspect of architectural practice as an important part of the design process. This chapter's sub-section 7.1 reflects theoretical considerations as well as discussions with oil and gas industry professionals.

Chapter 8 summarizes papers IV and V by outlining them and demonstrating relevance of the research presented there to the subject of the thesis work in subsections 8.1 and 8.2.

Chapter 9 presents papers IV and V abstracts and synopses.

Chapter 10 summarizes and analyzes the information and research presented in the thesis and outlines directions for work to be done towards the PhD defense. The chapter also suggests possible outcomes of the presented study.

The report concludes with the list of references used and appendix that includes full texts of referred peer-reviewed papers, surveys with industry professionals and summary of discussions described in the chapter 7.1.

The diagram below represents the thesis structure and relationships between chapters.

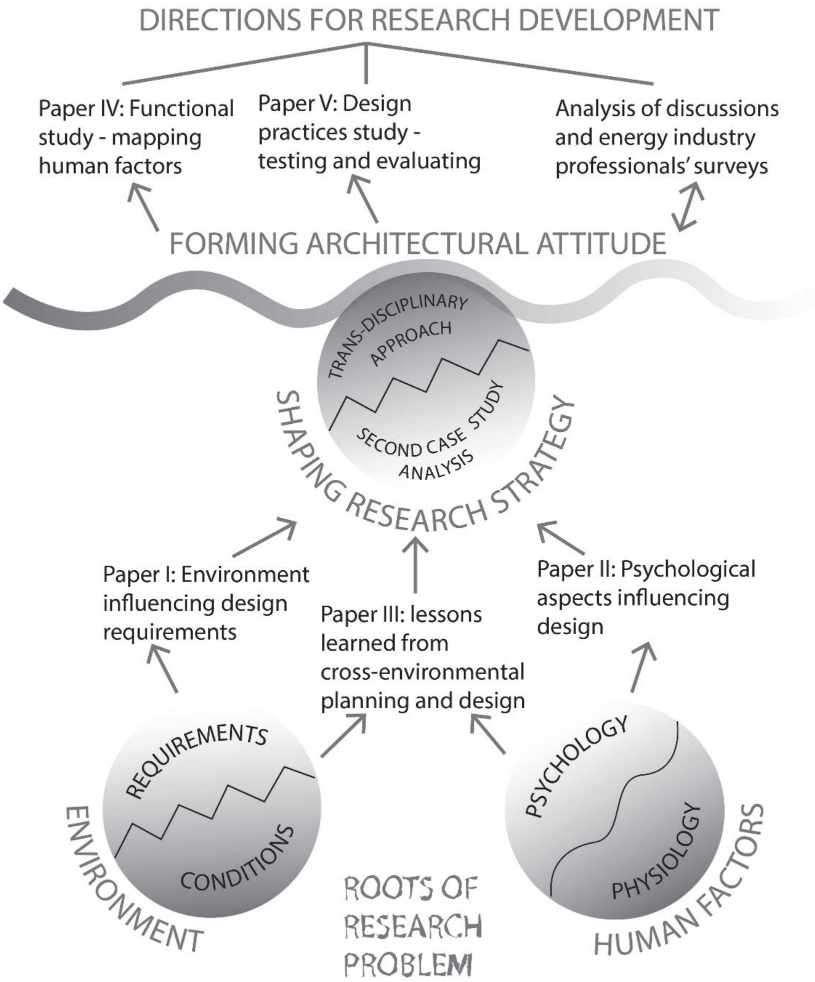


Figure 3. Thesis structure diagram.

2. Roots of the research problem

In his "Designerly ways of knowing" Nigel Cross compares scientific, humanistic and designer problem solving approaches. (Cross, Designerly ways of knowing 1982) I find it especially interesting and helpful for identification of cross-disciplinary areas between architecture, engineering, social and psychological studies. In discussion of Lawson's studies of design behavior (Lawson 1979) he concludes that:

> "These experiments suggest that scientists problem-solve by analysis, whereas designers problem-solve by synthesis."

Design is one of most complex processes and requires well researched interdisciplinary preparation work including not-traditionally design-related disciplines such as climatology, meteorology, engineering, etc. Miscommunications or even absence of communication between diverse professions involved in developments in the extreme environment of Polar Regions leads to critical mistakes and may result in vast environmental, time and money losses (Rasmussen 1999).

An ultimate goal of any design process depends on successful identification of a design research problem which always lays in finding a proper "translation from individual, organizational and social needs to physical artifacts" (Hillier and Leaman 1976).

Another motivation comes from an observation made during presentations and discussions at different engineering oriented conferences and also from my experience of working with space grants and projects together with aerospace engineers and managers. In many occasions I witnessed a complete obliviousness to the fact that any design or planning project has to deal with *all* components of the whole planning process at *every* stage of it. Professional engineers are good at bringing their product to the perfection…but often without reference to the rest of the project and other parties contributing to design requirements, execution, maintenance of the final product and overall user perspective.

The figure four below is a map of potential oil and gas resources in Arctic. It clearly demonstrates that exploration and production will continue to expand there and as a result of it, all spheres of life and environment will be affected (Nielsen 1999) (Klett 2011). The two following maps display population density and population common migration paths in the same regions (Figures 5 and 6). These diagrams evidently reveal a lack of population in arctic regions in northern countries where the largest oil and gas potentials have been recently discovered. Canada, United States, Norway and Russia (Spencer, et al. 2011) (Klett 2011) – all will face logistics and maintenance challenges when moving their massive equipment, large number of workers and supporting crews and developing necessary temporary and permanent infrastructures within stringent timeframes of short transportation windows. Developments in the energy industry require substantial workforce and technology involvement as well as advanced infrastructures 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).

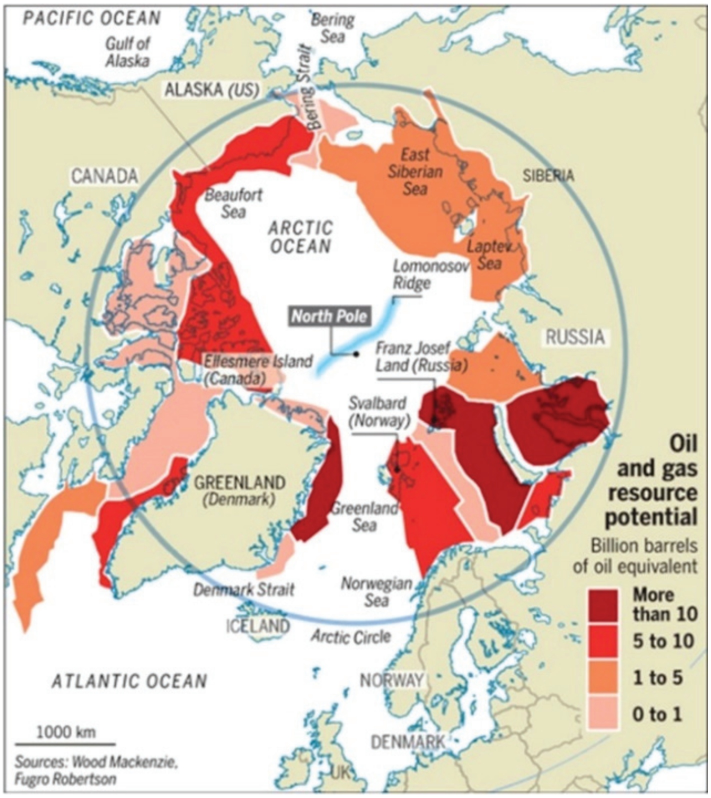
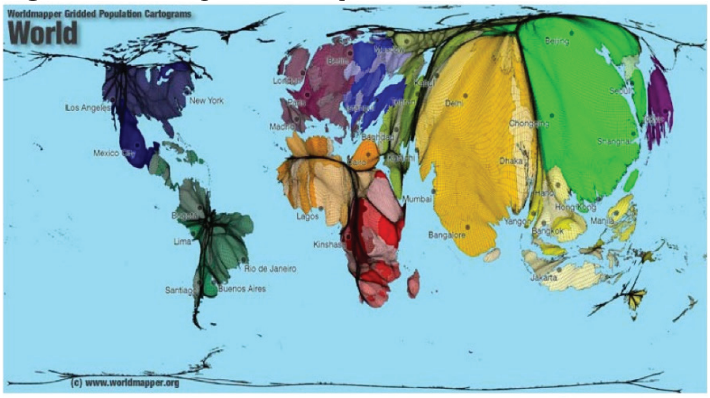
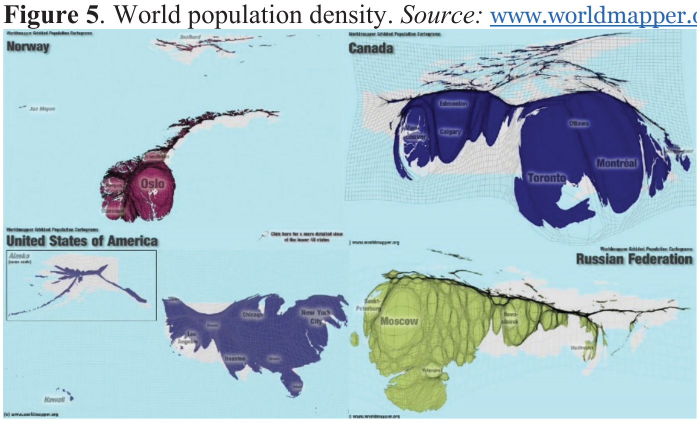


Figure 4. Oil and gas resource potential. *Source: Wood Mackenzie, Fugro Robertson.*



Rank	Territory	Value
MOST AND FEWEST PEOPLE		
1	China	1295
2	India	1050
3	United States	291
4	Indonesia	217
5	Brazil	176
6	Pakistan	150
7	Russian Federation	144
8	Bangladesh	144
9	Japan	128
10	Nigeria	121
		millions

Figure 5. World population density. *Source:* www.worldmapper.org



Rank	Territory	Value
191	Saint Kitts & Nevis	42
192	Monaco	34
193	Liechtenstein	33
194	San Marino	27
195	Palau	20
196	Cook Islands	18
197	Nauru	13
198	Tuvalu	10
199	Niue	2
200	Holy See	1
		thousands

Figure 6. Population density: Norway, Canada, Russian federation and the USA. *Source:* www.worldmapper.org.

The goal
The current research aims to demonstrate that a systematic design process strategy would help to organize planning and design activities for extreme environments in a more time and resources effective way that will be also beneficial for local communities and working personnel. The goal of such an approach is to provide a better planning tool which would include: sustainable systems and operations, up-to-date and cutting-edge building technologies and construction methods. It is expected that investigating and comparing two case studies create a foundation for further investigations and justify the necessity of generating a common design and planning matrix for remote areas and extreme conditions. The thesis research also addresses:

- Physical requirements influencing design;
- Environmental conditions influencing design;
- Budget conditions influencing design;
- Design as a tool to address social and cultural challenges.

Research questions
In the present fast changing world it is important to use a big picture approach when addressing any complex problem.
Therefore, the research questions are: What are the major influencing aspects of development processes in the extreme environment of Polar Regions? Why and How (in what aspects) are they related to each other and what is missing in those connections? How can the related aspects be organized?

3. Initiation of research – Understanding of basics

What would be or what is a theory and definition of "extreme" or "extreme environment" and what does "human factors" term mean? There are definitions based on a variety of personal backgrounds, different perceptions and physical and chemical characteristics (Thiel 2014). It seems people very often become confused with these terms and many have quite different perceptions about what they are. Those perceptions usually depend on many factors: social, cultural, behavioral, financial, political, and of course environmental with multiple characteristics included. For example, environmental factors reflect on all aspects of life and at the same time depend on them. Misbalance or disturbance in one of these areas can lead to the environment becoming "extreme" for living or/and to a social or other "struggle" that may also lead to a bigger disturbance and creation of even more extreme conditions than before.

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. Although most habitat arrangements in extreme environments cannot be considered "cities", some of the urban assets can definitely be applied to their planning and design practices. Social, cultural, and political aspects have to be addressed in the overall planning and throughout the design process (Rasmussen 1999). Such settings present a high degree of design functionality, with a tendency to demand an adaptation from habitants to the technology.

This research starting points are based on my experience at SICSA[2] in research and design for extreme environments, including orbital and lunar planetary facilities, 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 conditions, remoteness with restricted access and return opportunities, limitations on available equipment and support services, and ever-present safety risks (Bannova, Design considerations for exterior and interior configurations of surface habitat modules 2007). All of these environments have many similar kinds of technical and operational priorities. Key among these are needs for appropriate transportation and construction systems, efficient energy, effective and environmentally-responsive waste management and life support systems, maintenance and repair provisions, and emergency accommodations.

3.1 Extreme environments: characteristics

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)

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

Echoing NAI's description, "extreme environment" in Wikipedia is defined exclusively by extreme physical conditions:

> "An extreme environment exhibits extreme conditions which are challenging to most life forms. These may be extremely high or low

[2] Sasakawa International Center for Space Architecture, Gerald D. Hines College of Architecture, University of Houston, Houston, TX, USA. http://www.uh.edu/sicsa/

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. There are organisms referred to as extremophiles, that inhabit these spaces and are so well-adapted that they readily grow and multiply.
Examples of extreme environments include the geographical poles, very dry deserts, volcanoes, deep ocean trenches, upper atmosphere, Mt Everest, outer space and other planets."

These conditions can definitely be described as extreme and hazardous to human life but the environment may pose danger to people even without those factors being present. That 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 overlooked in planning and design efforts and therefore contributing factors are not addressed in the overall design process for extreme environments.
What makes a place we visit or live "extreme"? I suggest that this is an environment that poses special limitations and/or hardships for people to survive and maintain relative physical and psychological comfort. These limitations are usually in:

- Resources;
- Availability of services and/ spaces;
- Mobility and transportation.

These 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.

Two case studies discussed in this report were chosen based on their locations in extreme and challenging settings, relevant similarity of design objectives, and research conducted during their program development stages. Interdisciplinary aspect of projects was also one of determining selection factors as well as providing a means for enabling sustainable practices in building design, maintenance and utilization.
Table 1 summarizes environmental and geographical characteristics of both cases: Polar desert and Boreal. Case study one 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 two is in the wetlands of Amur River of Russian Eastern Siberia. Both geographical locations present challenges for life conditions and demand a proper response from architects and planners when planning development activities in these regions.

Characteristics Zone /climate	Temperature	Weather	Geography	Case study
CASE I, Polar desert	Mean temperature during warmest month less than 10C	Brief summer, precipitation less than 250mm (annual)	Greenland	Summit station
CASE II, Boreal	Most extreme temperature variations, at least one month must have a 24-hour average t° of 10C	Subarctic, short and warm summer, cold winter	Russian southeastern Siberia (Amur region)	Muraviovka park

Table 1. Characteristics of proposed case studies.

Other factors present additional conditions and influences contributing to the environment becoming extreme for living. Those factors discussed further in the report in chapters that describe case study two and papers referring to research of case study one.

3.2 Human factors and ergonomics: definitions and differences

The International Ergonomics Association council approved definitions of Ergonomics (or human factors) in the year of 2000 as follows:

> 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. (What is ergonomics 2011)

I want to argue the above definition and equaling human factors with ergonomics in spite of the fact that it is well expressed and sufficiently inclusive. There are many disciplines and professions referring to human factors in their practices and every one of them understands it somehow differently. I suggest that architectural meaning of this terminology is more comprehensive and addresses physical conditions of human body as well as its psychological status and health. Architectural approach also includes understanding of consequences of inadequate behavior or actions that caused by inappropriate architectural approach to the project development and may lead to non-desirable or even catastrophic events. Such understanding should be part of design and planning prerequisites and programming (Reason, Human error: models and management 2000).

In extreme conditions and environments more advanced design approach should be implemented into practice, where focus is not solely given to survival of people but also to planning it as "a place for living". According to a psychological point of view, visual impressions have a high value for humans, since we are used to get approximately 75% of our sensory information from the eyes. 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 surrounding environment and understanding of extensive use of this information in different brain centers is very important. Experience of interaction with aesthetics is linked to this information and interrelated to centers which stimulate pleasure in the brain. (Matthews, et al. 2000) Details in the design, choice of materials and active use of three-dimensional space and colors can therefore be important tools to heighten the quality of the habitat environment. The quality of life in relation to the quality of design could be focused on a salutogenic (Palinkas 1986) approach, offering not only mitigation of psychological and sociological crew problems, but also a health promoting approach when the design improves physical and mental health beyond survival limits.

Methodological considerations for this could be based on a present knowledge about humans in extreme environments and on active anthropological investigation as a key factor in human life. What defines a cozy meal besides that is eaten outdoors, in a dwelling of a third world country, in the wilderness or in a middle class home? What defines a place where people meet and relax together in a crowded submarine or in a busy city office? Is it possible to define some key points using anthropological methods no matter what the settings are? By answering these questions we may understand important information for quality design for future housing in Polar regions or habitats in other extreme locations.

Human factors became a common term when applied to risk management and related disciplines. James Reason's model of organizational accidents (Figure 7) is well known and widely applied in healthcare (Reason, Human error 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, Human error: models and management 2000). These holes are known as 'latent conditions'." (from *Patient Safety First: Implementing human factors in healthcare*).

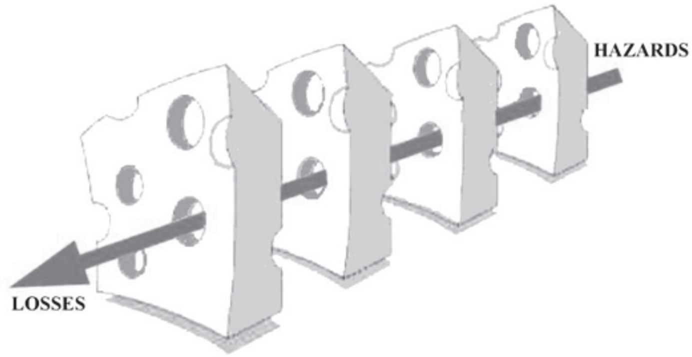


Figure 7. Swiss Cheese Model of organizational accidents. *Source: J. Reason* (Reason, Human error 1990)

If applied to operations in extreme environments or under extreme conditions it may help to identify ways to prevent potential errors in design organizational process. The "cheese model" can be translated into a processing matrix to be applied to design and planning.

- Swiss Cheese model can be used as a base for processing matrix;
- It addresses design and planning errors;
- Can help to build design that tackles organizational errors.

This model becomes multi-dimensional when applied to design process as a reflection to design and planning multi-staged hierarchal nature. The multi-dimensional character of the process affects overall design approach in a way where all components are influenced and influencing one another (Figure 8). Figure 9 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 elements. The integration model or tool's role is to facilitate these relationships and promptly respond to their demands.

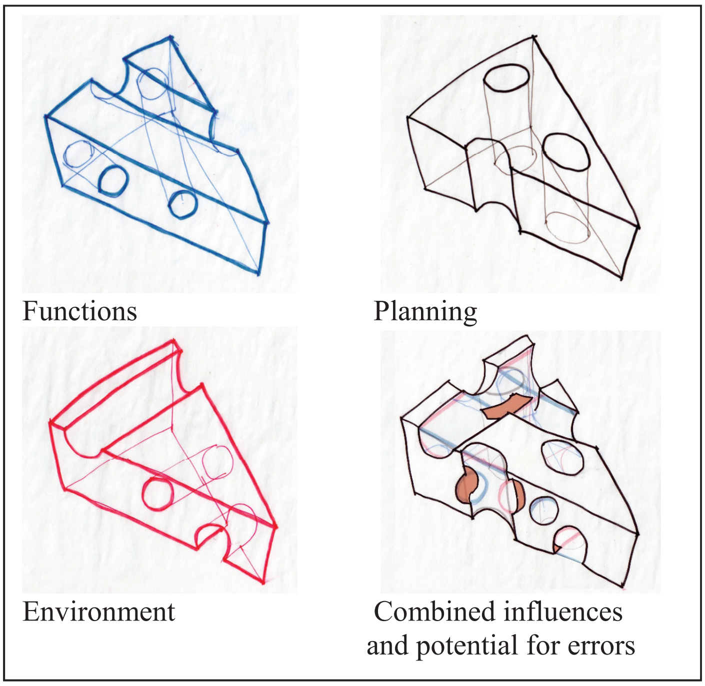


Figure 8. Multi-Dimensional Swiss Cheese (SC) Model of organizational influences. *Source: O. Bannova.*

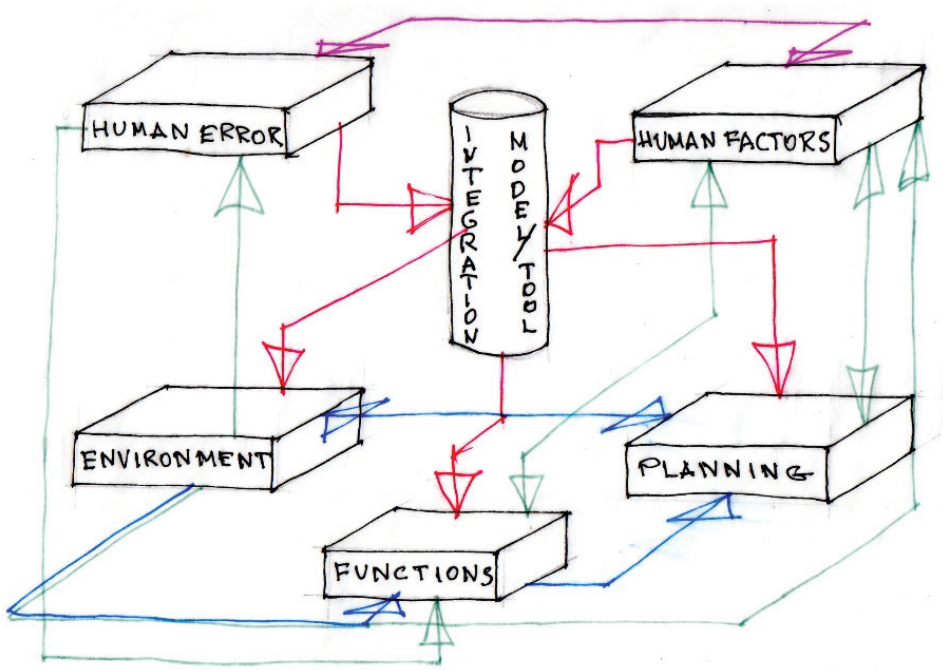


Figure 9. Multi-Dimensional SC Model applied to project development process. *Source: O. Bannova.*

4. Summary of papers on design for extreme environments

The following chapters 4.1, 4.2 and 4.3 summarize papers presented at international conferences dedicated to developments and design in extreme environments. These papers were peer-reviewed and published in affiliated professional journals accordingly. The papers were selected for this thesis based on the data presented and its relevance to the topic of the research. Design requirements and environmental characteristics described in these publications play an essential role in understanding of the origin of research questions.

4.1 Paper I (2005) Case study - Environment influencing design requirements

Some of these assumptions and ideas were addressed and presented in several papers focused on research and design work conducted prior to acceptance to the PhD program. First two papers were based on the project that is used as one of the case studies: a Summit science station in Greenland operated by the US National Science Foundation (NSF).
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 the maximum use of renewable energy through analysis of site influences, transportation constraints, building and utility systems requirements; and planning living and research accommodations, support structures while optimizing budget and schedule.
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.
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. 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.

4.2 Paper II (2006) Case study – Psychological aspects influencing design

Psychological health and support of morale climate within 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 between space architecture and space psychology provides ways 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 for the crew (Bannova and Jorgensen, Can We Test Design for Coming Interplanetary Expeditions in the Arctic? 2006). There are three key issues influencing design in extremes that are based on historical examples of Arctic and Antarctica expeditions 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".

I tried to identify and explore here a few “edges” that frame and contribute to conditions becoming extreme. All of the edges refer not only to spatial conditions or elements but personal and public mentality. There are many more edges, faces, vertices that interfere and affect each other at different levels.

Psychological, social, and cultural aspects of life in Arctic and Antarctic remote areas, outer space and other extreme environments have similar isolation, confinement, deprivation, and risk factors that building designers must consider. There are direct analogies related to symptoms, time lines of missions, and research goals, opportunities and risks (Harrison, Clearwater and McKay 1990)
Experiences on US and Russian space stations, underwater vessels, and polar stations have revealed a variety of common human factors, psychological and physical health and behavioral issues (Figure 10):

Figure 10. Destiny Module Interior, Antarctic Station, Submarine Interior. *Source: NASA, NSF, Wikipedia.*

- 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.

Common types of constraints 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.

4.3 Paper III (2010) Method – lessons learned from cross-environmental planning and design

This paper was based on the research I conducted for several years at the Sasakawa International Center for Space Architecture at the University of Houston and focused on identification of important lessons that can be applied to 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 that can be applied to design and planning for various extreme environments and adjusted to diverse harsh conditions. Human requirements and environmental factors specific to each different type of environment, operation and facility must be correlated with resulting planning needs. Some general considerations are listed below in the Table 2:

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 2. Planning considerations.

One of research methodologies that I use in my work is Figures Of Merit (FOM) approach. *Figures Of Merit (FOM),* a common format that is frequently used by the National Aeronautics and Space Administration (NASA) centers as a "practical and efficient way to characterize and compare project's attributes and to evaluate them."
Business dictionary defines FOM quite similar:
"Numerical value representing a measure of effectiveness, efficiency, performance or other important factor, and ascertained or approximated from analysis, appraisal, or estimation techniques." (BusinessDictionary.com)
Classification of recurrent and specific to environment events and categorizing them using FOM is presented in the Table 3.

Settings / **Factors**	**Polar regions**	**Under water**	**Deserts**	**Disaster areas**
Transportation	Maximum	Less	Less	Medium
Environment	Medium	Maximum	Less	Less
Crew: Size/activities/ durations	Maximum	Maximum	Less	Less
Construction methods	Medium	Maximum	Medium	Medium
Safety and Emergency requirements	Medium	Maximum	Medium	Maximum

Maximum   Medium   Less

Table 3. Compatibility and testing abilities of terrestrial analog settings for space applications.

Using the FOM method helps to identify important lessons that can be applied across different settings which present common priorities, issues and challenges. Such environments include future bases on the Moon and Mars, offshore surface and submersible facilities, polar research and oil/natural gas exploration stations, military desert operations, and natural and man-made emergency shelters.

5. Papers I, II and III abstracts and synopses

Paper I: Autonomous Architecture Proposal for Summit Science Station in Greenland. (2005)

Peer-reviewed conference paper presented at ICES-05 in July 2005.
Authors: Bannova, O., College of Architecture, University of Houston, Smith, I. & Landschulz, A., École Polytechnique Fédérale de Lausanne.

This paper investigates design rationale influenced by remote location, environmental challenges, functional versatility and client requirements. The research findings were implemented into design of a science station and resulted in building a mock-up that was tested in the original location of the Summit station in Greenland. The project was conducted in collaboration with computational engineering department of the Polytechnic University of Lausanne, Switzerland.

Abstract

This paper reports results of collaboration between the Sasakawa International Center for Space Architecture (SICSA), Houston, USA and the Applied Computing and Mechanics Laboratory (IMAC), Lausanne, Switzerland. A design project has been initiated in response to growing international scientific research interest at Summit Station in Greenland and a requirement for better accommodation and support. Research at IMAC involves the study of intelligent cable-strut structures that are adaptable and self-repairing. An architectural and engineering development approach as well as conceptual proposals for the Summit Station in Greenland for science research and operational support is proposed.

The proposed facility in Greenland supports 50 people during the summer season and 25 people during the wintertime. Primary elements of the modular configuration include a triangular platform with two upper floors that is supported by three jacking columns. This approach means that structure can be adjusted to accommodate differential settlement of supports. An adaptable apron structure around the primary platform is used to modify the form of the underside of the platform to maintain predetermined clearance criteria between the structure and level below, thereby avoiding excessive snow accumulating around the building and minimizing drifting and scour underneath it (on Mars, dust storms might be the difficulty). A separate structure for a mechanical shop and power support is added to complete the initial configuration. Important priorities are to provide a high quality environment and to minimize development, construction and operational costs while optimizing safety, versatility, autonomy and human factors.

Testing of a plywood model of the primary facility that was installed in Summit in May 2005 and a wind tunnel model at EPFL confirmed that if the structure was not sufficiently elevated, drifting could bury it. Important parameters are the shape of the building, the form of the bottom of the platform, snow accumulation points, snow drift distribution, wind direction, wind speed and distance between the structure and the snow surface.

Paper II: Can We Test Design for Coming Interplanetary Expeditions in the Arctic? (2006)
Conference paper presented at AIAA Space 2006 in September 2006.
Authors: Bannova, O., College of Architecture, University of Houston & Jorgensen, J., SpaceArch, Copenhagen.

This paper focused on psychological aspects of living and surviving in remote and isolated conditions and how architectural design can influence and improve psychological climate and overall human health and life conditions.

Abstract
New space exploration programs around the world show growing demand on research in human factors, interaction between crew members and their habitat environment, human and robotic relations. The year 2007-2008 is announced as an International Polar Year that presents an excellent opportunity to develop a project for extreme environment and to investigate design challenges and test bed opportunities for space applications. Proposed paper will discuss key space architectural aspects of designing for extreme environments and reciprocity between terrestrial and space architecture in a dialogue between space architecture and space psychology. Experiences from past polar expeditions and habitats can act as background information in the design process focused on: survivability, functionality and quality of life for the crew. The paper will discuss application of these principles to design study for a planned new research station on the center icecap in Greenland. (Summit II)

Due to almost complete isolation in wintertime, the Summit station project had to provide a high quality design to offer most convenient and comfortable environment for the scientists and operation crew members, it had to be self-sufficient and sustainable. Interior design, furniture, lighting, colors, choice of materials, facilities for private time and social gathering were very important for creating a hospitable and well-organized quarters for station population as a micro-society (Bannova, Design considerations for exterior and interior configurations of surface habitat modules 2007). Such requirements are very typical when designing for remote locations and essential for successful planning and development in harsh climate and disaster areas.

Paper III: Terrestrial Analog Selection Considerations for Planetary Surface Facility Planning and Operations. (2010)
Book chapter 28 in: Lunar Settlements. Edited by H. Benaroya.
Author: Bannova, O., College of Architecture, University of Houston.

This article talks about reciprocity of conditions specific to challenging environments. Those conditions demand important design and planning considerations to be addressed at earlier stages of development and throughout the implementation process.

Abstract
This paper will draw parallels and define differences between factors that drive the planning and design of human surface facilities in space and in extreme environments on Earth. Primary emphases will highlight influences upon general habitat requirements, constraints upon delivery and construction, and special provisions for safety and hazard interventions. The overall intent is to identify important lessons that can be applied across different settings which present common priorities, issues and challenges. Such environments include future bases on the Moon and Mars, offshore surface and submersible facilities, polar research and oil/natural gas exploration stations, military desert operations, and natural and man-made emergency shelters.
Important topics of emphasis include the following considerations:

- Design 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.

This presentation will draw upon research and design activities at the Sasakawa International Center for Space Architecture (SICSA). Information is also taken from a SICSA-sponsored conference “International Design for Extreme Environments One” (IDEEA-One) at the University of Houston which attracted more than 400 interdisciplinary participants from 12 countries representing diverse professions and environmental settings.

6. Shaping research strategy

The foundation of forming a research strategy is identification of professional disciplines as tools that should collaborate and interact with each other in order to achieve comprehensive and balanced design solutions that would satisfy human needs and might be applied to diverse extreme environments. It is critical to demonstrate importance of addressing all types of human activities at earlier stages of structures and facilities design rather than adapting existing engineering solutions to various human needs and incorporating them into final design product (Bannova, Harrison, et al. 2009). Since Space Architecture and extreme environment design and planning practice, is a very broad field, determining and counterbalancing attention on all underdeveloped dimensions of latter is essential to the long-term goal of developing better, more effective, and more adequate human environments in challenging conditions. Two core needs are considered to be essential for the field of extreme environment design and education: educating the engineering community about the architect's process and role within the enterprise; educating architects and associated specialists about constraints, conditions, and priorities unique to locations with remote and harsh conditions (Bannova and Bell, Space Architecture Education as Part of Aerospace Engineering Curriculum 2011).

I looked and evaluated several research methods that can be applied to review and analyze my design for extreme environments experience including case studies I described earlier in the section 4.3.

- Science and design methodology (N. Cross);
- Standardized case study approach (Battisto and Franqui 2013);
- Development of Figures Of Merit (FOM) (NASA);
- Analyzing effectiveness using Living Lab project as a tool.

The whole idea of creating a *design methodology* has been heavily criticized and discussed since 1960s (Cross, Designerly ways of knowing 1982) but has been more accepted by architectural community later. Characteristics and differences between science and design approaches were explored by design theorists since earlier days (Alexander 1964). 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."

Nigel Cross notes that even though design methodology originates from scientific methods, they should not be mistaken one with another (Cross, Science and design methodology: a review 1993). While scientific methodology calls for problem solving by analysis, design methodology deals with problems through synthesis. (Cross, Designerly ways of knowing 1982). In 1980s design methodology grew into a more developed academic discipline but still had little influence and practical application. I suspect that it has not happened on a bigger scale because of the individual or subjective nature of design and secondly, because design processes are usually distant from engineering and scientific research parts of the overall planning process.

Effectiveness of *standardization of case studies' approaches* has been also questioned recently and some argumentation can be found in recent publications at architectural research conferences (Battisto and Franqui 2013). Battisto and Franqui advocate that planned case study design research methodology "could be used to inform the development of design guidelines, rules of thumb and "best practices."

Figures Of Merit (FOM) approach is described earlier in Chapter 4.3 in relation to paper III.

Even though it may not seem to be very practical to compare proposed case studies elements using Figures Of Merit technique, as many of these projects' attributes are rather qualitative than quantitative by the nature of architectural discipline itself, it appears to be important to understand the Figures Of Merit approach when different design solutions are compared and evaluated. Application of this method to results of case studies research precedes testing and evaluation stage of proposed extreme environment methodology matrix.

6.1 Trans-disciplinary approach to design strategy

Minimalistic and sustainable approach to design and planning in extreme conditions can be considered a core of strategic efforts for planning developments in remote locations with limited or absent infrastructure, transportation, and resources. A lot can be learned from strategic planning for space exploration missions which addresses not only requirements to meet barest living and work essentials, but to consider evolutionary pathways forward as well. This entails a deliberate long view perspective of progressive growth sequences ranging from early expeditionary missions – to operational outposts – to more self-sufficient settlements that process and maximize use of in-situ resources (Bannova and Bell, Designing From Minimum to Optimum Functionality 2011). A set of Figures of Merit for design considerations and comparison tables and matrixes can be used as an effective methodology for analysis of all design elements for every stage of a settlement or other planned and built developments. That can be developed further and proposed as a planning matrix with multidisciplinary plug-ins where all elements can be addressed and tackled simultaneously (Bannova, Terrestrial Analog Selection Considerations for Planetary Surface Facility Planning and Operations 2010).

Determination and evaluation of recurrent and specific to project design aspects is a necessary step of the research process in order to develop a design and planning methodological approach. Structural and infrastructural design solutions depend on location in every design case and are always challenged by extreme conditions. I look at structural and infrastructural design elements and derived architectural requirements specific to the environment they applied.

Another important and significant part of research addressed other than physical conditions in extreme environments and concentrated on humanistic perspectives and other, non-physically measurable qualities and sides of human life.

6.2 Second case study analysis

Second case study is based on a project conducted at SICSA and supported by the ICF (International Crane Foundation) to design Muraviovka Park for Sustainable Land Use development plan in Russian Far East (Amur region) (Figure 11).

Figure 11. Map of Russia. *Source: O. Bannova modified from www.wikitravel.org*.

Muraviovka park is dedicated to research, protection, restoration and management of endangered wildlife species and communities. The park was established in 1996 by the International Socio-ecological Union (ISEU, Moscow) on 5,206 hectares of wetlands and

arable lands leased in 1994 from Tambovka district authorities in Amur region of southeastern Russia. The park is the first privately operated nature territory in Russia and is supported by ICF, international and local donations and by its sustainable operation management.
Six species of cranes, the Oriental White Stork and over 20 other rare and endangered species of birds inhabit the park. The park and adjacent territories in the Amur River valley present very unique environmental conditions and were included in the Ramsar List of Wetlands of International Importance (The Ramsar Convention on Wetlands 2008).
The park's management is implementing sustainability into park practices aiming to provide independent operational support. The major goal is to benefit wildlife and ecological conservation and at the same time increase living standards and educational level of the local community. Figure 12 summarizes activities that can be or already are carried out in the park and relationships and opportunities that they present.

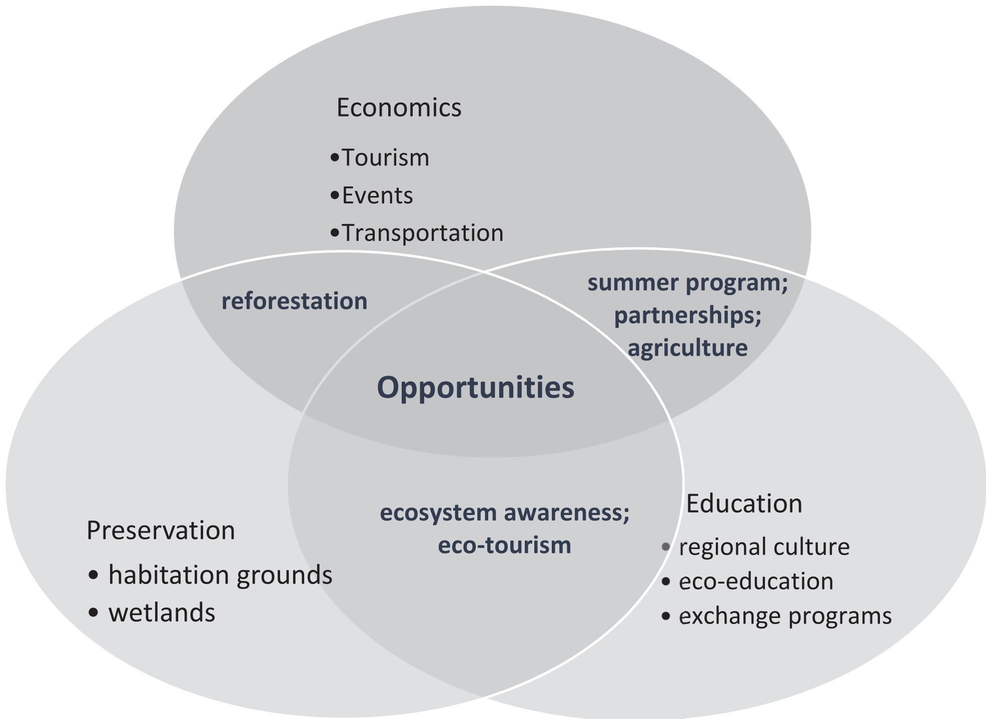


Figure 12. Relationships between Muraviovka park activities. *Source: O. Bannova.*

The purpose of the project was to produce a new development plan expanding park's existing capabilities, facilitating its activities and optimizing usage of current facilities and operations. The design approach was based on the idea of creating an environment to facilitate sustainability in all spheres of life: social, cultural, economic and technological.
At the Muraviovka Park, I focused on creating a development plan for the park that offers a unique sense of place. The goal was to encourage sustainable planning and living through a highly natural example. One of biggest challenges was that the park has a substantial local support on personal level and not much of support on local governmental level. Major design solutions accommodated the following:

- Extreme temperature swings:
    - Building envelope design;
    - Building's on-site orientation;

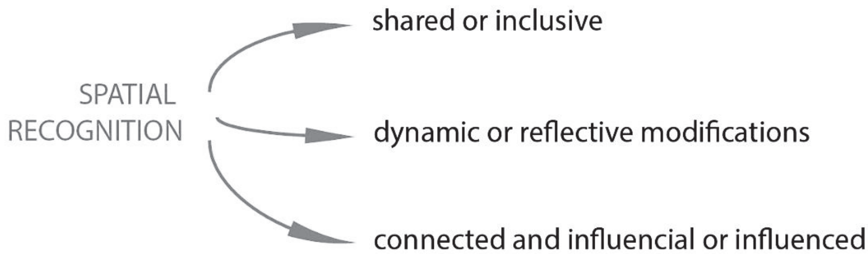
- Economics:
    - Trade with China;
    - Locals can benefit from the visitors coming to the park;
- Education:
    - Locals from Balgoveshchensk, Heihe, and nearby villages can come for seminars and summer camp;
- Preservation:
    - Local citizens can help build the park and help with the upkeep.

Sustainable design solutions included accommodating Trombe wall structure, solar panels and battery storage, electric and solar water heating, baseboard heating system (Appendix 4).

Work on this project demonstrated that park development and support initiatives benefit from systematic design approach plan. Data collecting stage and design requirements although with specific local attributes shared many aspects with Summit station project and could be dealt following similar procedures. Transportation, power, sustainability, economic questions have to be brought into design process at corresponding stages.

7. Forming architectural attitude

Seeing a "big picture" and treat problems holistically is important to follow an architectural attitude when treating problems in not strictly architectural areas or disciplines.
Architecture as a collective agency encouraging 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 and "big picture" architecture can be an answer to many problems that architectural practice is facing now and difficulties when planning large-scale developments (Figure 13).



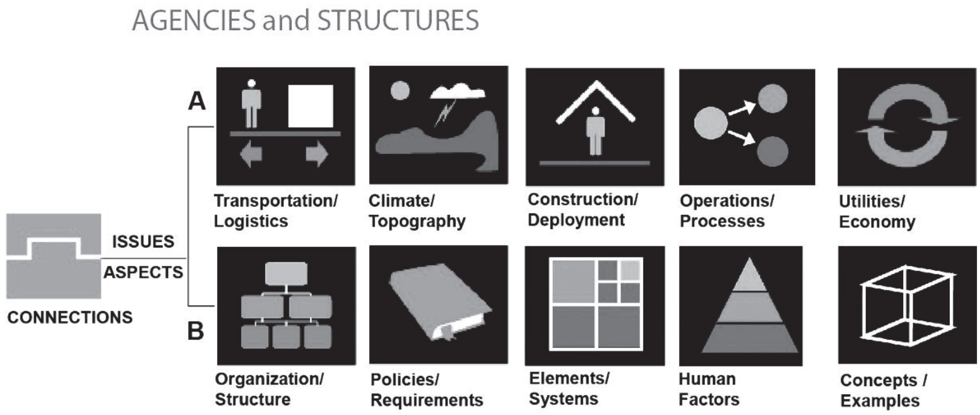


Figure 13. Transferring architectural "limitations" into actions through critical architecture and understanding of practice itself. *Source: O. Bannova.*

Figure 13 illustrates the idea that difficulties of dealing with limitations during planning developments in challenging environments can be transferred into actions as critical elements of methodological approach. Those actions can make a difference not only in construction industry but in society by creating a ripple effect of enabling social and cultural sustainability through personal responsible behavior.

7.1 Analysis of discussions and energy industry professionals' surveys

Discussions with Andreas Ruby and Michael Rock during a Communications course (Toorn 2013) organized by ResArc at the School of Architecture in Umea (Sweden), triggered deeper analysis of a role of an architect during planning efforts in Polar Regions and probably other extreme conditions. Perhaps the biggest architectural asset is the ability to create an "integral" view to a problem. Designing a building may seem as a 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 undivided and connected approach that an architect should be able and can bring to the table.
For better understanding of the current situation with energy companies' exploration plans in polar climates I reached to the ConocoPhillips development management and asked company's professionals to answer a short survey about their work in extreme environments. I interviewed three ConocoPhillips managers after they answered the survey to expand and summarize the knowledge. The locations of discussed projects include: off-shore platforms, Alaska North Slope developments, Gulf of Mexico (deep-water), Russian Arctic region, and Northern Alberta County in Canada (Table 4). 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, communication issues between involved parties including contractors, local authorities and workforce and the project management, and logistics problems at different degrees.

Locations **Characteristics**	**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 4. Projects referred in surveys.

Although all mentioned projects were referred 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 other elements of planning and execution processes are either dismissed or not given proper attention and may sometimes jeopardize the project flow.
The survey results and follow-up discussions are summarized in the appendix 1. The survey contributors 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. Most important drivers of success in all projects are safety, cost, schedule and quality while 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.

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 systematic architectural approach. "The (architectural) philosophy is centered on what architecture and design *do* over time, rather than what they *are*." (M. Nystrom 2002)

8. Summary of papers on human factors for sustainable design

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

I tried to identify and explore here a few "edges" that frame and contribute to conditions becoming extreme. All of the edges refer not only to spatial conditions or elements but personal and public mentality. There are many more edges, faces, vertices that interfere and affect each other at different levels. This is just a brief overview, the beginning; I will continue exploring most significant ones in my further research.

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, individual or group commitment obtaining, feedback on individual or group performance. But some psychological theories emphasize that informative techniques are not very effective if used alone (Staats, Wit and Midden 1996). Therefore a combination of strategies tends to be more effective in promoting sustainable behavior.

Discussions with students during preliminary workshop sessions 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 resources utilization practices. Implementing advanced technology in design affords a means for informing and coordinating residents' responsible efforts helping people to make conservative choices to become a part of their everyday routine. Figure 14 depicts basic level of essential relationships between an individual and a group, some of them may be present periodically while others belong to common attributes of human behavior.

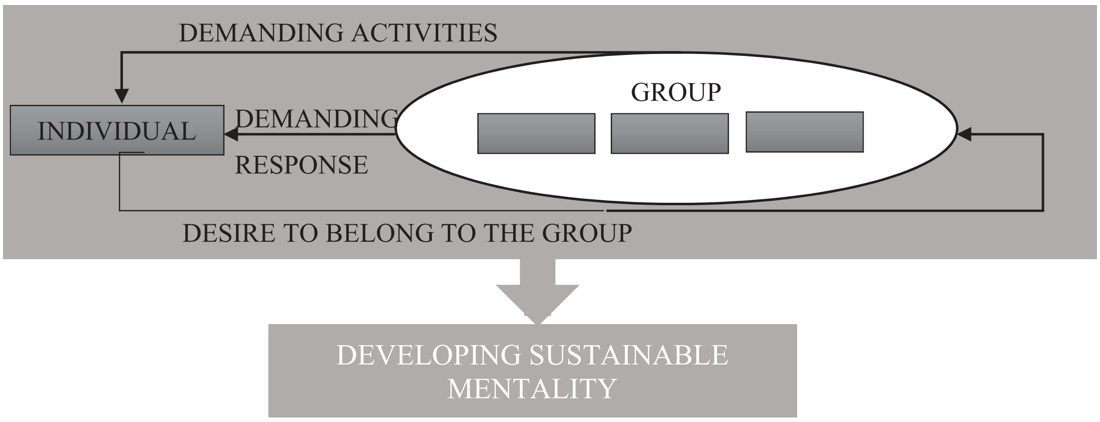


Figure 14. Individual and group relationships shaping sustainable behavior. *Source: O. Bannova.*

It is important to consider a possible influence of human error or undesirable behavior, therefore relaying information about successful sustainable practices back to residents is also fundamental.

8.1 Paper IV (2013) Functional study – mapping human factors

Bannova, O. & Hagbert, P., 2013. *Experiments in mapping human factors for sustainable design and living.* Paper presented at the IAPS International Network Symposium; 25-28 June 2013, A Coruña, Spain. Paper accepted for publication. Peer reviewed.

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 multi-level balanced design. That includes studying and connecting functional design approach with sustainable living through implementing 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 cannot in this sense be seen as an addition, but should rather be considered an integrated part of educational and professional practice. In situations when the resources are limited, confined or restricted living space, and overall challenging and hostile environment, 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 (University of Houston) in parallel to similar activity at the Architectural department in Chalmers University. That resulted in mapping human activities in connection to functional analysis of levels of private or shared use of space and resources presented in the table 5 below:

	Sleep	**Eat**	**Chores / cooking**	**Study**	**Hygiene**	**Leisure**
Collective (sharing activity and resources)	Minimum	Maximum	Maximum	Maximum	Less	Maximum
Individual/ sharing resources	Medium	Medium	Medium	Maximum	Less	Medium
Private/ not sharing at all	Maximum	Less	Medium	Less	Maximum	Less

Maximum Medium Less Minimum

Table 5. Desired levels of privacy in relation to living activities.

Next step of the 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 explores how sustainable innovations are applied and perceived in everyday life and living environments.
The research presented in the paper mainly concerns 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. It is suggested that the process can be advanced farther by incorporating an explorative design studio environment where a transdisciplinary group of students will be involved.

8.2 Paper V (2014) Design practices study – testing and evaluating

Bannova, O., Nystrom M., Femenias P., Hagbert P., Toups L., 2014. *Testing and Evaluating Sustainable Design Practices.* ARCC/EAAE 2014 International Conference, February 12-15, 2014. Peer reviewed.

Design solutions in general can be 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. An on-going project of building a student housing on the campus of Chalmers University, Johanneberg, is a challenging but possible solution to test some of technological and design approaches. Moreover a proposed design studio can be used as an evaluating tool of the multidisciplinary design for sustainable development efforts.
Educational engagement of the project will include Building Functions Analysis studies in a full-scale laboratory in a form of on-campus student housing. The emphasis will be given to the role of designers and design education in facilitating academic methodologies, offering benefits of hands-on learning and real-time experimenting to students. The discussed research and educational approach mainly concerns full-scale research house studies (sustainable living environment) with integrated instant design reviewing process. Uninterrupted feed-back by users is essential for optimizing design considerations and for advancing research in the test environment (Figure 15).

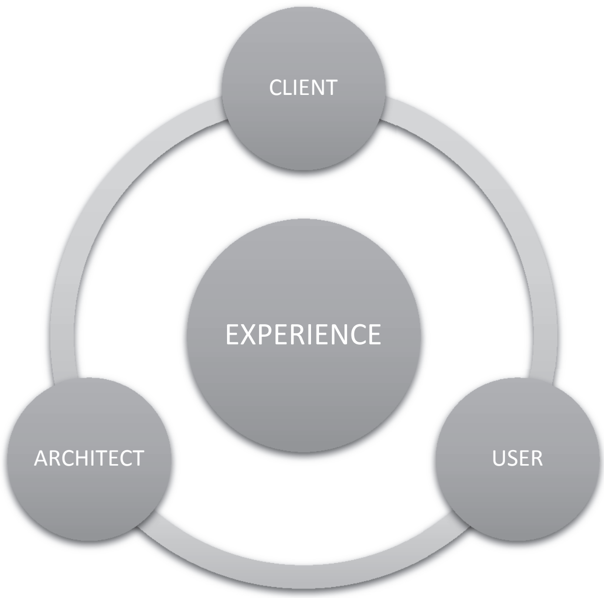


Figure 15: Collaborative efforts provide inclusive experience. *Source: O. Bannova.*

The paper also briefly discusses 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. It is recognized that the introduction of collaborative processes that promotes critical reflection is vital to applying sustainable practices to everyday life. There is however, a lack of effective communication between "users" (or clients) and "professionals" (architects). Shaping those links by providing research in design and learning through building opportunities, along with creating new advanced outreach prospects for architects, are key steps towards new sustainable architectural practices. Also, applications analysis should be performed not only as a final result but in the context of the whole process and with an emphasis on human factors, systems and elements' relationships and inter-dependability. Based on the knowledge gained, a design and planning process is proposed to optimize sustainability approaches implementation into practice through incorporating testing and evaluating stages into design process.

9. Papers IV and V abstracts and synopses

Paper IV: Experiments in mapping human factors for sustainable design and living (2013)

Paper presented at IAPS International Network Symposium in June 2013, peer-reviewed paper for post-conference publication.
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 V: Testing and Evaluating Sustainable Design Practices (2014)

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. A new design approach is investigated where students will be designers, clients and users in simultaneous and homogeneous design process. The on-going Living Lab project is considered as an initiation point of the research and design and as 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[1]. 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.

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

10. Conclusions and directions for research development

Analysis of two discussed case studies demonstrated shared and recurrent design aspects that can be addressed in design process in a similar way, which perhaps can help to optimize planning processes for extreme environments conditions starting from first stages of their development and become a part of a common methodology for planning, design and other developments in Polar Regions. The table below summarizes structural and infrastructural recurrent and specific to case design aspects (Table 6).

		Recurrent	Unique
CASE I, Polar Desert	Structure	Avoid heavy construction needs; Interior zoning; Use of renewable energy; Use of recycling systems; Apply tight building envelop; Optimize elements packaging for efficient transportation.	Strict limitations applied to mass and dimensions of structural elements; Structurally balance weight distribution; Incorporate automatic and robotic systems.
	Infrastructure	Plan for tight transportation windows; Develop site zoning; Minimize environmental impact.	Year-around assembly operations are possible; Very limited transportation means are available.
CASE II, Boreal	Structure	Avoid heavy construction needs; Propose interior zoning; Use of renewable energy; Use of recycling systems; Apply tight building envelop.	Constrained construction and assembly time; Many transportation means are available but limited for economic reasons.
	Infrastructure	Plan for transportation limited by weather conditions; Develop site zoning; Minimize environmental impact.	Many transportation means are available but limited for economic reasons. Create economic and social sustainability

Table 6. Recurrent and unique design aspects.

Other recurrent design influencing aspects are associated with human factors and were discussed earlier in sub-sections of the *Initiation of research – Understanding of basics* (Chapter Three). They can be combined under non-structural or human-related category where psychological, societal, cultural and mental challenges demonstrate comparable levels of stress and other risk factors. Some of them are summarized in the table 7.

Optimization of design requirements based on the summary of design aspects presented in Tables 6 and 7 is the next step of the research development. The set of requirements is a key element of the proposed programming and planning matrix.

In a summary, an interdisciplinary, comprehensive approach includes highlighting influences upon general habitat requirements, constraints upon delivery and construction, and special provisions for safety and hazard interventions. 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, Terrestrial Analog Selection Considerations for Planetary Surface Facility Planning and Operations 2010).

		Recurrent	Unique
CASE I, Polar Desert	Individual	Psychological: motivation for excellence in performance; acceptance of some hardships and challenges. Physical: regular exercising, demand for personal spaces.	Total isolation during winter-over operations
	Group	Social and cultural tolerance; educational outreach programs for local communities and visitors; staff seasonal rotations.	Lack of social or other group activities other than scientific researchers visiting.
CASE II, Boreal	Individual	Psychological: motivation for excellence in performance; acceptance of some hardships and challenges. Physical: regular exercising, demand for personal spaces.	Constrained construction and assembly time; Many transportation means are available but limited due to economic reasons.
	Group	Social and cultural tolerance; educational outreach programs for local communities and visitors; staff seasonal rotations.	Involvement of local communities in some activities and being involved in local events.

Table 7. Other recurrent and specific aspects influencing design.

The Licentiate thesis is an initial part of further investigations to be conducted towards doctoral thesis. Further research will include more discussions with industrial engineering specialists at the University of Houston and professionals from NASA JSC (Johnson Space Center) involved in a collaborative effort in occupational error and fatigue factors research. My role in this study will include analyzing human error contributing factors, identifying potential design interference and possibilities of incorporating preventive measures into design and planning processes. This work is at the beginning stage of forming a research cluster and responds to demand from oil and gas companies to research human factors influences and human error preventive measures not only in Arctic regions but within the industry in general. The goal of those efforts is providing a better methodology to address them in design and planning activities.

The research findings of PhD work and the logic behind them will be organized into a programmatic tool using Microsoft Visio software for visualization and VBA coding. Operational data for that will be listed in a form of tables with attributes and features linked to required information resources.

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Appendix

1. Research questionnaire summary
2. Follow-up comments and discussions