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Habitability in extreme environments: A participatory design approach to assess wellbeing.

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Abstract: This paper investigates habitability in extreme environment habitats by examining how occupants contribute to the evolution of functional infrastructures into human-centered environments that support wellbeing. Through fieldwork at the Bulgarian Antarctic Base (BAB), the study combines architectural on-site observations with interviews, questionnaires, and participatory workshops. Three trends emerged from the combined material, highlighting the importance of regulating social interaction through semi-private spaces, the value of flexible spatial organization across work and leisure, and the role of personalization in supporting emotional stability, helping occupants claim the base as a lived habitat over time. By using occupants' evaluations and spatial adaptations as evidence, the study informs design in a context rarely experienced firsthand by designers and proposes a participatory framework for assessing habitability in constrained environments already shaped by standardized planning and logistics. It offers an informed approach for translating lived spatial experience into qualitative interior characteristics.

Keywords: participatory design; extreme environments; habitability; spatial familiarity

1. Introduction

Antarctica stands out as one of the harshest and most potentially lethal natural environments on Earth (Harris, 2011). With no indigenous population, the continent's only habitats are research stations, facilities whose size, design, and provisioning are constrained by engineering and economic limitations (Harrison et al., 2013). Though few will inhabit this remote environment, those who do are likely to face prolonged isolation, confinement, uncertainty, and environmental stressors. It is well-documented that such conditions can trigger sleep disturbances, anxiety, increased territoriality, reduced motivation, and other psychological and physiological challenges (Schlacht, 2012, Harris, 2011, Sandal et al., 2006).

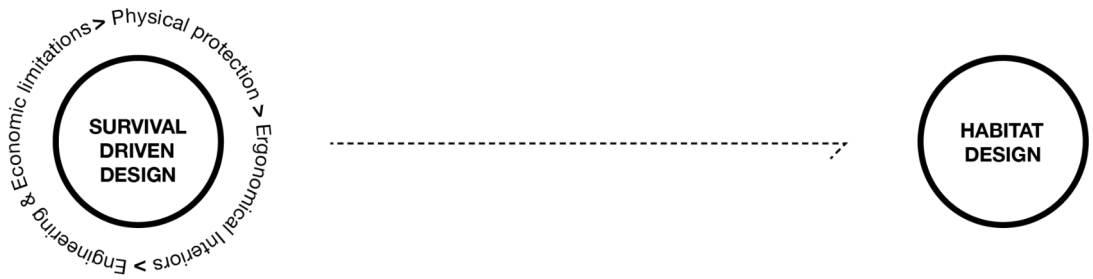


Figure 1 Existing frameworks in extreme environment design, centered on life-support requirements.

In everyday life, an unsupportive environment can often be escaped or offset by other sources of stimulation or emotional connection. In contrast, within confined and inescapable habitats, such as Antarctic stations, the interior space becomes a constant presence, amplifying its influence on psychological states and group dynamics. These unique settings not only offer valuable insights into human behavior in isolation but also reveal how spatial qualities can deeply affect the communities inhabiting them.

Existing frameworks in the design for extreme environments are centered primarily on life-support requirements (Figure 1). However, since the success of a mission also depends on sustained motivation, mental wellbeing and social cohesion under pressure (Harrison et al., 2013), current habitat design has begun to expand toward supporting occupant wellbeing more broadly.

Inclusive habitat design increasingly considers occupants' wellbeing through strategies like flexible layouts and sensory-adjustable interiors. Design is also treated as an active countermeasure to withdrawal and isolation, encouraging social interaction and supporting the desire to spend time in common areas of the habitat (Jorgensen & Bannova, 2006). This is especially relevant in environments where outdoor access is limited or impossible. In such settings, interior spaces must support both functional demands and a standard level of livability , through a "maximum of habitable quality, seen as quality of life in dialogue with quality of design. " (Bannova, 2014, p.56) This dialogue underlies the principle that wellbeing emerges from the fulfillment of fundamental human needs, which guide motivation and shape the way people inhabit space. (Desmet & Fokkinga, 2020).

This research supports these evolving priorities and proposes a method to further inform design choices by introducing a participatory design methodology that directly involves occupant insight in assessing and improving habitat conditions. While survival remains an unquestioned priority, this research expands the design process to include the human experience through participation and spatial awareness (Figure 2). The goal is to define the spatial and experiential parameters that affect habitability, and to argue for future designs grounded in lived, not just engineered, experience.

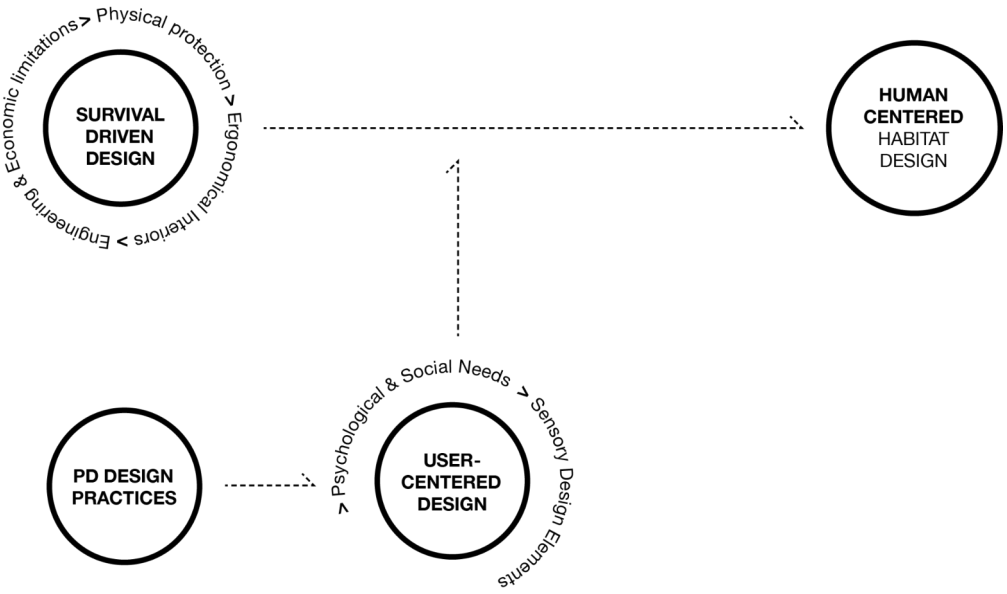


Figure 2 Proposed framework integrating human-centered methods into habitat design.

2. Conceptual foundation

2.1 Habitability in extreme environments

Habitability is a dynamic quality shaped by how space is adapted over time, applicable to all contexts where people must adjust to environmental or situational stressors. It describes the capacity of environments to sustain, comfort, functionality, and a sense of belonging under varying physical or psychological pressure (Sterly et al., 2025). In the context of remote and extreme settings and for the purposes of this research, the term follows Häuplik-Meusburger's approach (2011), describing the suitability of a built habitat for its occupants within a specific environment and over a defined period of time.

One of the key factors influencing habitability is the duration of stay. Research has shown that short term occupancy can tolerate a wide range of spatial limitations, provided that basic safety and performance are maintained. Over longer periods, however, the built environment must also support psychological wellbeing and social interaction, where shared rhythms and interpersonal dynamics become critical to daily life (Messerschmid & Bertrand, 2010). This view shifts the focus toward the human experience of space. As Häuplik-Meusburger (2011) argues, architecture in extreme settings is not only about comfort, it's a functional necessity, making the quality of the built environment a critical factor for performance and success.

Building on this, the following dimensions are drawn from existing literature on space habitat design by Schlacht (Schlacht, 2012), where habitability has long been a critical concern. For the purpose of this research, they were adjusted through early field engagement to reflect the lived realities of an operational Antarctic station. In this context, habitability is defined in terms of:

- Usability: The design of a complex habitat system that is user-friendly and intuitive to best facilitate human-machine tasks.

- Livability: The capacity of a habitat to support psychological and emotional wellbeing, enabling comfort, routine, and social connection even within isolated, or resource-limited environments.
- Flexibility: The ability of the space to accommodate changing user needs through adjustable layouts, overlapping functions, or personalized modifications supporting adaptation over time.
- Innovation: The application of new technologies or systems aimed at improving daily life, enhancing autonomy, and supporting comfort without adding unnecessary complexity.

In this study, habitability is assessed through a layered set of "spatial" and "experiential" parameters. As defined above, usability, livability, flexibility, and innovation were selected because together they bring together functional, social, and adaptive aspects of habitat design into one framework, particularly relevant in extreme settings, while also providing a workable structure for linking design literature to lived evidence.

2.2 Participatory design and wellbeing

Participatory design presents a fundamental shift in the traditional designer-user relationship by involving participants in the framing of design problems, as well as in the production of knowledge relevant to the resolution, roles previously led predominantly by designers (Tsekleves, 2019). In extreme environments, where design experts seldom experience the habitat directly, occupants must be recognized as experts in its lived reality, holding essential knowledge for informing design through their daily evaluation and adaptation of space. In this study, participatory design helps structure occupants' "lived experiences" by introducing a set of experiential parameters through which participants' perceptions of space can be understood (Simonsen & Robertson, 2013). This approach draws on the work of Elizabeth Sanders and her development of "generative tools", which enable participants to express themselves beyond fixed-choice formats or predefined categories (Sanders, 2000; Sanders & William, 2002).

Habitat occupants in this study are treated as co-observers, actively contributing to the evolving understanding of their environment. Through interpretive and expressive tools, they are invited to reflect on past, present, and anticipated spatial conditions, surfacing lived experiences in ways that conventional technical methods often overlook. These tools support the articulation of routines, discomforts, attachments and adaptive practices that might otherwise remain unspoken (Visser et al., 2005; Sanders & Stappers, 2008).

Beyond their instrumental role, such participatory encounters can hold intrinsic value as social and emotional experiences (Vaajakallio et al., 2013). As Tsekleves argues (2019), the act of "sharing information" itself can be understood as an opportunity for shared reflection and empathy. This perspective informs the participatory framework in the present research and suggests a further line of inquiry into how such processes may prove especially fitting within the isolated settings of an Antarctic station.

Ultimately, participatory design is employed here as a key tool within a broader habitability assessment framework, combining spatial analysis with occupant input to examine how

design-defined qualities of the habitat are experienced in practice. In this way, the framework brings together established dimensions of habitability with the spatial conditions occupants associate with wellbeing. The goal is to develop a flexible framework that makes situated knowledge visible and to inform the ways in which constrained environments are understood and ultimately designed for habitability.

3. Research context: Description of the expedition

Fieldwork was conducted in person at the Bulgarian Antarctic Base (BAB), St. Kliment Ohridski, by Gourounti and simultaneously monitored remotely by Liapi and Oungrinis, during 29 December 2024 to 15 January 2025, aligned with the base's core operational window. During the author's stay, the base hosted thirty-five people including permanent personnel, researchers and the construction team working on a new laboratory building.

St. Kliment Ohridski Base is a Bulgarian Antarctic research station on Livingston Island, in the South Shetland Islands, off the coast of the Antarctic Peninsula. Situated on slightly elevated, ice-free terrain near South Bay, it operates as a seasonal summer base with a network of buildings connected by informal pathways. Established with its first refuge in 1987, the base has expanded to eleven separate structures, constructed over different periods, collectively able to accommodate 25 to 35 occupants with some flexibility.

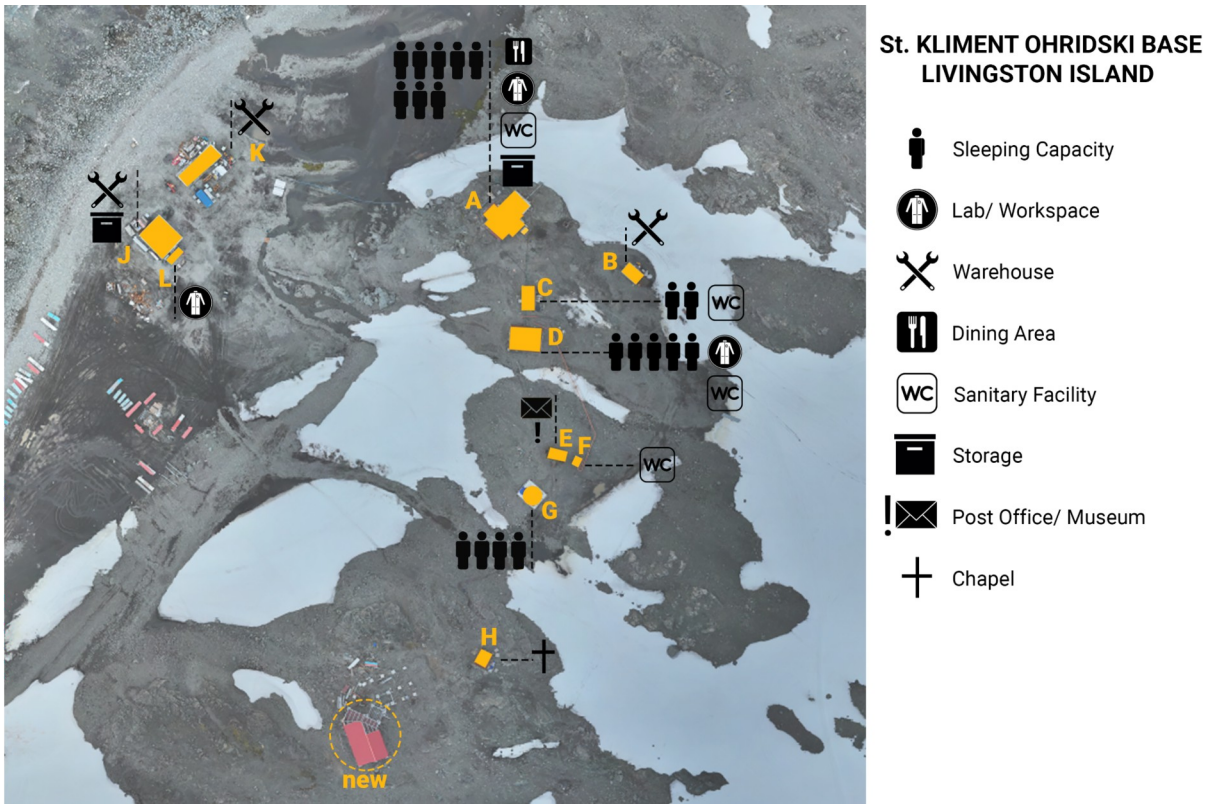


Figure 3 Area view of the BAB and spatial organization of key facility functions.

As shown in Figure 3, core daily activities are distributed across separate buildings, often with overlapping use. Several rooms shift function over the course of the day, while others remain limited to a single purpose.

The “Main Building” [A] accumulates all daily activities including shared sleeping quarters, a kitchen, workstations, “Shackleton Bar” and the dining room—the base’s primary communal spaces. It is the most consistently active structure throughout the day, with minimal downtime between uses. Casa España & the Main House [C & D] combine sleeping quarters with workspace and small gathering areas, supporting mixed use, although they remain secondary in overall activity. Buildings B, J, and K are used primarily for technical work and equipment storage, active during working hours but largely idle otherwise. “Lame Dog Hut” [E] holds significant historic importance as it is the first building of the base, now used, along with Building G, exclusively for sleeping and informal resting. They are unoccupied for most of the day. Building L is a single-use container functioning as a laboratory, supporting work-related activity. Building F contains shared sanitary facilities for the surrounding buildings. The Chapel [H], serves primarily as a symbolic and ceremonial space, occasionally used for overflow sleeping. The newest addition to the base [circled on the site plan] was under construction during the study visit and is not yet operational. All buildings were documented during the stay, with notes on circulation and spatial patterns across the site.

4. Development of the habitability assessment framework

To assess habitability at the BAB, spatial and experiential parameters were considered interconnected and translated into a working “loop” methodology (Figure 4). Spatial parameters were documented directly through observation and analysis of the built environment, while experiential parameters required active participation from the base’s occupants.

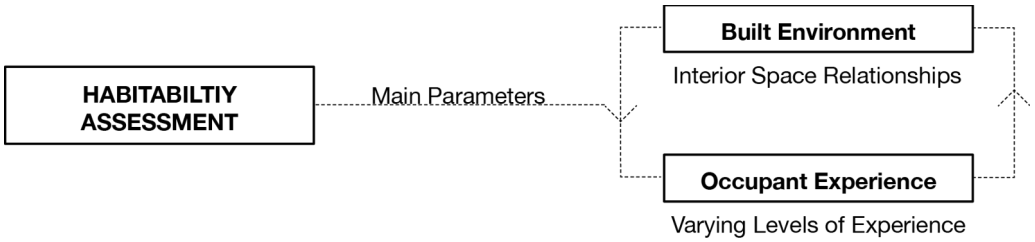


Figure 4 Habitability Assessment Loop, linking spatial and experiential parameters.

Experiential parameters were assessed through direct engagement with participants, using open-ended tools designed to elicit familiarity, discomfort, routine, or subtle forms of adaptation. The participatory tools were informed by Sanders and Stappers’ distinction between different levels of user knowledge: perceptual (what people say or think), behavioral (what people do), and experiential (what people feel or internalize). These distinctions help align each method used in the study in relation to the kind of insight it aimed to surface (Sanders & Stappers, 2008). Drawing on established participatory design practices, the tools were grouped into three types of engagement formats: individual activities, individual sessions, and group sessions (Figure 5).

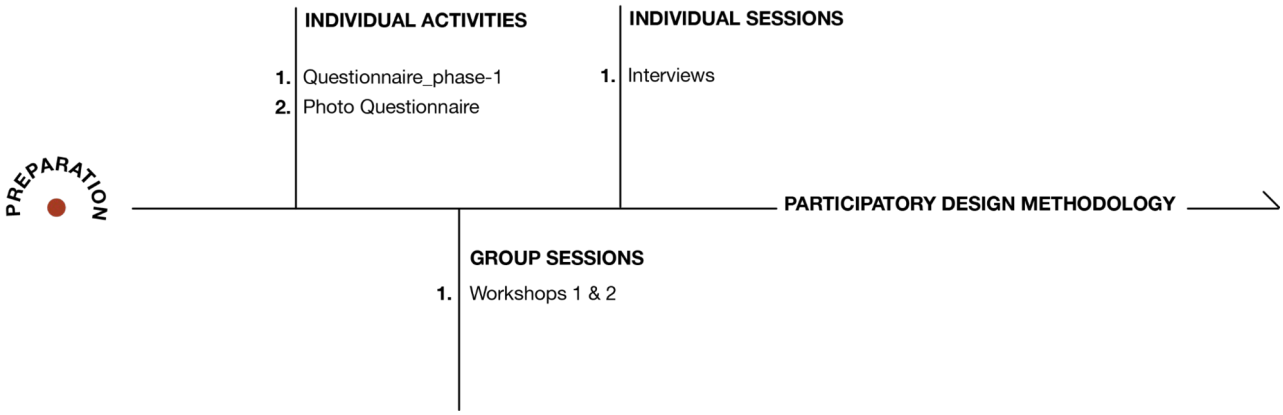


Figure 5 Modes of Participatory Engagement

Adapted to the Antarctic context, these tools formed the experiential side of the framework, adding a reflective layer to the spatial analysis in order to help reveal the ways in which habitability is shaped not only by physical conditions but also by the participants' lived interpretation.

5. Application of the habitability assessment framework

5.1 Procedure

The study procedure, illustrated in Figure 6, was structured around the interaction of spatial and experiential parameters within the habitability assessment framework (Figure 4). Before arrival at the BAB, a preliminary questionnaire was shared with potential participants to introduce study concepts on "comfort and well-being in familiar environments". The nature of the responses, or the lack of one, quickly indicated who was likely to engage further. Upon arrival, the completed questionnaires were reviewed alongside informal interviews to confirm participants' background and refine the engagement plan accordingly.

To establish a shared spatial reference for subsequent inputs, a complete recording of all the base's buildings was produced, including floor plans, circulation patterns, material use and key furnishings, that was refined throughout the researcher's stay. In parallel, participants became engaged with the individual photo-based activity, titled "Familiar Environments", which complemented the spatial documentation with qualitative input on areas of personal relevance.

Participatory Workshop 1 and Participatory Workshop 2, were the only group sessions in the study, and were scheduled during the second week, once the first draft of the floor plans was completed. During the last days of the study visit, research focused on the completion of the spatial analysis and upon conducting selected follow-up interviews with workshop participants.

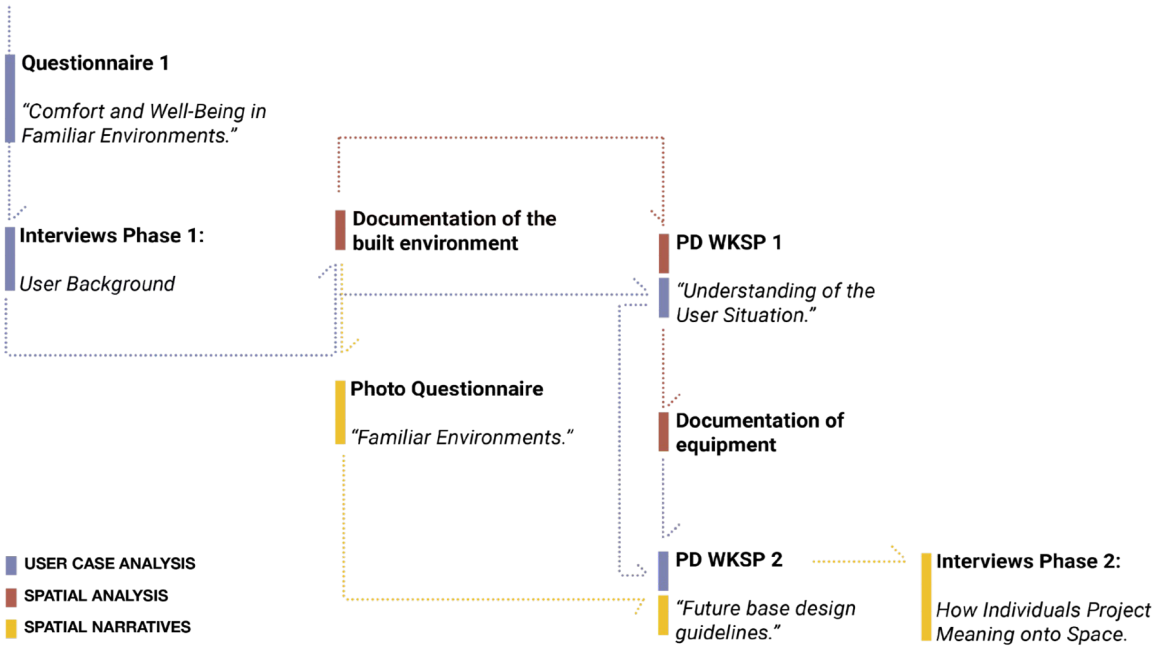


Figure 6 Application procedure of the Habitability Assessment Framework.

Across individual activities and group sessions, the concept of "spatial narrative" was treated as an exploratory dimension that helped reframe the notion of habitability in the participants' understanding.

5.2 Participant selection

The study involved **12 participants** (9 male, 3 female). Participant selection focused on experienced individuals, all of Bulgarian nationality, working across different roles at the base, such as engineers, scientists, logistics and medical personnel. Ages ranged from mid-30s to late 50s, with most falling between 36 and 55. A few held dual roles, balancing research with operational or technical duties. This range of responsibilities and experience helped shape a layered view of daily life at the base. Practical constraints, such as limited free time and language comfort, shaped how each person could engage and reinforced the need for a flexible engagement strategy.

A few first-time expeditioners were also included in an adapted version of the individual activities (not listed in Table 1). Although their responses were not incorporated into the formal habitability assessment, their participation helped this research capture how immediate engagement with the environment influenced those with no prior connection to it.

Table 1 A breakdown of participation across tools.

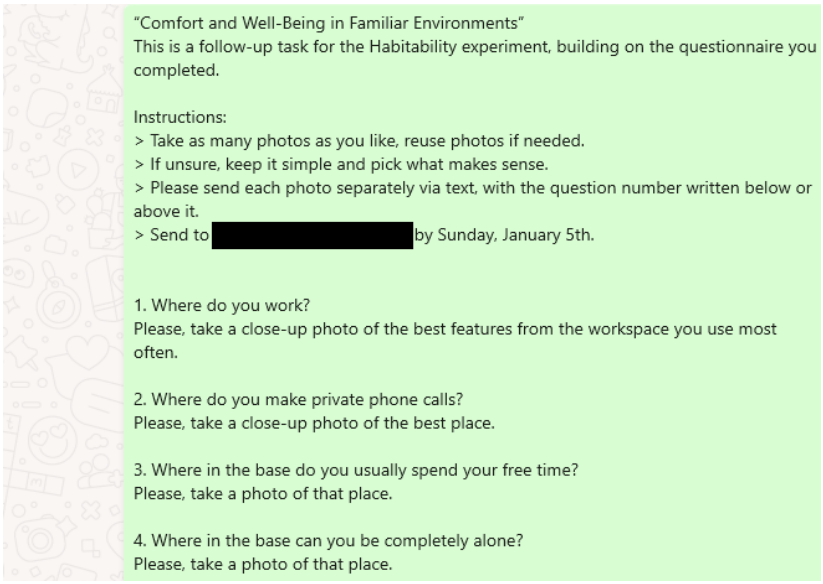
Ptcp. ID	Gender	Age Range	Occupation	Role in Antarctic Station	Past Exp.	Individual PD Activities	Group PD Sessions	Individual PD Sessions
P1	Female	50-59	Musician	Observer	2	prelim.qtn. _ photo qtn.	wksp. 1 _ wksp. 2	Interview
P2	Male	30-39	Mechanic/ Construction	Maintenance/part of the logistics team	1	prelim.qtn. _ photo qtn.	wksp. 1 _ wksp. 2	Interview
P3	Male	40-49	Mechanic/ Construction	Maintenance/part of the logistics team	1	prelim.qtn. _ photo qtn.	wksp. 1 _	Interview
P4	Male	30-39	_	Base Commander/ lead of the logistics team	6	prelim.qtn. _ photo qtn.	wksp. 1 _ wksp. 2	_
P5	Male	40-49	El. Engineer	El. equipment support	4	_ photo qtn.	wksp. 1 _	_
P6	Male	40-49	Engineer	Research Engineer/ general support	7	_	wksp. 1 _ wksp. 2	Interview
P7	Female	40-49	Researcher	Researcher	5	prelim.qtn. _	wksp. 1 _ wksp. 2	Interview
P8	Male	50-59	Doctor	Base Doctor	7	prelim.qtn. _ photo qtn.	_	Interview
P9	Female	30-39	Boat Driver	Boat Driver/part of the logistics team	4	prelim.qtn. _ photo qtn.	_	Interview
P10	Male	30-39	El. Engineer	El. equipment support /part of the logistics team	1	_ photo qtn.	_	Interview
P11	Male	50-59	Researcher	Researcher	3	prelim.qtn. _	_	_
P12	Male	30-39	Construction	Construction of the new building	1	prelim.qtn. _	_	_

5.3 Participatory tools and initial observations

Individual Activity: Photo Questionnaire

Timeline of Activity: Beginning - End of author's stay at the base
Participants: 8 people (P1, P2,P3,P4,P5,P8,P9,P10)

Description of activity: Selected participants received sixteen "photo prompts" via a personal text, under the theme "Comfort and Well-Being in Familiar Environments" (Figure 7), inviting reflection on daily life at the base. Since they were experienced participants, the tool offered a chance to see how they chose to introduce "their" base to an outsider. While an initial five-day window was suggested, participants' continued interest led the activity to remain open until the end of the fieldwork, making the gradual deepening of engagement a meaningful part of the process itself. The tool proved especially effective in this confined setting, becoming a point of shared interest and curiosity, with the resulting material later informing the analysis, particularly in relation to personal space and patterns of spatial use. At the same time, its application suggests border potential in confined environments, where the visibility of everyday actions can encourage informal engagement among others living in close proximity.


"Comfort and Well-Being in Familiar Environments"
This is a follow-up task for the Habitability experiment, building on the questionnaire you completed.

Instructions:
> Take as many photos as you like, reuse photos if needed.
> If unsure, keep it simple and pick what makes sense.
> Please send each photo separately via text, with the question number written below or above it.
> Send to [redacted] by Sunday, January 5th.

1. Where do you work?
Please, take a close-up photo of the best features from the workspace you use most often.

2. Where do you make private phone calls?
Please, take a close-up photo of the best place.

3. Where in the base do you usually spend your free time?
Please, take a photo of that place.

4. Where in the base can you be completely alone?
Please, take a photo of that place.

Figure 7 Partial screenshot of the instructions participants received for the "Photo Questionnaire."

Group Session: Workshop no.1

Timeline of Activity: Second week of author's stay at the base
Participants: 7 people (P1, P2,P3,P4,P5,P6,P7)
Title: "Understanding of the User Situation"
Duration: 1.5h. Materials: 2 base maps | markers | post-it | polaroid photos

Description of activity: This session aimed to produce a collective visual record of spatial patterns and areas of personal or operational relevance. It began with a warm-up activity

where participants traced their daily routes on a printed map of the base. Once familiar with the format, an identical map was introduced for the main activity. Participants were prompted with open-ended spatial questions and invited to mark their responses directly on the map, using color-coded markers for positive and negative feedback.

The session remained flexible, and discussion developed naturally when participants disagreed or elaborated on each other's input. In doing so, the activity opened a space for participants to compare stories about the base, something they rarely seemed to do in form, and revealed a clear sense of pride in presenting and discussing their lived environment.

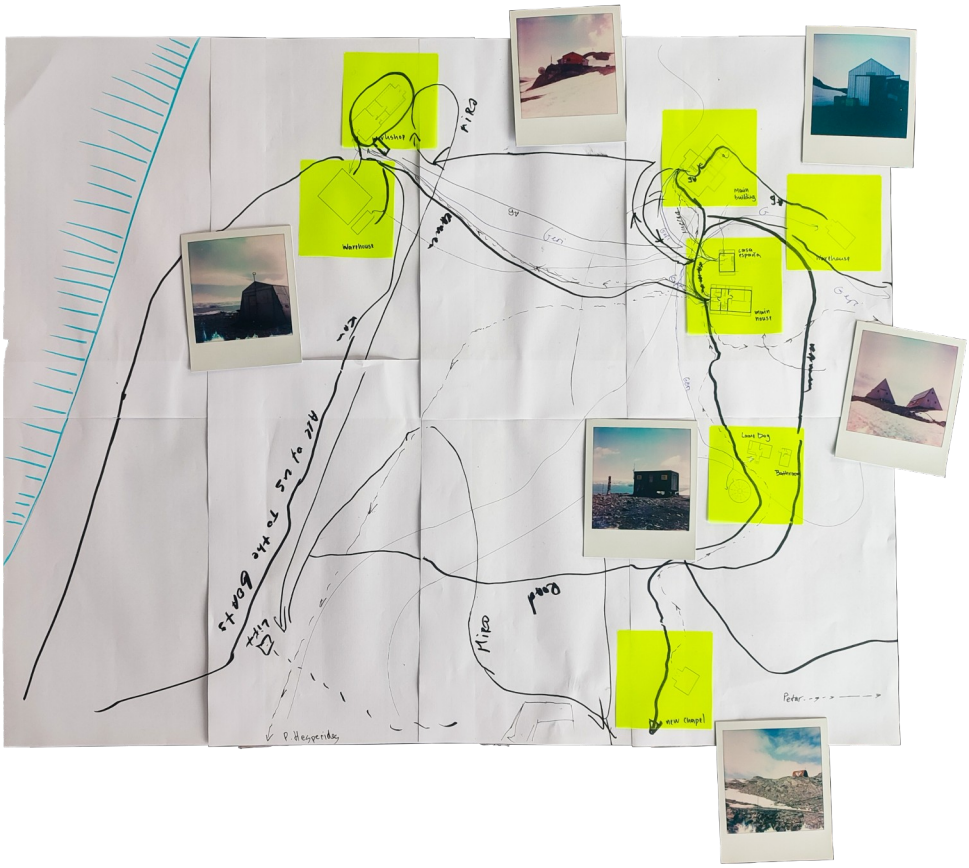


Figure 8 Base map created during Workshop 1, showing participants' daily routes. Activity centers on the main building and main house (top right), with secondary movement toward the warehouse and lab (top left).

Group Session: Workshop no.2

Timeline of Activity: Second week of author's stay at the base

Participants: 5 people (P1, P2,P4,P6,P7)

Title: "Future base design"

Duration: 1.5h. Materials: Cardboard with designed height curves | 3D printed pieces | markers | Post-it

Description of activity: This session aimed to identify design priorities for a hypothetical new base. The activity divided participants into two teams and presented them with simple

contoured shapes on cardboard along with a set of white 3d printed rectangular blocks. Participants were encouraged to think beyond familiar limitations and express deeper preferences and ideals.

Finally, each team was asked to highlight and incorporate the elements of the current base that felt worth preserving into their design and present it to the group, bringing the activity full circle. Participants identified what they considered "invaluable" and produced some of the richest responses of the session. These centered on material choice, the historical importance of certain buildings within the base's narrative, and the value of in-between spaces that carried strong memories and clear attachment. Together, these observations guided the research forward and reinforced the need for follow-up interviews through which more personalised accounts could emerge.

Figure 9 Proposed base design during Workshop 2. Beyond high-tech labs and warehouse areas, it includes a "Museum Area" to preserve the "Main-Building," "Main-House," and "Casa España."

Individual Sessions: Interviews

Timeline of Activity: Last week of author's stay at the base

Participants: 7 people (P1, P2,P3,P6,P7,P8,P9,P10)

This final activity of the fieldwork focused on participants who had shown strong observational skills and a deep connection to the base throughout the participatory process. Its goal was to closely explore the reciprocal relationship between space and personal experience: how does the built environment shape behavior and how do individuals, in turn, reshape space through use, habit, and memory. The interviews brought forward repeated references to hand-made items, personal marks, and spatial interventions, suggesting that these modest alterations carried meanings beyond function alone. Their recurring

importance across the participatory tools informed the author's interest in the exploratory concept of spatial narratives.

Together, these activities laid the groundwork for the research's core findings, not only by capturing participant reflections, but also by revealing how the tools themselves interacted with the rhythms and the culture of the base across the different assessment parameters.

6. Findings from St. Kliment Ohridski

The Bulgarian Antarctic Base served as the primary case study, with an on-site analysis that was used to refine the methodology in real time. As previously outlined, the habitability assessment was structured around four dimensions: usability, livability, flexibility, and innovation, approached through a layered set of spatial and experiential parameters. These dimensions guided research across all tools. No individual tool was intended to privilege one dimension over another, as they were all examined in parallel through the same framework. They did not, however, emerge with the equal weight in the field material.

To interpret the diverse material generated through participatory methods, the study adopted an inductive analytical logic informed by Grounded Theory (Corbin & Strauss, 1990), allowing patterns to emerge through the relation between lived accounts and spatial observations. The process unfolded in three phases: immersion in the field setting, deliberate review of transcripts, photographs, fieldnotes and clustering of recurring patterns across participants and tools. While this process remained flexible, it was not incidental. It revealed the aspects of the base that participants gravitated toward.

6.1 Reading the framework across four dimensions

Livability: In this research, livability was initially defined as "the capacity of a habitat to support psychological and emotional wellbeing, enabling comfort, routine, and social connection, even within, isolated, or resource-limited environments." Participant contributions across multiple tools increasingly tied livability to a recurring quality: familiarity. (Balomenaki et al., 2025)

This sense of familiarity was expressed through what this study terms as spatial narratives: the layered stories and associations people project onto space over time. These narratives emerge as people personalize their surroundings, interpret small cues left by others and pass on memories embedded within a certain place.(Figure 10)

Figure 10Sleeping areas. When asked to photograph a place where they could be alone, most participants chose their beds, each evidently personalized in different ways.

Participants engaged with this concept both directly and indirectly. In "Workshop 1", they marked places of personal significance or comfort on a shared map, often linking them to informal rituals or remembered conversations. During interviews and photo questionnaires, prompts such as "Where do you remember telling the best stories inside the base?" or "What is the best souvenir you've left behind?" offered them emotionally and spatially anchored reflections. These insights revealed that the base was never perceived as a neutral or purely functional space. Participants described physical details like: hand-crafted furniture, drawings on the walls, well-worn communal objects that linked their experience to an intergenerational memory of the base.

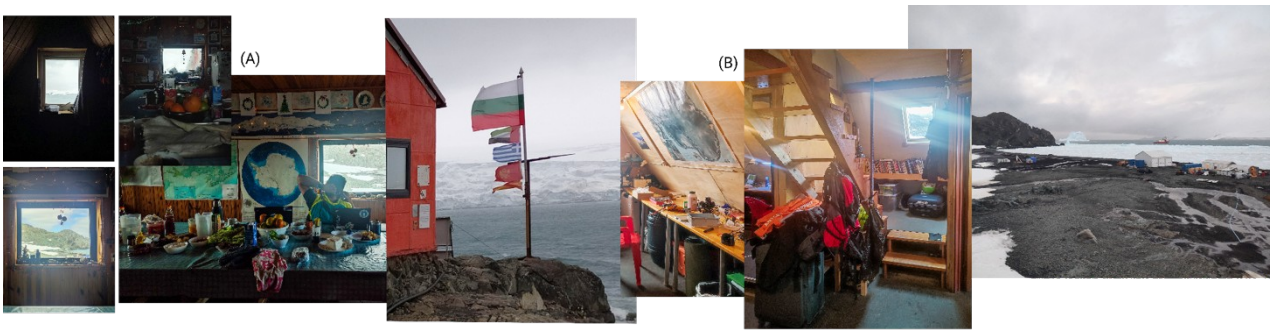


Figure 11 Collage of base interiors contrasted with the surrounding environment. The photos were taken by the author during their stay.

> **P1:** "The dining room window is like a TV channel, completely different every time and completely captivating. When someone's staring into it, we know they're working something out." **(A)**
>
> **P6:** "We tell the best stories around the staircase in the main house. It's funny, wherever you are in the house, you just instinctively gather there and sit on the steps." **(B)**

Familiarity, however, was not experienced uniformly. While many found personalization meaningful, others expressed concern about the lack of shared control over how space changed. As one participant noted, "*People think they can come into the base for what feels like a minute and they're entitled to make changes to our space*." Another added, "*We don't get to decide what changes stay, someone could pin something to the wall, and I might have to look at it forever.*" These moments suggest that spatial flexibility, while central to livability, can also introduce tensions around ownership and visual control in communal environments. Taken together, these narratives positioned familiarity as a multi-layered quality, both social and personal, that could be expressed spatially through warm materials, shared gathering points and objects that anchor routine or identity.

Figure 12 The dining room. Photo submitted by participant [P5].

A clear example is the dining room, the main shared space (Figure 12). Elements like warm, indirect lighting and hand-crafted furniture create an atmosphere that is, as some participants noted, rare in newer stations. These design choices, combined with accumulated decorations, give the room a familiar, welcoming quality. Even visiting expedition members described feeling an immediate connection to the space despite not living there.

Across tools and formats, these spatial narratives affirm that livability in extreme environments depends not just on function or comfort, but on recognition, that is the ability to see space as layered with meaning, memory, and belonging.

Flexibility: Within the framework of this research, flexibility was defined as “the ability of a space to accommodate changing user needs through adjustable layouts, overlapping functions, or personalized modifications that support adaptation over time”. At the BAB, flexibility was not embedded through formal architectural systems, but instead emerged through every day practice. Field observations, photographic documentation and workshop discussions all revealed how inhabitants routinely improvised, reassigned, and repurposed different areas according to shifting routines (Balomenaki et al., 2025).

Figure 13 Interior of Container L, the site of participatory workshops. Left: setup during workshops. Right: the same space following the researcher’s departure from the base repurposed as a private resting/working area.

Material choices also played a quintessential role as they provided the trigger to create tacit knowledge (Bofylatos & Spyrou, 2017) of how the space could be adapted. Wooden surfaces (used throughout the base) offered tactile cues and physical flexibility. They could be fixed, marked and repurposed with ease, producing what participants often described as a sense of "permission" to modify. Over time, these small acts of maintenance seemed to invite subtle acts of personalization accumulated into a form of "spatial authorship" that supported adaptation without erasing continuity.

Fieldwork further indicated that not all spaces remain flexible. Rooms with a strong layering of personalization, already rich in memory and tacit social rules, proved most resistant to change. In contrast, newer or more utilitarian structures, not yet inscribed with meaning, remained more open to experimentation. The dining room, for example, served as a charged social core, with a clear rhythm and inherited atmosphere, while the experimental work done in the newer blue container showed how open-ended spaces could easily shift function and identity when needed.

Together, these patterns suggest that flexibility in extreme environments is less about continuous "transformation" than about "responsiveness", that is the capacity for space to absorb change through incremental, human-scaled adjustments. Such responsiveness supports wellbeing by fostering the freedom to act and adapt within shared limits (Desmet & Fokkinga, 2020).

Usability and Innovation: In this research, these dimensions were associated with human-machine tasks and technologies intended to improve comfort without unnecessary complexity. At St. Kliment Ohridski Base, however, they emerged less strongly than livability and flexibility. This partly reflects the conditions of the base itself, where limited resources and gradual development offered fewer opportunities to observe complex systems or technological upgrades in practice. Even so, the research material collected suggests that innovation was not the primary factor through which occupants described wellbeing. In the "Future base design" workshop, participants readily welcomed better connectivity, energy efficiency, and similar improvements, but were very careful to condition that these would preferably not come at the expense of the personalized elements that made the base feel familiar and distinctly theirs. This points to a possible tension between familiarity and innovation. In the Antarctic context, certain inconveniences have historically been absorbed into expedition life, just as some distance from everyday technologies has shaped the station's social rhythms. During fieldwork, for example, improved internet access was generally welcomed, yet it also became a source of ambivalence, as the presence of phones began to interrupt communal dinners that participants valued as part of base life. In this sense, innovation was not rejected, but neither was it experienced as unconditionally positive. Its value appeared to depend on whether it could be integrated without disrupting the familiar social and spatial qualities that made the base feel lived-in and shared. The present study cannot substantiate this relationship more fully, and further research is needed to examine it in settings where technological options are more available.

6.2 What participation made possible

Participant engagement and willingness to contribute were among the early uncertainties of this project. Initial responses to questionnaires and interviews were marked by politeness and restraint. For some, the idea of reflecting on one's spatial environment seemed

unnecessary, perhaps even indulgent. Over time, that skepticism gave way to curiosity. Engagement became more fluid. Participants began initiating walkthroughs, shared routines and offered thoughtful suggestions about how the base could be improved. This shift reflected growing trust in the process and, importantly, the fact that participatory design provided accessible tools for articulating spatial values that participants already held.

More broadly, the participatory design framework in this study became a way to recognize the design intelligence already embedded in everyday practice. In the context of constrained or highly specialised settings, such an approach could be valuable for strengthening existing patterns of habitability to ensure occupants wellbeing.

6.3 Future applications

The 'Habitability Assessment" of the St. Kliment Ohridski base served as the primary observational process on which a future “applied habitability” model could be grounded. Building on these findings, we propose a next phase depicted as an activity loop (figure 14), extending the earlier assessment framework into a process of gradual, small-scale design actions. These interventions would be directly guided by the participation of experienced expeditionaries, with design propositions aimed at enhancing spatial expressions of familiarity and spatial responsiveness. It would be particularly valuable to further test the relevance of these parameters, while simultaneously trying to reconstitute these types of situational knowledge and their place in the design process, especially in an extreme yet culturally different context.

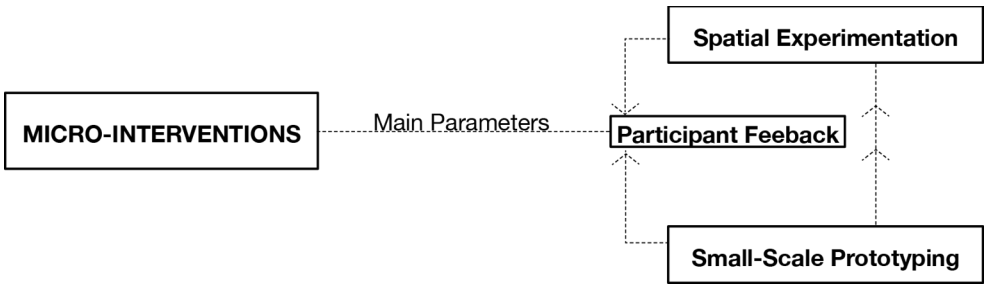


Figure 14 “Activity Loop”. Proposed next phase extending the “Habitability Assessment Loop” (Fig. 4) into gradual, small-scale design interventions.

By doing so, this study aims to explore the concept of enhancing extreme environment habitats with design solutions that encapsulate the occupants’ situational knowledge actively testing whether lived experience can be a transferable design input.

By trusting expeditioners to lead with their expertise and together with a design team facilitating the process, we believe the resulting outcomes could make a meaningful contribution in future habitat development, benefiting at the same time the wellbeing of the crew.

7. Transferability to other constrained contexts

The field research on an antarctic habitat offered a controlled setting to begin understanding how design supports people living with limited space, comfort, and stability. Yet, the spatial pressures observed there are not exclusive to remote environments. The notion of an

“extreme environment ” need not be reserved for the distant or the extraordinary as urban life itself increasingly presents conditions of extremity. Informal settlements, post-disaster shelters and the spaces inhabited by the unhoused, all reveal similar struggles for habitability under constraint.

In these contexts, moving past wellbeing, a person's survival and dignity depends on the environment’s capacity to remain adaptable and responsive (Desmet & Fokkinga, 2020).

There is growing recognition that the complexity of such challenges can no longer be addressed in isolation. The idea that human-centred design can play an active role in addressing them through spatial, social and organizational interventions deserves careful exploration (Buchanan, 2001, Junginger, 2017, Pable et al., 2021).

In what Buchanan (2001, p. 37) describes as “the ongoing search for ways to support and strengthen human beings as they act out their lives within varied social, economic, political, and cultural circumstances”, this research extends its scope toward urban contexts where the habitability assessment framework could be applied. The spatial qualities identified as beneficial to occupants’ wellbeing at the BAB could be adapted to test how environments under pressure might still sustain dignity and agency. Through this, the study aims to demonstrate how participatory design can translate lessons from isolation into meaningful strategies for everyday extremes, where designers working alongside frontline actors for societal wellbeing can use participatory methods to surface spatial needs and co-develop responsive, context-specific solutions.

8. Conclusions

This research set out to understand how built environments in extreme conditions can better support those who inhabit them. At the Bulgarian Antarctic Base, participatory design surfaced familiarity and an unprecedented, for the base, spatial flexibility as central factors in achieving habitability. Familiarity remained constantly relevant in how people described their routines and attachments, while flexibility supported it through the adaptive use of space and materials. This functional responsiveness was more than efficient, as it enabled collective shaping of the environment, leading to a sense of shared ownership.

These insights contribute to a broader theoretical understanding of design under constraint, demonstrating that human-centered methodologies can improve limited infrastructures and transform them into supportive environments. While the theoretical link between participation and wellbeing is well established, this study offers evidence of its application within a highly constrained environment, further extending its relevance to urban settings shaped by imbalance and by a defining expression of “urban extreme”. In doing so, it offers a foothold for designers and researchers to employ participatory design not only as a method for inclusion, but as a framework to navigate complexity, to enable adaptation, and to reinforce resilience across contexts.

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