Architectural Approach to Planning in the Extreme Arctic Environment

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ABSTRACT

Extreme environments in Polar Regions share similar facilities and operations, design and planning challenges: extreme cold temperatures, structural problems, high standards for materials, 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'[1] project is suggested for effectiveness and verification purposes.

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.

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

INTRODUCTION

Today life conditions in the Arctic changing rapidly due to climatological changes, recent trends in industries, demographics, and the built environment. In arctic extreme environment, it becomes essential to respond to those changes with design and planning just as fast as they occur. It is also critical to proceed with construction almost immediately after a decision to begin any type of development is made and the personnel and crew has to be moved to a remote location within limited timeframe. (Lempinen, 2013)

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

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

- Strong restrictions to execute everyday work task
- Impossibility to perform social interactions or maintain necessary privacy level
- Impossibility to fulfill necessary living needs.

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

The paper outlines prerequisites and reasoning for developing a systematic methodology for planning and design efforts in extreme environments of the Arctic and potentially other polar regions. Although existing methods applied to planning and design in remote and extreme locations address some environment-specific challenges, they lack a holistic approach. Such methods do not cover or include a systematic tactic to the design process from preliminary design phase to construction stage and conducted on case-by-case basis (Nielsen, 1999). As a result, some of previous experiences are used in new conditions but without comprehensive arrangements and systematic methodology the result of such application can be misleading, causing abuse and waste of resources and vital time delays. (UNESCO, 2009)

Federal laws, standards and regulations generated by companies, local authorities, developers and other entrepreneurships are disconnected at many levels and often have different objectives. That leads 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 more vulnerable and sensitive to changing conditions in any of their subsystems, such as cultural, political, ecological, technological, societal (Rasmussen, 1999). Malfunction in one of those subsystems may easily make the whole system dysfunctional and handicapped (Nuttall, 2005).

Any planning project in the Arctic is a system where all subsystems play their roles within environmental boundaries of the extreme conditions. Design is one of the subsystems and is a complex process that requires well researched interdisciplinary preparation work including not-traditionally design-related disciplines (e.g. climatology, meteorology, agriculture, petroleum engineering). Miscommunications between diverse professions involved in developments in arctic regions leads to mistakes resulting in vast environmental, time and money losses (Rasmussen, 1999).

Efforts in fixing not properly addressed problems later in the process are costly, time consuming and sometimes too late to be corrected (Reason, 2000). Creating a logical path for planning and maintaining activities in extreme conditions is a vital necessity in pursuit of sustainability in the Arctic. (Kozlov, et al., 2015) Identifying aspects or elements for the proposed methodology as well as understanding why they are connected is important for building a dialogue model for local communities, engineers, individuals, that will serve as a design and development planning tool.

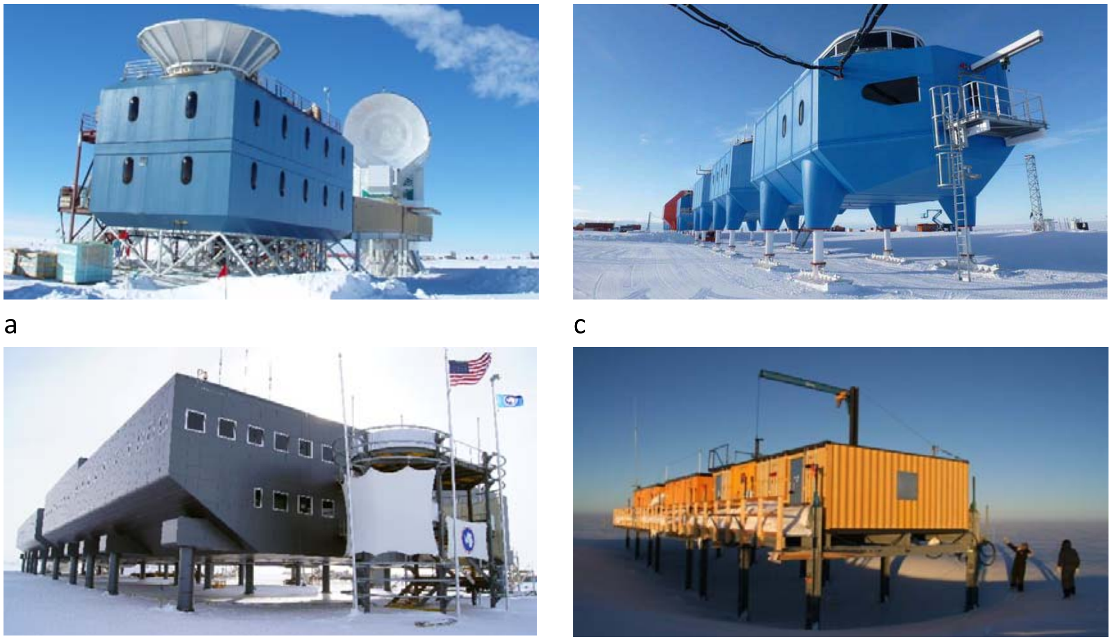
Precedents and literature review. There is scarce literature concerning development of a system of systems methodological approach for planning large-scale activities in arctic and subarctic regions. (US National Research Council 2014, Expert Group on Ecosystem-Based Management 2013) Therefore, the approach in the literature review is a combining approach that includes construction experience in Antarctica and design precedents and projects for the 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 the presented here 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. (Muller 2010) (Figure 1)

Nevertheless, 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[2] and Arctic Perspective Initiative[3] 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

[2] http://www.artscatalyst.org/
[3] http://arcticperspective.org/

commercial and even military activities and population expansion are evident during the last decades there. (Figure 2)



a c b d

Figure 1. Antarctic Elevated Stations: a – the BICEP[4] 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).

a b

Figure 2 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[5]); b – The US military abandoned radar station DYE-2 in Greenland (photographed by the author in June 2005).

METHODOLOGY

The paper briefly describes several research methods that used as foundation for development of the proposed methodology. These methods include:

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[4] Background Image of Cosmic Extragalactic Polarization

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

- Verbal data collection (mono- and transdisciplinary)
- Case studies analysis
- Selection of Figures Of Merit (based on NASA's approach to data analysis and systematization) and application to case studies projects
- Analysis of effectiveness and verification of proposed method by means of Living Lab project at Chalmers University of Technology (using it as an evaluating tool).

Mono-disciplinary and transdisciplinary approaches represent two platforms of knowledge production and often referred as Mode 1 and Mode 2 of the 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). Both modes are necessary for development of a balanced research process and knowledge accumulation. (International Council for Science, 2005)

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) 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).

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. All of them deal with scientific evidence and can have quantitative or qualitative dimensions. Applied analytical strategies include:

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

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

The multi-dimensional character of the process affects overall design methodology in a way where all components are influenced and influencing one another. Figure 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 elements. The integration model or tool's role is to facilitate these relationships and promptly respond to their demands.

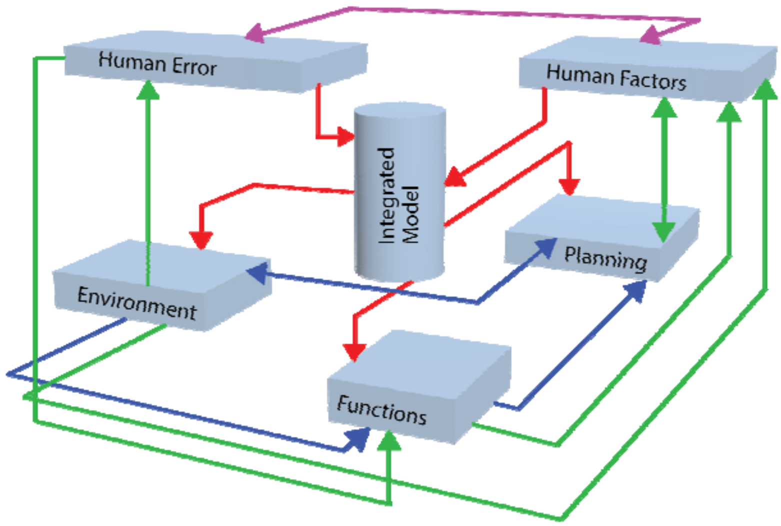

Figure 3. Multi-dimensional model applied to project development process. (Author)

An ultimate goal of any design process depends on successful identification of a design research problem, which lays in finding a proper "translation from individual, organizational and social needs to physical artifacts" (Hillier & Leaman, 1976). Architectural approach also includes understanding of consequences of inadequate behavior or actions that caused by inappropriate attitude to the project development and may lead to non-desirable or even catastrophic events.

Data collection. For better understanding of the current situation with energy companies' exploration plans in the Arctic, professional engineers and managers from several energy companies[6] answered a structured questionnaire about projects in extreme environments. Three ConocoPhillips managers were interviewed referencing multiple projects at four different locations. The interviews aimed to expand and summarize the knowledge after the respondents answered the survey. The locations of discussed projects include off-shore platforms, several Alaska North Slope developments, Russian Arctic region, and Northern Alberta County in Canada (Table 1). The schedule was the main driver for all projects as well as cost and safety for operational projects. All of them were challenged with remoteness, communication issues between contractors, local authorities, workforce and the project management, and logistics problems at different degrees.

Table 1. Projects referred in survey responses.

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

[6] ConocoPhillips, ExxonMobile, Shell, Fluor Corporation

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 a proper attention and that may sometimes jeopardize the project flow.

Interviewed professionals and practitioners from other energy companies [7] and researchers 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.

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

Table 3. Characteristics of investigated case studies.

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

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

[7] ExxonMobil, Shell (Moscow office), Fluor Corp.

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

Figures Of Merit (FOM). Figures of Merits can be justified as Characteristics of Values where the designer of the method identifies the values. Using the FOM method helps to identify important lessons that can be applied across different settings, which present common priorities, issues and challenges. Such environments include future bases on the Moon and Mars, offshore surface and submersible facilities, polar research and energy exploration stations, military desert operations, and emergency shelters in disaster zones.

Even though it may seem not be very practical to compare proposed case studies elements using FOM technique as many of these projects' attributes are rather qualitative than quantitative by the nature, it appears to be important to understand the FOM approach when different design solutions are compared and evaluated.

Analyzing effectiveness and verification. To test and evaluate responsible planning and design practices was proposed to use The 'HSB Sustainable Living Lab', which is a collaborative effort between the largest Swedish co-operative housing association, HSB, and Johanneberg Science Park, and is currently under construction as a student housing, located on Chalmers main campus[8]. Its location offers a unique opportunity to merge research, education and outreach.

The goal of the HabLab initiative is to explore new building and construction ideas and concepts, new materials implementation, to test design and planning approaches, develop new technologies and adapt products and systems innovations to local context culturally, economically and socially (Nystrom, et al. 2000). An architectural input is focused on a definition of sustainable living environment and design practice exploring students' interactions in design/build process, construction and use of housing units while efficiently optimizing consumption of energy and other resources.

RESEARCH APPROACH

A concept of a new interdisciplinary and comprehensive approach highlights extreme environment boundaries to be applied to general habitat requirements, and constraints upon delivery, construction, and special provisions for safety and hazard intervention. Consolidation of such design requirements based on the summary of vital design aspects is a key logic for a new programming and planning methodology.

Identification of common priorities, issues and challenges leads to 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 in table 4.

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

Table 4. Planning considerations.

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

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

Table 5. General and specific planning and design requirements.

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

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

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

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

Table 6. Human factors influencing design and planning requirements.

		General	Specific
Polar desert (arctic)	Individual	Psychological: motivation for excellence in performance; acceptance of hardships and challenges. Physical: regular exercising, demand for personal spaces.	Total isolation during winter-over operations
	Group	Social and cultural tolerance; educational outreach programs; staff seasonal rotations.	Lack of social or other group activities other than scientific researchers visiting.
Boreal (sub-arctic)	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 available but limited due to economic reasons.
	Group	Social and cultural tolerance; educational outreach programs for locals; staff seasonal rotations.	Involvement of local communities in some activities and being involved in local events.

The research presented in this paper is built upon 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. It is recognized that this research has limitations, which come from Case Studies projects' conditions: both are earlier performed student projects and both were retrospectively reviewed. Other limitations come from inadequate number of existing records about 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 current ConocoPhillips project in North Slope Alaska – GMT1[9]. (Figure 4)

[9] http://alaska.conocophillips.com/who-we-are/Pages/projects.aspx

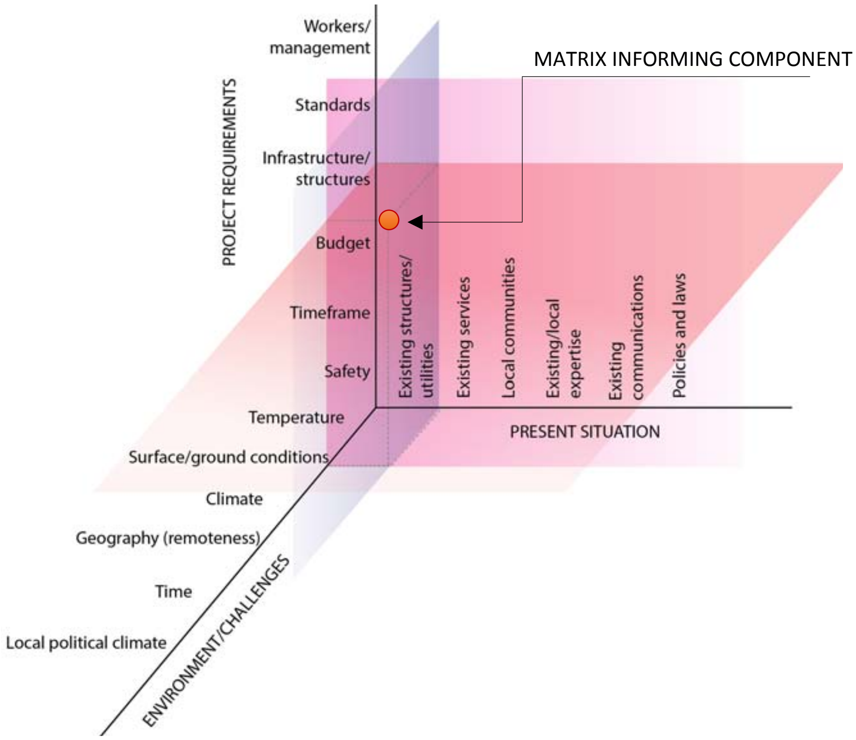

Figure 4. Subsystems and elements to consider during a planning process.

The purpose of the Matrix application to the GMT1 is to demonstrate how a transdisciplinary logic of the Matrix can identify most critical points of the project development. Figure 4 depicts systems that need attention in any planning process in Arctic conditions: project requirements, environmental challenges, present situation of conditions and physical structures. The figure illustrates how elements of the Matrix are created. The 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 on temperature conditions and availability of existing structures and utilities at the location. Intersection of these systems creates Matrix informing components. Most critical components of the Matrix are closest to the axes intersection point.

CONCLUSIONS

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

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

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

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

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