IAC-25-E5,6,5,x95232

Enhancing Psychological Well-being in Extreme Environments: Customized Environmental Projection System applied at the "St. Kliment Ohridski" Bulgarian Base in Antarctica

Christina Balomenaki[a]*, Dr. Kynthia Chamilothori[b], Klea Biniakou[a], Iason Paterakis[c], Nefeli Manoudaki[c], Prof. Konstantinos-Alketas Oungrinis[a]

[a] *School of Architecture, Technical University of Crete, Akrotiri Campus, Chania, Crete, Greece 73100*
[b] *Human-Technology Interaction Group, Department of Industrial Engineering & Innovation Sciences, Eindhoven University of Technology, Eindhoven, 5612 AE, the Netherlands*
[c] *Media Arts and Technology, University of California, Santa Barbara, 3309, Phelps Hall, Santa Barbara, California, United States of America*
* Corresponding Author

Abstract

This paper presents an experimental study conducted at the Antarctic Base of the Bulgarian Antarctic Institute (BAI), investigating the potential of audiovisual systems to mitigate the psychological and emotional challenges associated with prolonged stays in confined and extreme environments. The experiment examines how personalized environmental projection techniques, combined with customized visual and auditory stimuli, can alleviate negative psychological effects of isolated, confined and extreme environments (ICE) on emotions, mood, and concentration.

The present study examines whether personalized visual content of landscapes that an individual is familiar with, depicting two types of natural landscapes (forest and icescape) and one type of urban landscape, differ in how it can influence the participants' reported emotional state, mood, relaxation, motivation, and focus. In addition, we explore the potential of AI-generated visual content as a means to avoid habituation to the projected content, and thus investigate imagery type by retaining visual characteristics from literal landscapes and generating corresponding abstract representations. To this end, the experiment followed a 3x2 within-subjects design with two factors, landscape content (forest, icescape, urban environment) and imagery type (literal, abstract), and 13 participants were exposed to 16-minute audiovisual projections in three sessions and completed questionnaires before and after.

The outcomes of this study show a significant interaction between the displayed landscape content and imagery type in how much participants liked the projection. Both natural landscapes were found to be more preferred than the urban landscape, but only for the literal imagery type. At the same time, imagery type also had a significant influence on liking, with the literal visualisations being more preferred than the abstract ones. Analyses comparing the change in participant responses from the beginning of the experimental session with those after exposure to the audiovisual projections showed no influence of either landscape content, imagery type, or their interaction on changes in happiness, excitement, relaxation, or mood. On the other hand, we found an energizing and vitalizing effect of landscape content, and particularly of the icescape compared to the urban landscape, on how energized participants felt after exposure to the projection compared to the beginning of the experimental session, as well as how easy it was for them to focus and how motivated they felt.

Despite the limited sample size, these outcomes provide insights on how customized interventions can support well-being and guide strategies to enhance crew performance and mental health in space and other extreme environments.

Keywords: Human factors, Habitability, Extreme environments, Environmental psychology, Audiovisual projections, GenerativeAI

Acronyms/Abbreviations

Audiovisual (AV)
Extreme and confined environments (ICE)
Bulgarian Antarctic Institute (BAI)
Heart Rate (HR)
Electroencephalography (EEG)
Linear Mixed Model (LMM)

1. Introduction

This study investigates the effectiveness of audiovisual projections in improving participants' emotional state, relaxation levels, and perceived energy of individuals working in an Antarctic research station. This work is part of a broader study investigating the effects of audiovisual projections as a low-mass and low-power environmental countermeasure for the negative psychological and cognitive effects of ICE environments and long-duration space missions. The experimental setup in Antarctica is used as a space analog, with the aim to test the environmental projection system in a real-world isolated, extreme, and confined (ICE) environment with people who experience these conditions for prolonged periods [1].

In particular, this study investigates the effects of exposure to projected landscapes with varying content and imagery type, with the aim to establish the potential and characteristics of audio-visual projections to be used as a countermeasure to the psychological challenges posed by long-term residence in extreme and confined environments. The outcomes of this study offer valuable insights for designing supportive strategies for contexts such as Antarctic expeditions and future space missions.

1.2 Nature visualisations as a way to counteract the negative effects of ICE environments

Long-term isolation, such as that experienced in space missions, has been observed to affect the psychological well-being, physiology and cognitive performance of those experiencing it [2]. Disconnection from family, friends and one's social network can lead to intense feelings of social isolation and loneliness [3]. In turn, social isolation can lead to emotional exhaustion, heightened anxiety and depressive symptoms, causing decline of concentration capacity, memory and decision-making [4,5,6]. Additionally, the lack of variety in stimulation, often associated with monotony, further affects the cognitive performance and psychological well-being of participants in long-term space missions and analog missions [3,5,7]. Therefore, there is a need for countermeasures to these issues that will support the crew members and increase their well-being for longer periods of time [8].

A promising means of alleviating the aforementioned negative effects of confined and extreme environments is exposure to nature. There is substantial and consistent scientific evidence showing that exposure to nature can be beneficial through positive effects on psychology and physiology [9,10] as well as certain measures of attentional performance [11]. A hypothesized explanation is the concept of Biophilia [12], the innate tendency of humans to connect with the natural world, which is believed to have deep evolutionary roots and to impact human psychological resilience and the sense of purpose. In addition, two core theories in the field of environmental psychology, the Stress Recovery Theory (SRT) [13] and the Attention Restoration Theory (ART) [14,15] aim to explain the mechanism behind these beneficial effects by hypothesizing that nature elicits an immediate positive emotional response (SRT) or that it replenishes depleted attentional resources (ART), respectively. What constitutes nature can take many forms: in addition to exposure to greenery, exposure to water [16], as well as to real or simulated daylight [17] have also been shown to have beneficial effects on humans.

Research on the positive psychological and physiological effects of nature often compares natural to urban landscapes, and relatively few studies examine the effects of different types of natural landscapes. Experimental studies measuring subjective responses and brain activity to images of mountains, forests, water, and urban landscapes, showed significant differences not only between the natural and urban, but also between the natural landscapes [18]. In particular, mountain and water landscapes were found to have the highest reported restorative properties. At the same time, activation of brain areas used in visual processing and adjusting attention differed when viewing water compared to urban landscapes, but not when viewing forests compared to urban landscapes, showing differences in the effects of these natural landscape types on brain activity.

Moreover, beyond exposure to actual nature, schematic imitations of nature in indoor environments have been suggested to reproduce nature's beneficial effects [19]. A core motivation behind this approach is that nature scenes have been suggested to possess unique visual characteristics. Such a characteristic is fractal complexity, a measure of self-similarity [20]. The level of fractal complexity found in nature scenes is considered to be processed more easily, a phenomenon termed fractal fluency [21]. Previous studies that examined schematic imitations of nature have employed stimuli such as flooring with fractal patterns [22], façade designs that imitate natural patterns [23], as well as projections of fractal patterns [24]. In addition to visual stimuli, the inclusion of natural sounds has been shown to enhance the perceived restorative potential as well as feelings of calmness, excitement, awe, and nostalgia [25], and are a promising means of enhancing the beneficial effects of nature visualisations.

Studies on place attachment, i.e., the emotional attachment that people establish with important places in their life, have shown that the participants' familiarity with a presented natural landscape influenced how restorative it was expected to be [26]. Similarly, Smalley and colleagues [25] showed that the memories elicited by audio-visual nature content had a significant influence, with participants reporting positive memories also showing higher ratings in perceived restorative potential, and positive emotions compared to participants who reported no related memories [25]. As a result, one's familiarity and memories evoked by a nature-based intervention could be used to increase its positive effect.

In the context of ICE environments, virtual nature environments were used in combination with psychological practices for emotional regulation during the Mars-500 experiment, with positive effects being suggested on participants' mood [27]. In another series of experiments in ICE environments, participants were shown varying scenes of recorded or simulated nature, recorded urban scenes, or scenes with animals [28]. Recorded nature was perceived to be more restorative than animal or urban scenes, while no effect of scene type was found on mood. Importantly, the authors note that preferences for the VR content varied greatly among participants, and recommend that the content should be tailored to the setting and individual [29]. In a similar vein, interviews on participant experience of a VR-based nature intervention used during confinement in ICE environments showed that participants appreciated the access to experiences and emotions offered by the VR content, and also highlighted the need for customizing the VR content to the participants' preferences and needs, such as stimulation or personal connection [29].

1.3 Projection-based visualisations in ICE

In previous work, the potential of nature scenes in the context of ICE environments has been examined through computer [27] and head-mounted Virtual Reality [28,29] displays. However, head-mounted displays can often cause cybersickness, making them unsuitable for prolonged use [30,31]. Projection-based visualisation technologies have been suggested as a promising alternative strategy to create environments that promote mental health and enhance habitability in space habitats and terrestrial analogues [32]. By projecting images and sounds directly onto architectural surfaces, the dimensions of confined interiors can appear larger, creating sensory-rich environments without the need for bulky hardware or head-mounted displays [32]. Moreover, unlike head-mounted solutions, projection-based visualizations can enable prolonged and multi-user engagement by integrating it seamlessly to the architectural fabric of the habitat. The use of projection-based visualisations offers distinct operational advantages, as it requires physical spatial intervention while providing a variety in content and atmosphere achieved mostly through software control [30,32].

Therefore, projections can be a solution to mitigate the well-documented negative effects on mental and physical health of prolonged stay in extreme and confined environments. Furthermore, the versatility of this technology allows it to be used in a private context, where users can personalize the content based on cultural and personal preferences, while in communal areas, it can enhance social cohesion and build stronger bonds among crew members [1]. Such interventions are especially critical for long-duration missions, where psychological resilience is as essential as technical reliability. Studies emphasize that projection mapping should be treated as a fundamental architectural element that shapes perceptions of volume, privacy, and functionality within the spacecraft and analog interior [1,30]. To our knowledge, the only study to employ projection-based visualisations in a simulated ICE environment is that of He and Jiang [33]. In that study, participants in the experimental group were shown silent videos of underwater landscapes and animals during a 7-day isolation period, and were found to experience lower negative emotions and higher positive emotions compared to a control group. This work marks an important first step toward delineating the potential of projection-based visualisations of nature in ICE environments. Nevertheless, further research employing customized landscape content in projected visualisations could broaden our understanding of the capabilities of such an intervention.

1.4. Generative Artificial Intelligence in ICE environments

Long-duration missions and Antarctic analogues are vulnerable to monotony and habituation, which can blunt the restorative impact of fixed media. Generative Artificial Intelligence (Gen AI) allows us to introduce controlled unpredictability and novelty [34], which have been suggested to sustain interest and positive affect while remaining within safe sensory bounds [35,36]. Diffusion models can also be steered to produce naturalistic complexity (e.g., fractal-like, midspatial-frequency structure) associated with soft fascination and stress reduction in nature studies [14,37,38]. Unlike finite libraries, Artificial Intelligence (AI) driven image synthesis pipelines afford effectively unlimited, stochastic, parameterized content that can be tailored to crews and refreshed over time [39], and, with parameter-efficient adaptation (e.g., LowRank Adaptation (LoRA); [40], it can be tuned to domain-specific styles or preferences. Real-time diffusion pipelines run locally with GPU hardware acceleration and can even be connected to biosignals (EEG, ECG, etc.) for closed-loop adaptation of scene dynamics [41,42]. To our knowledge, the potential of real-time GenAI visualization content has not been explored in the context of ICE environments. The present study aims to address this research gap by examining not only the influence of landscape content, but also that of imagery type on participant responses, using both human-captured and AI-generated landscapes.

2. Method

The experiment followed a 3x2 within-subjects design, with landscape content (forest, icescape, urban environment) and imagery type (literal, abstract) as factors. Each participant took part in three experimental sessions where they conducted office-like tasks while exposed to the AV projections (described further in section *Procedure*). In each experimental session, participants were exposed in random order to both imagery types in the same landscape content, selected randomly, and physiological measures (HR, EEG) and self-reports were recorded. This paper examines the effects of landscape content and imagery type on self-reported ratings of happiness, excitement, relaxation, mood, preference, focus, and feeling energized.

The following subsections outline the study setting, participants, stimuli, measures, equipment, and procedure, aiming to provide sufficient detail to enable replication. All methods were adapted to the operational constraints of the Antarctic research setting to ensure both feasibility and reliability.

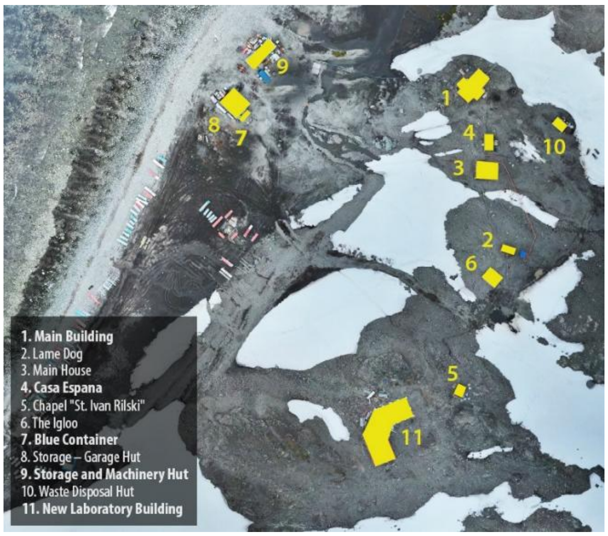

Fig. 1. Masterplan of Antarctic Base.

Fig. 2. Exterior view of the "Blue Container".

2.1 Study Setting: the 'St. Kliment Ohridski' Base

The experimental study was conducted at the 'St.Kliment Ohridski' Bulgarian Antarctic base during the period from 28 December 2024 to 18 January 2025. St. Kliment Ohridski Base, located on Livingston Island in the South Shetland Islands near the Antarctic Peninsula, serves as Bulgaria's primary Antarctic research facility. The station lies on slightly raised, ice-free ground along the shore of South Bay, adjacent to the Grand Lagoon, — a freshwater lake of about 10,000 m² situated 2.4 m above sea level. In contrast to single-building installations such as Concordia Station, St. Kliment Ohridski comprises a cluster of separate structures, each erected at different times and designed for distinct purposes. These buildings are interconnected by transitional spaces and access routes, forming an integrated operational complex. At present, the base encompasses 11 individual premises dedicated to accommodation, research, and logistical functions (Fig. 1, 2). Among the available facilities, the experimenter, with support from the base personnel, selected a container located near the bay shoreline, separated from the more densely occupied main buildings, as the site for the study.

The unit, commonly referred to as the "Blue Container" (Fig. 2, 3, 4) is a repurposed standard-sized shipping container (6.06 m × 2.44 m), serving a versatile role, commonly used as a laboratory for scientific research. The interior surfaces were mainly achromatic (light grey), with low visual complexity (Figures X-X). The furniture inside the container consisted of 2 tables (2.15m x 0.75m), two chairs and a wooden bench, allowing office work. It is the only building on the base equipped with shutters, allowing full control over the amount of the constant daylight of Antarctic summer entering the interior.

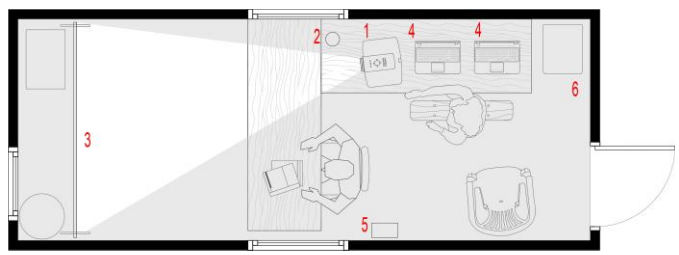

Fig. 3. "Blue Container" interior layout during the experiment, showing: 1. Projector, 2. Audio source, 3. Screen, 4. Laptop, 5. Heater, 6. Trash can.

Fig. 4. Photograph from the experimental procedure.

2.2. Participants

Participation was voluntary among staff that resided at the base during the conduction of the experimental study. Eligibility criteria for the study included normal or corrected-to-normal vision, absence of colour blindness, and right-handedness, in order to ensure consistency in the physiological measurements. Participants with a diagnosed mental disorder, post-traumatic stress disorder (PTSD), or anxiety disorder would not have been considered eligible, as these conditions may influence brain neurophysiology and affect the characteristics of recorded EEG activity [43,44,45].

Another key eligibility criterion for participation in the experiment was the nationality of the subjects. Specifically, only individuals who were permanent residents of Bulgaria and had spent the majority of their lives in the country were included. This requirement was based on the findings in existing literature that perceptions of a “familiar location” are strongly influenced by cultural characteristics of the participants [46]. Therefore, ensuring cultural homogeneity was deemed essential to minimize the potential confounding effect of cultural differences on the results. For this reason, inhabitants of the base that were not Bulgarians were excluded from the study.

Out of the 33 individuals residing at the base during the study period, the experiment involved 13 participants (10 male, 3 female), who met all the criteria. The participants ranged in age from 35 to 56 years (M = 43.7, SD ≈ 6.4), representing a mid-adult sample. The largest cluster fell within the early-to-mid 40s, with only two participants above 55 years of age. This age distribution ensured that the study group remained within a relatively homogeneous adult age range.

During the period of the experiment, three distinct groups were present at the station: (i) the permanent staff, who typically remain for three to five months; (ii) visiting researchers, who usually stay for one to two months; and (ii) exceptionally, a group of construction workers engaged for the past two expeditions in the construction of the new laboratory facilities. To ensure representation of the station’s overall population, participants from all three categories were included in the study (n=9 permanent staff, n=2 visiting researchers, n=2 construction workers).

Another important characteristic is the participants’ prior experience in polar expeditions This factor is closely linked to their level of familiarity with such conditions as well as their overall engagement and enthusiasm. Participants were distributed across three experience categories: four were first-time visitors, five had between 2 and 4 previous expeditions, and four had extensive experience with 5–7 stays (M = 3.2, SD ≈ 2.0). As 9 out of 13 participants had previous experience with polar expeditions, we consider that our sample is overall familiar with Arctic landscapes. Moreover, we recorded the duration of time that participants had already spent at the base before the onset of the experiment. Longer stays have been associated with increased exposure to emotional and psychological challenges, such as monotony and adaptation fatigue [6]. At the start of the experiment, 6 participants had been at the base for only 1 week and were considered newcomers, while 7 had already spent approximately two months at the station. This distribution enabled the inclusion of both recently arrived individuals and those more acclimatized to the Antarctic environment.

All participants provided written informed consent before the beginning of the experiment. The study was approved by the Ethics and Deontology Committee of the Technical University of Crete (approval No.71/21-05-2024) and complied with the tenets of the Declaration of Helsinki.

2.3. Stimuli

2.3.1. Choice of Stimuli

For this study, we prepared a 3×2 stimulus set of videos with varying landscape content (forest, icescape, urban) and imagery type (literal, abstract) (Fig. 5). The variations of landscape content had a twofold aim: to compare participant responses to natural and urban environments, a common juxtaposition in the literature, and to examine the role of familiarity with a natural landscape. As a result, prior to the study, we conducted in-person interviews with the participants prior to their departure to Antarctica about the environments in which they had lived, grown up, or spent most of their lives. These interviews explored the types of natural settings that were characteristic of their everyday surroundings, the landscapes typically seen from their homes, and the kinds of natural environments they preferred for leisure.

From this process, forests were identified as the most familiar natural landscape and were therefore selected as one of the experimental conditions. This condition consisted of footage of a forest, recorded from a static location [47]. To contrast familiar natural settings with human-made but equally familiar environments, a second condition was represented by an urban landscape: the city of Sofia, where the participants reside when away from Antarctica. The urban landscape was recorded by the experimenters. Finally, to introduce a natural landscape that is entirely unfamiliar to most people, but was relatively familiar to our own sample (see previous section) the third condition featured an Antarctic icescape [48]. The use of an Antarctic landscape provides an environment for which we expect lower place attachment in our sample of staff working at BAI, and at the same time allows future comparison with participants with no connection or any prior experience with Antarctica.

In addition to examining the effects of different types of landscapes on participants, the study also aimed to investigate the impact of imagery type. Accordingly, for each of the three landscape categories described above, two versions were created, one literal and one abstract, while keeping core audio-visual properties constant between the two variations, as described below. Screenshots of all stimuli are shown in Figure 5.

Fig. 5. Screenshots from the stimuli, varying in landscape content (y axis, from top to bottom: forest, icescape, urban landscape) and in imagery type (x axis, from left to right: literal –human-recorded— and abstract –AI-generated— imagery type).

2.3.2. Artificial Intelligence Content Generation

The abstract imagery type conditions were generated with AI using the human-recorded, literal content as a basis, as described below. In this study, we utilized pre-rendered outputs from the real-time content creation pipeline to maximize robustness. Abstract variants were generated in TouchDesigner using StreamDiffusion [41], a real-time diffusion approach that stabilizes video synthesis by reusing denoiser states across frames and applying a small, fixed number of denoising steps per frame. We operated both video-to-video (conditioning on the literal footage blended with animated noise) and text-to-video modes. Prompt control followed a two-channel scheme: a primary prompt expressed scene semantics (e.g., ice crystal microscopy), while a secondary prompt modulated structural complexity (e.g., abstract fractal (Mandelbrot)). TouchDesigner controls allowed continuous mixing of prompt weights during generation.

To decouple low-level image complexity from content, we blended animated Perlin 3D noise with the literal input before diffusion; a single noise-amplitude parameter regulated geometric simplification in real-time. A custom GLSL patch within Touch Designer computed the mean relative luma (Y′, ITU-R BT.709) from the gamma-encoded sRGB (R′G′B′) of the literal condition video and applied per-frame gains to the abstract output, maintaining matched average luma within each landscape category.

Real-time generation ran on an Alienware m16 Intel i9 13900HX laptop with an RTX 4090 Laptop GPU and 64 GB RAM. TensorRT acceleration for StreamDiffusion achieved significantly higher, more stable frame rates within the TouchDesigner pipeline. Generated sequences were recorded inside TouchDesigner and then AI-upscaled with Topaz Video AI to 3840×2160 at 30 fps. Although the projector operated at 1920×1080, downscaling the 4K masters on playback produced sharper edges and fewer aliasing and compression artifacts. Videos with compression artifacts, playback judder, or photometric mismatches were re-encoded or excluded.

Each 16-minute projection consisted of a 15’ landscape video and a 1-minute masking video with white noise audio to reduce carry-over effects [55] (Fig. 6). For each landscape category, the abstract–literal pair was matched in average color and luma to allow comparisons between image types. In addition, the literal

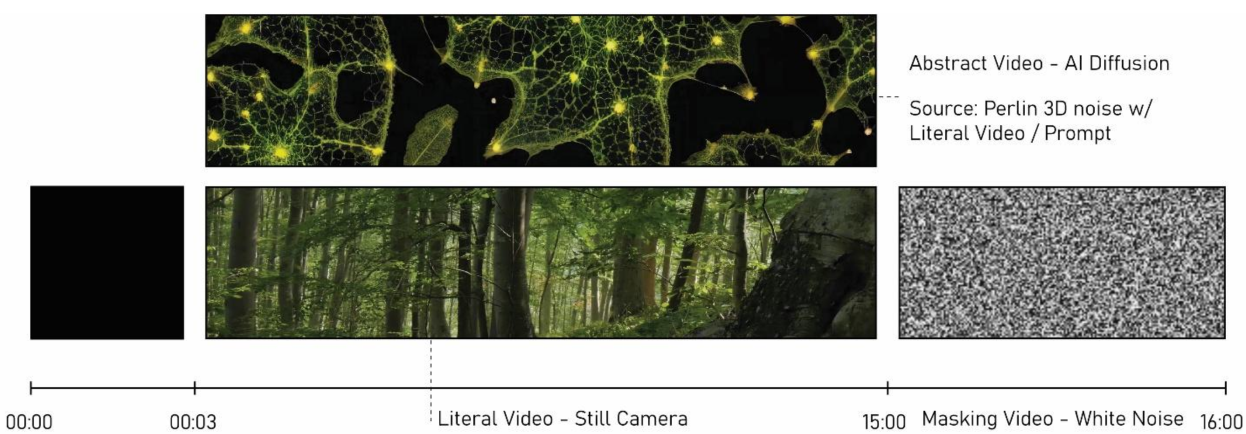

Fig. 6. Timeline of the 16-minute projection, showing the semantic and perceptual content maintained across literal-abstract pairs, and the use of a masking video.

and abstract versions featured the same audio track (e.g., identical sound compositions of wind, leaf rustle, and birdsong for both forest clips). The audio was loudness-normalized across all stimuli and did not include identifiable speech.

Table 1. Overview of the questionnaire items analysed in the present study.

Variable	Question	Rating scale
Happiness	How would you describe your current emotional state?	11-point SAM, ranging from 'Sad' to 'Happy'
Excitement	How would you describe your current emotional state?	11-point SAM, ranging from 'Calm' to 'Excited'
Relaxation	How relaxed do you feel right now?	11-point scale, ranging from 0 (Not relaxed at all) to 10 (Extremely relaxed)
Mood	How would you rate your mood right now?	11-point scale, ranging from 0 (Very negative) to 10 (Very positive)
Energized	How energized do you feel right now?	11-point scale, ranging from 0 (Very tired) to 10 (Very energized)
Preference	How much do you like the projection?	11-point scale, ranging from 0 (Not at all) to 10 (Very much)
Ease of focus	How easy is it to focus on your thoughts or tasks during the session so far?	11-point scale, ranging from 0 (Very hard) to 10 (Very easy)
Motivation	How much do the projections help you feel more motivated in your tasks?	11-point scale, ranging from 0 (Not at all) to 10 (Very much)

2.4 Measures

In addition to physiological responses, which were recorded throughout the experimental sessions and are outside the scope of this paper, participants provided subjective responses through paper-based questionnaires and an interview.

The paper-based questionnaire was administered before (baseline) and after exposure to the stimulus in each experimental session. In the baseline questionnaire, participants were asked about their initial state. These measures controlled for confounding factors and defined a point of reference for each participant. In the post-exposure questionnaire, the participants were asked about the content they had just been exposed to to assess its immediate emotional impact. After completing all experimental sessions, a semi-structured verbal interview was conducted by the primary researcher on the participants' experience and impressions of the interventions.

The paper-based questionnaires examined the participants' momentary affective state through a Self-Assessment Manikin [49,27]. In addition, participants were asked to rate their impressions of the projections, as well as their perception of their behaviour and performance after or during exposure to the projections using 11-point Likert scales. The use of 11-point scales was chosen to approximate an interval scale [50] and offer a neutral response option [51]. The present paper focuses on a subset of these questions, presented in Table 1. Particularly, we focus on the within-subjects comparisons of participants' self-assessment of momentary happiness, excitement, relaxation, mood, and energy levels between the baseline and post-stimulus questionnaires. In addition, we examine the participants' reported preferences and impressions on ease of focus and motivation after exposure to the projection.

2.5. Equipment

Visual stimuli were displayed using an EPSON EB-L265F Laser Projector (1920 × 1080, 3LCD, 4,600 lumens, noise 37 dB/27 dB Eco) The images were projected onto a BlitzWolf BW-VS6 Screen with a display area of 265 × 149 cm (16:9 aspect ratio) and a wide viewing angle of approximately 160°. The screen material is anti-wrinkle and supported by a stable freestanding frame (assembled dimensions: 276 × 207 × 49 cm). Audio playback was provided by a JBL Flip Essential Portable Bluetooth Speaker, offering a frequency response of 80 Hz–20 kHz and a signal-to-noise ratio (SNR) of ≥ 80 dB, ensuring clear sound reproduction of the experimental audio tracks. The projection was performed on an Alienware m16 laptop equipped with an Intel i9-13900HX processor, an RTX 4090 Laptop GPU, and 64 GB of RAM.

Physiological responses were recorded using a set of wearable devices: the Polar H10 chest strap heart rate sensor, the Garmin Forerunner 55 smartwatch and the Unicorn Hybrid Black EEG Headset, an 8-channel wearable EEG amplifier. The Unicorn application run on a Dell XPS 15 9550 laptop.

2.6. Procedure

The experiment followed a repeated-measures design across three sessions per participant (with an additional fourth session for some participants, see below). All sessions were performed under comparable environmental conditions, following a standardized procedure, described below.

The experimental procedure comprised three sessions. Before the start of each session, the projection system was set up so that only a black screen was visible, and audio was enabled. Upon arrival, the experimenter assisted the participant in putting on the wearable devices. After this stage, participants were free to choose from a variety of office-like tasks that they would carry out during the session. These included exclusively paper-based activities, as electronic devices were not permitted during the experiment. Options consisted of participants' own personal paperwork, writing in their diary, reading magazines, articles, or books, and solving crosswords, which were commonly available at the station. Additionally, different aptitude tests (abstract tests and diagrammatic reasoning tests, [52] were provided by the researcher as optional tasks. For the present study, we consider all aforementioned options of office-like tasks as equivalent.

The first session differed slightly in procedure and was longer in duration (65 min) (Fig. 7), compared to the second and third sessions (46 min), as it began with a 15-minute period with no stimuli to establish baseline physiological response, and two tasks to determine individual minimum and maximum physiological arousal levels (a 2.5-minute exposure to an aquatic video [53] and a balloon inflation task [54], respectively). Due to availability issues, for a subset of participants (n = 4), the 15-minute baseline was collected in a separate fourth session, while for some others, this extended baseline was introduced at the beginning of the second (n=2) or third session (n=4) instead of the first.

Each session, including the first session after completing the 15-minute period and two additional tasks, started with a 5-minute baseline period, during which participants were instructed to remain still without any video projection or task. Immediately afterwards, they were asked to complete the first questionnaire (≈2 minutes). Afterwards, participants began the office-like tasks they had selected, while being exposed to an audio-visual projection. In each experimental session, participants were exposed in random order to two projections, each corresponding to one of the two types (literal or abstract) of the same landscape content. Each projection lasted 16 minutes, during which the designated visual stimulus was presented in full-screen mode. Twelve minutes after the beginning of each projection, an auditory signal prompted participants to respond to the paper questionnaire, which they usually continued until the end of the projection. In cases where additional time was required, the experimenter paused the projection at the masking video until the participant completed the questionnaire. This procedure was repeated with the second projection type for the same landscape content. Recording of physiological data was stopped after the second projection.

To control for potential order effects, the presentation sequence of imagery type was randomized within an experimental session, and the presentation sequence of landscape content type was randomized across sessions for each participant. In total, 39 experimental sessions were conducted with 13 participants.

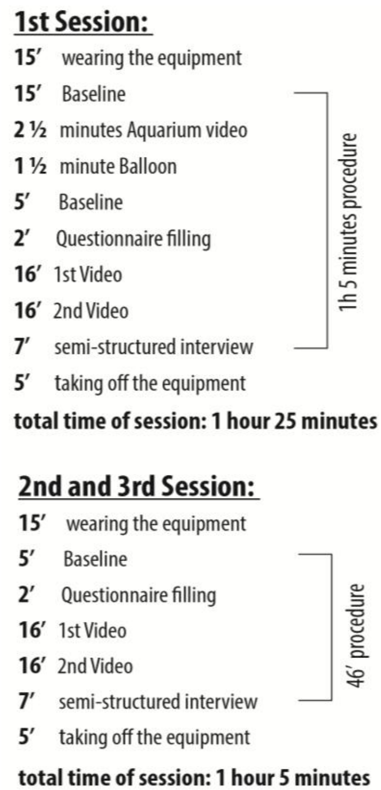

Fig. 7. Overview of experimental session procedure.

2.6. Statistical analysis

Statistical analyses using Linear Mixed Models (LMM) were conducted to examine the effect of stimulus *Type*, *Content*, and the interaction between *Type* and *Content* on the differences between the participants' responses at the baseline of each experimental session and those after exposure to the projection on ratings of happiness, excitement, relaxation, mood, and feeling energized, denoted with Δ (e.g., ΔHappiness). In addition, we examined the effect of stimulus *Type, Content*, and their interaction on the participants' reported ease of focus and motivation after exposure to the projections. For each LMM, *Type, Content*, and their interaction was specified as a fixed effect, and the unique participant ID was specified as a random intercept to account for the repeated responses. Assumptions for the LMM tests were respected, with the exception of residual normality for certain variables, where skewness was within normality thresholds (<1) but residuals were moderately kurtotic (excited: 6.85; relaxed: 7.05, mood: 2.99, energized: 4.64). Given the robustness of LMM to violations of distribution assumptions for the model residuals [56], we proceed with the use of LMM, but nevertheless outcomes for these variables are suggested to be interpreted with caution.

Lastly, the potential confounding effects of experimental session and stimulus order presentation were examined by adding these variables as covariates in the final LMM models. Analyses were conducted in R (4.4.2) using R studio, with the packages *lmerTest*, and *car*. Post-hoc pairwise contrasts were conducted for significant main effects using the package *emmeans* and Šidák correction. Analyses were conducted at the .05 significance level, and effect sizes are interpreted following the thresholds suggested by Ferguson [57].

3. Results

A significant interaction between *Type* and *Content* was found for ratings of liking ($F(2, 60.25) = 6.34$, $p = .003$, $\eta_p = .17$). No significant interactions between *Type* and *Content* were found for the remaining studied variables (all *ps* > .25), and thus they were removed from subsequent analyses from the corresponding models.

The results of the LMM analysis, presented in Table 2, showed that *Content* influenced the difference from baseline ratings in how energized participants felt (ΔEnergized), how easy it was for them to focus during the session, and how motivated they were in their tasks, with a small-to-moderate effect. Post-hoc pairwise comparisons showed that this result was driven by significant differences between the icescape and urban content in both cases.

Table 3. Results of the LMM analysis for the factors of stimulus *Content* and *Type* for all target variables. Significant outcomes are highlighted in bold.

Variable	Predictor	*df*	*F*	*p*	η_p
ΔHappy	Content	2, 60.25	2.31	0.11	0.07
	Type	1, 60.12	0.11	0.74	<0.001
ΔExcited	Content	2, 62.00	1.05	0.35	0.03
	Type	1, 62.75	0.23	0.63	<0.001
ΔRelaxed	Content	2, 62.00	0.53	0.59	0.02
	Type	1, 62.90	0.31	0.58	<0.001
ΔMood	Content	2, 62.00	0.51	0.60	0.02
	Type	1, 62.25	0.04	0.84	<0.001
ΔEnergized	**Content**	**2, 62.00**	**3.57**	**0.03**	**0.10**
	Type	1, 62.84	0.08	0.78	<0.001
Preference*	Content	2, 60.11	1.76	0.18	0.29
	Type	**1, 60.00**	**10.49**	**0.002**	**0.15**
Easy focus	**Content**	**2, 62.00**	**5.31**	**0.007**	**0.15**
	Type	1, 62.33	0.30	0.59	<0.001
Motivated	**Content**	**2, 57.41**	**6.42**	**0.003**	**0.18**
	Type	1, 57.06	0.09	0.77	<0.001

*Significant interaction: Content*Type (p=0.003), see text.

Table 2. Marginal and conditional R^2 values for each LMM model.

Variable	$R^2_{marginal}$	$R^2_{conditional}$
$\Delta Happy_{diff}$	0.03	0.56
$\Delta Excited_{diff}$	0.03	0.08
$\Delta Relaxed_{diff}$	0.02	0.03
$\Delta Mood_{diff}$	0.01	0.33
$\Delta Energized_{diff}$	0.08	0.11
Preference	0.25	0.50
Easy focus	0.10	0.32
Motivated	0.08	0.55

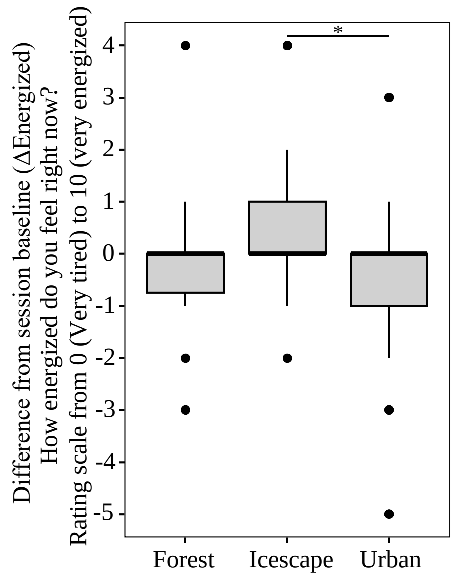

Fig. 8. Boxplots showing the distribution of differences from baseline in ratings of feeling energized after exposure to the projection (ΔEnergized), grouped by Content. Significance levels: * = p < .05.

Exposure to the urban content, compared to the icescape, led to an average 10.5% decrease in our 11-point scale in how energized the participants felt after viewing the projection compared to the baseline ($B = 1.16$, $SE = 0.43$, $t = 2.67$, $p = 0.03$; all other *ps* > 0.4). Similarly, exposure to the icescape compared to the urban content led to an average 14.8% increase in our 11-point scale in the ratings of how easy it was for participants to focus ($B = 1.63$, $SE = 0.53$, $t = 3.096$, $p = 0.009$; all other *ps* > 0.05). Interestingly, the difference between the icescape and forest content approached significance ($B = 1.28$, $SE = 0.53$, $t = 2.44$, $p = 0.052$), with the icescape content being rated higher on average in how easy it was to focus, but did not meet our significance threshold. Regarding motivation, results showed an average 16.9% increase in how motivated they reported feeling ($B = 1.86$, $SE = 0.54$, $t = 3.45$, $p = 0.003$; all other *ps* > 0.05) after viewing the icescape compared to the urban setting. Moreover, viewing the icescape was more motivating than viewing the forest content (B = 1.41, SE = 0.54, t = 2.64, p = 0.03), with an average 12.8% increase in our 11-point rating scale. Figures 8-9 illustrate these effects of *Content.* No significant effects of *Content* were found for the remaining attributes (all other *ps* > .11).

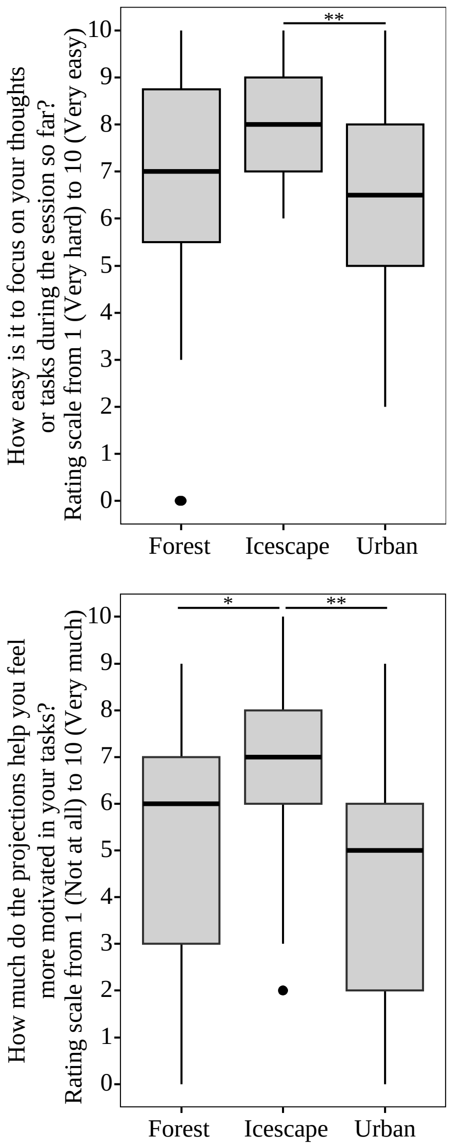

Fig. 9. Boxplots showing the distribution of ratings of how easy it was to focus (top) and how motivated participants felt (bottom) after exposure to the projection, grouped by Content. Significance levels: * = p < .05, ** = p < .001.

Regarding *Type*, a significant effect with a very small effect size was found for preference, with a higher liking ratings for literal (EMM = 5.92, SE = 0.44, 95% CI [4.57, 6.42]) compared to abstract visualisations (EMM = 5.50, SE = 0.44, 95% CI [4.99, 6.85]). No significant effect of *Type* was found for any of the remaining attributes (all *ps* > .58). Following the aforementioned significant interaction between *Content* and *Type* for liking, post-hoc pairwise comparisons were conducted separately for each *Type* of stimuli. Results showed that for abstract visualisations, landscape content had no significant influence on preference ratings for any of the stimulus pairs (all *ps* > .19). On the other hand, as shown in Figure 10, for literal visualisations, both the forest (B = 3.92, SE = 0.69, t = 5.7, p < .0001) and the icescape (B = 2.77, SE = 0.70, t = 3.9, p < .001) were more liked than the urban landscape, while no significant differences were found between them (p = .28).

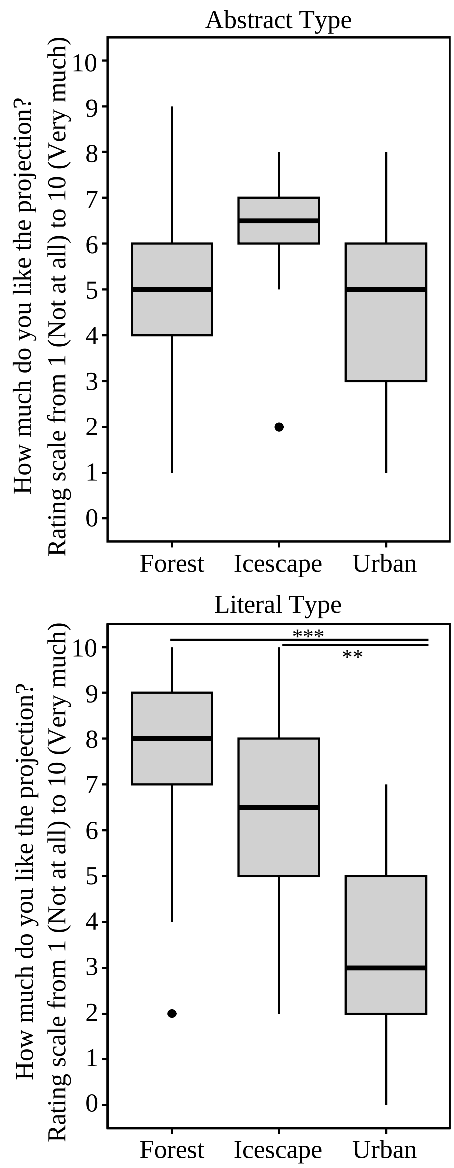

Fig. 10. Boxplots showing the distribution of liking ratings after exposure to the projection for the abstract and literal imagery *Type*, grouped by *Content*. Significance levels: ** = p < .001.

Marginal R^2 values (Table 3) show that, as expected from the outcomes of the statistical analysis, the variance explained by the fixed factors was below the thresholds for "practically" significant effect [57] for ΔHappiness, ΔExcited, ΔRelaxed, and ΔMood. A small proportion of the variance was explained through the fixed factors through the models for ΔEnergized, ease of focus, and motivation, and a moderate amount of variance was explained for the model of preference. Adding the random effects improved the proportion of explained marginal R^2 values for some, but not all models, indicating that factors beyond individual differences or the displayed projections might explain participant responses.

Lastly, additional analyses with the session number and order of stimuli as fixed factors showed no significant effect of either on participant responses (for ΔMood, p = .08 for session number, and p = .09 for order of stimuli; all other *ps* > .22 for session number and >.10 for order of stimuli) and thus do not influence the aforementioned findings.

4. Discussion

4.1 Overview of Main Findings

This study examined, to our knowledge for the first time, the influence of landscape content and imagery type in audiovisual projections on reported preferences, emotional responses, ease of focus, and motivation for staff working at an Antarctic base.

Familiarity emerged as a key factor in shaping participants' preferences for the projections. Specifically, liking ratings were higher for the literal than the abstract stimuli, although with a small difference in responses. Even though the abstract stimulus versions preserved the core audiovisual properties (average color, average luma, audio track) as the literal ones, liking ratings were lower for the AI-generated abstract visualisations. Notably, insights from the semi-structured interview after the experiment showed that most participants did not recognize that the abstract stimuli originated from the literal versions: only two out of thirteen participants identified the shared source of the videos.

At the same time, both the questionnaire analysis and preliminary outcomes from the semi-structured interviews revealed a strong preference for the forest projection, with many participants associating it with their home country of Bulgaria. Qualitative data showed that this projection evoked a sense of familiarity and elicited positive emotional responses linked to memory and place attachment. These findings are also in alignment with previous research relating familiarity with preference for natural scenes and showing that more common scenes for the viewer (such as a forest) were more preferred than uncommon scenes (such as polar landscapes) [58]. The higher preference for forest compared to ice landscapes was also confirmed in our sample, although our participants were more familiar with arctic landscapes than the average population, having spent at least one week (N=13) or two months (N=7) at the Antarctic station.

The study aimed to contrast natural settings of varying familiarity with human-made and familiar environments, with the latter represented by an urban landscape (the city of Sofia, where participants reside when away from Antarctica). Findings revealed that for the literal stimuli, participants expressed significantly lower liking for the urban condition, an outcome which agrees with previous research [58]. This result suggests that even though the urban environment was familiar, it did not elicit the same positive responses as natural settings, showing that not only familiarity, but also environmental content influence environmental preference.

In addition, the findings indicate that exposure to the Antarctic icescape had an invigorating effect, leading to higher ratings in how energized and motivated participants felt, as well as how easily they could focus compared to the urban landscape. This finding aligns with previous evidence that viewing nature exposure enhances subjective vitality compared to urban scenes [59], and shows promising effects for productivity in ICE environments. However, it is notable that in the present work, these significant increases compared to the urban landscape were found for exposure to the icescape, rather than the forest landscape. Moreover, the icescape was rated as more motivating than the forest landscape. A potential explanation for this finding is the content of the visualisations. For example, the icescape visualisations were brighter and less enclosed than the forest landscape: these visual characteristics have been related to higher energetic arousal in indoor environments [60]. The depiction of a cold, rather than warm, landscape, could also be influential, as viewing landscapes associated with cold compared to warm temperature has been found to improve cognitive control [61]. Lastly, in this context, the icescape was uniquely also the participants' work environment, which might have contributed further to associations with energy, motivation, or focus.

Analysis of the differences between the baseline measures at the beginning of an experimental session and those after exposure to the projections showed significant effects of the experimental factors only for ratings of how energized the participants felt, and not for reported happiness, mood, excitement, or relaxation. A potential explanation for this finding is the relatively high ratings at baseline for all variables except excitement (happiness: M = 7.29, SD = 1.37; relaxed: M = 7.62, SD = 2.21; mood: M =7.94, SD = 1.43, energized: M = 6.15, SD = 2.53, excited: M = 3.97, SD = 2.48). These high ratings might have introduced a ceiling effect, leaving little or no room for further improvements from the audiovisual intervention. These ratings also show that the experimental process seemed to have a positive effect on the participants. From their responses to the semi-structured interview, participants seemed to associate the time spent in the experiment with relaxation and uninterrupted time to themselves. While very much appreciated, this reaction also meant that the expected negative effects of ICE environments were not identified in our present study, possibly because of the novelty of the experimental manipulation. On the other hand, these effects are also promising for further research and application of audiovisual projections, as they indicate that participants were positive towards the projections. In the same vein, it should be noted that the base crew used the location of the experiment as an area to hang out and relax with fellow crew members.

4.2 Limitations and Future Research

The study's sample size was limited (n = 13) due to logistical constraints of conducting research in Antarctica, in a base with a total population of 33 people. Furthermore, participants were drawn from a highly specific group—mostly staff of the Antarctic base experienced in the Antarctic environment —who may possess greater resilience and adaptability to ICE environments compared to the general population. In addition, the participants formed a close-knit community, which raises the possibility that discussions among them about the experiment and questionnaires could have introduced bias into several aspects of the study. These limitations should be taken into account when interpreting the results.

Moreover, differences in participants' prior Antarctic experience may have shaped their responses: while some were long-term base staff, others were visiting for the first time. Further research in this domain is encouraged to aim for a more homogeneous sample in participants' previous experience with the target ICE environment. Another intriguing research direction regards examining further one's familiarity with the Arctic environment. A subsequent step in the research will be to replicate the experiment, following the same procedure, this time with participants in an urban setting who have never visited or had any prior exposure to Antarctica. This control group will enable us to determine whether responses to the stimuli differ from those of the Antarctic sample, with particular interest in the reactions to the Antarctic landscape condition.

One limitation of the study was the language barrier between some of the Bulgarian participants and the principal researcher, who primarily spoke English with limited capacity in Bulgarian. To minimize potential miscommunication and misunderstanding, the questionnaires were translated into Bulgarian by a certified translator, ensuring greater accuracy and clarity in participants' responses. However, certain study materials, like the aptitude tests, could not be translated, which may have influenced the depth of participants' engagement for these particular tasks. Nevertheless, the office-like tasks themselves are not examined in this study, and were used to ensure uniformity in the conducted tasks during exposure to the projections.

Another notable factor was noise and disturbances during the experimental conditions. The container where the experiment was conducted was in close proximity to the loading and unloading area where the fork lift machinery was used to move goods and equipment. As a result, the container was occasionally subject to vibrations from the handling of heavy objects, as well as noise from the surrounding activities (were observed in 41% of sessions), which may have affected the experimental conditions and participants' ability to maintain focus during the sessions.

Lastly, a crucial next step involves the systematic analysis of the physiological data collected during the experiment. To this end, future work will examine physiological markers such as heart rate variability and EEG activity, with the aim to compare subjective and objective responses to strengthen the validity of findings and help identify reliable indicators of psychological well-being in extreme environments.

Looking ahead, AI-driven, on-device media pipelines can be a promising complement for ICE habitats. Open-source diffusion models (e.g., Stable Diffusion) and procedural systems can run locally to synthesize or adapt content in real time, eliminating internet reliance and reducing the need to ship large fixed libraries. In our study, the AI-generated, abstract scenes were found to be less liked than the literal counterparts. As a result, further work on procedural systems should be configured to favor recognizable, high-fidelity literal content and subtle transformations, while varying parameters to sustain interest without overshooting novelty. A future direction we envision is a closed-loop, on-device media pipeline that adapts audiovisual (and optional olfactory/kinetic) stimuli using self-reports and biosignals (HRV/EEG). This pathway builds on our prior biodata-driven, generative work in immersive environments [62,63] and will be tested in controlled analog and operational settings with pre-registered subjective and physiological endpoints. This direction is consistent with existing work showing that integrated biofeedback–neurofeedback interventions can modulate stress and engagement and are suitable for real-time personalization [64], and with wearable, edge-deployable EEG biofeedback systems that demonstrate feasibility for continuous monitoring and adaptation [65]. Such an integrated AV-olfactory stack is maintainable, privacy-preserving (edge processing), and updatable over time, rendering it very promising for applications in ICE environments.

5. Conclusions

This study examined the influence of audiovisual projections with varying landscape content (forest, icescape, urban) and imagery type (literal, abstract) as a means to improve the reported emotions, mood, and concentration of staff members in an Antarctic base, as part of a broader study that examines the potential of such projections to improve conditions in ICE environments.

Results show that familiarity played a central role in how much participants liked the projections, with the literal, human-recorded landscapes being more liked than abstract, AI-generated landscapes. Moreover, very few participants recognized these literal landscapes as the source of the AI-generated counterparts. Within the literal landscapes, forests were found to be more liked than icescapes, while both natural landscapes were more liked than urban ones, in alignment with the literature. Notably, in our study, all three literal landscape content types were familiar to participants, with the icescapes being less so, which could explain the aforementioned results. No significant effects were found for reported happiness, mood, relaxation, or excitement, which, for the first three variables, are likely due to high baseline ratings and thus a potential ceiling effect. Lastly, findings show that the icescape projection was beneficial for invigoration and reported concentration, being rated as more motivating and conducive to focus and leading to participants feeling more energized than at baseline, particularly compared to the urban landscape.

The outcomes of this work showcase the potential of targeted audiovisual projections to support psychological well-being and concentration, and encourage further work in this domain to research and develop audiovisual interventions for ICE environments.

CRediT authorship contribution statement

Christina Balomenaki: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Project administration, Data curation, Conceptualization. Kynthia Chamilothori: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. Klea Biniakou: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. Iason Paterakis: Writing – review & editing, Writing – original draft, Visualization, Software. Nefeli Manoudaki: Writing – review & editing, Writing – original draft, Visualization, Software. Konstantinos - Alketas Ougrinis: Writing – review & editing, Supervision, Methodology, Project administration, Funding acquisition, Data curation, Conceptualization.

Acknowledgements

This study could not have been carried out without the support and collaboration of a number of individuals and institutions, to whom we express our sincere appreciation. We are especially indebted to the Bulgarian Antarctic Institute, whose essential contribution—through hosting, coordination, expert advice, and logistical assistance—was fundamental to the successful realization of the experiment. The research was conducted within the framework of the 33rd Bulgarian Antarctic Expedition. We also wish to thank the Hellenic Polar Zones Society, the official body coordinating the Greek participation, for its consistent support throughout the process. Our gratitude further extends to Laskaridis Shipping Company Ltd, whose generous sponsorship and unwavering support made the implementation of this initiative possible. We are equally grateful to the Hellenic Ministry of Foreign Affairs, the Ministry of Development, the Environmental Committee of the Hellenic Parliament, and the Greek Embassy in Argentina for their valuable contribution to the advancement of this endeavor. We also acknowledge with appreciation Michalis Zervakis and Marios Antonakakis of the Display Lab, Technical University of Crete, for his collaboration and assistance in the selection of the equipment. We also would like to warmly thank Prof. Yvonne de Kort (HTI lab, Eindhoven University of Technology) for her support and contribution in the conceptualization of the study. Our special thanks go to Efcharis Gourounti, architect researcher at the Transformable Intelligent Environments Laboratory (TUC TIE Lab), for her invaluable assistance throughout all stages of the work. We further recognize the important contributions of the participants in the experiment, whose engagement and feedback were vital for the development of the study. Finally, we warmly thank Rosen Stefanov and Kamen Nedkov for their dedicated involvement in organizing the experiment from the outset and for their technical support during all phases of the research.

References

[1] Balomenaki, C., Chrysochoou, I., Tsilia, A., Biniakou, K., & Oungrinis, K.-A. (2024, January). Proposition for Modular Space Habitat. In Proceedings of the 35th IAA Symposium on Space and Society, 75th International Astronautical Congress (IAC 2024), Milan, Italy. https://doi.org/10.52202/078382-0062

[2] Sandal, G. M., Leon, G. R., & Palinkas, L. (2006). Human challenges in polar and space environments. Reviews in Environmental Science and Biotechnology, 5(2–3), 281–296. https://doi.org/10.1007/S11157-006-9000-8/FIGURES/1

[3] Palinkas, L. A. (2001). PSYCHOSOCIAL ISSUES IN LONG-TERM SPACE FLIGHT: OVERVIEW. In Gravitational and Space Biology Bulletin (Vol. 14, Issue 2).

[4] Riva, P., Rusconi, P., Pancani, L., & Chterev, K. (2022). Social isolation in space: An investigation of

LUNARK, the first human mission in an Arctic Moon analog habitat. Acta Astronautica, 195, 215–225. https://doi.org/10.1016/j.actaastro.2022.03.007

[5] Tortello, C., Agostino, P. v., Folgueira, A., Barbarito, M., Cuiuli, J. M., Coll, M., Golombek, D. A., Plano, S. A., & Vigo, D. E. (2020). Subjective time estimation in Antarctica: The impact of extreme environments and isolation on a time production task. Neuroscience Letters, 725. https://doi.org/10.1016/j.neulet.2020.134893

[6] Nicolas, M., Bishop, S. L., Weiss, K., & Gaudino, M. (2016). Social, occupational, and cultural adaptation during a 12-month wintering in Antarctica. Aerospace Medicine and Human Performance, 87(9), 781–789. https://doi.org/10.3357/AMHP.4395.2016

[7] Sandal, G. M., van de Vijver, F. J. R., & Smith, N. (2018). Psychological hibernation in antarctica. Frontiers in Psychology, 9(NOV). https://doi.org/10.3389/fpsyg.2018.02235

[8] Palinkas, L. A. (2003). The Psychology of Isolated and Confined Environments: Understanding Human Behavior in Antarctica. American Psychologist, 58(5), 353–363. https://doi.org/10.1037/0003-066X.58.5.353

[9] Berto, R. (2014). The role of nature in coping with psycho-physiological stress: a literature review on restorativeness. Behavioral sciences, 4(4), 394-409.

[10] Hartig, T., Mitchell, R., De Vries, S., & Frumkin, H. (2014). Nature and health. Annual review of public health, 35(1), 207-228.

[11] Ohly, H., White, M. P., Wheeler, B. W., Bethel, A., Ukoumunne, O. C., Nikolaou, V., & Garside, R. (2016). Attention Restoration Theory: A systematic review of the attention restoration potential of exposure to natural environments. Journal of Toxicology and Environmental Health, Part B, 19(7), 305-343.

[12] Wilson, E. O. (1984). Biophilia. Cambridge, MA: Harvard University Press. (2003 reprint).

[13] Ulrich, R. S., Simonst, R. F., Lositot, B. D., Fioritot, E., Milest, M. A., & Zelsont, M. (1991). STRESS RECOVERY DURING EXPOSURE TO NATURAL AND URBAN ENVIRONMENTS 1. In Journal of Environmental Psychology (Vol. 11).

[14] Kaplan, S. (1995). THE RESTORATIVE BENEFITS OF NATURE: TOWARD AN INTEGRATIVE FRAMEWORK. In Journal o/Enuinm,mfol Ps>clmlog~ (Vol. 16).

[15] Kaplan, R., & Kaplan, S. (1989). The experience of nature: A psychological perspective. Cambridge University Press. https://psycnet.apa.org/record/1989-98477-000

[16] Britton, E., Kindermann, G., Domegan, C., & Carlin, C. (2020). Blue care: A systematic review of blue space interventions for health and wellbeing. Health promotion international, 35(1), 50-69.

[17] Madan, Ö. K., Chamilothori, K., van Duijnhoven, J., Aarts, M. P., & de Kort, Y. A. (2024). Restorative effects of daylight in indoor environments–A systematic literature review. Journal of Environmental Psychology, 97, 102323.

[18] Tang, I. C., Tsai, Y. P., Lin, Y. J., Chen, J. H., Hsieh, C. H., Hung, S. H., ... & Chang, C. Y. (2017). Using functional Magnetic Resonance Imaging (fMRI) to analyze brain region activity when viewing landscapes. Landscape and Urban Planning, 162, 137-144

[19] Joye, Y. (2007). Architectural lessons from environmental psychology: The case of biophilic architecture. Review of general psychology, 11(4), 305-328.

[20] Mandelbrot, & B., B. (1983). The fractal geometry of nature. W.H. Freeman and Co. https://ui.adsabs.harvard.edu/abs/1983

[21] Taylor, R. P., & Spehar, B. (2016). Fractal fluency: an intimate relationship between the brain and processing of fractal stimuli. In The fractal geometry of the brain (pp. 485-496). New York, NY: Springer New York.

[22] Smith, J., Rowland, C., Moslehi, S., Taylor, R., Lesjak, A., Lesjak, M., ... & Himes, J. (2020). Relaxing floors: Fractal fluency in the built environment. Nonlinear dynamics, psychology, and life sciences, 24(1), 127-141.

[23] Chamilothori, K., Wienold, J., Moscoso, C., Matusiak, B., & Andersen, M. (2022). Subjective and physiological responses towards daylit spaces with contemporary façade patterns in virtual reality: Influence of sky type, space function, and latitude. Journal of Environmental Psychology, 82, 101839.

[24] Abboushi, B., Elzeyadi, I., Taylor, R., & Sereno, M. (2019). Fractals in architecture: The visual interest, preference, and mood response to projected fractal light patterns in interior spaces. Journal of Environmental Psychology, 61, 57-70.

[25] Smalley, A. J., White, M. P., Sandiford, R., Desai, N., Watson, C., Smalley, N., Tuppen, J., Sakka, L., & Fleming, L. E. (2023). Soundscapes, music, and memories: Exploring the factors that influence emotional responses to virtual nature content. Journal of Environmental Psychology, 89. https://doi.org/10.1016/j.jenvp.2023.102060

[26] Menatti, L., Subiza-Pérez, M., Villalpando-Flores, A., Vozmediano, L., & San Juan, C. (2019). Place attachment and identification as predictors of expected landscape restorativeness. Journal of Environmental Psychology, 63, 36-43.

[27] Botella, C., Baños, R. M., Etchemendy, E., García-Palacios, A., & Alcañiz, M. (2016). Psychological countermeasures in manned space missions:“EARTH” system for the Mars-500 project. Computers in Human Behavior, 55, 898-908.

[28] Anderson, A., Stankovic, A., Cowan, D., Fellows, A., & Buckey Jr, J. (2023). Natural scene virtual reality as a behavioral health countermeasure in isolated, confined, and extreme environments: Three isolated, confined, extreme analog case studies. Human Factors, 65(6), 1266-1278.

[29] Lyons, K. D., Slaughenhaupt, R. M., Mupparaju, S. H., Lim, J. S., Anderson, A. A., Stankovic, A. S., ... & Buckey, J. C. (2020). Autonomous psychological support for isolation and confinement. Aerospace Medicine and Human Performance, 91(11), 876-885.

[30] Basu, T., Bannova, O., & Camba, J. D. (2021). Mixed reality architecture in space habitats. Acta Astronautica, 178, 548–555. https://doi.org/10.1016/j.actaastro.2020.09.036

[31] Chang, E., Billinghurst, M., & Yoo, B. (2023). Brain activity during cybersickness: a scoping review. Virtual Reality, 27(3), 2073–2097. https://doi.org/10.1007/s10055-023-00795-y

[32] Bannova, O., Camba, J. D., & Bishop, S. (2019). Projection-based visualization technology and its design implications in space habitats. Acta Astronautica, 160, 310–316. https://doi.org/10.1016/j.actaastro.2019.04.053

[33] He, X., & Jiang, A. (2023, July). A 7-day space habitat simulated task: using a projection-based natural environment to improve psychological health in short-term isolation confinement. In International Conference on Human-Computer Interaction (pp. 399-414). Cham: Springer Nature Switzerland.

[34] Manovich, L., & Arielli, E. (2025). Artificial aesthetics: Generative AI, art and visual media. Retrieved September 11, 2025, from https://manovich.net/index.php/projects/artificial-aesthetics

[35] Bunzeck, N., & Düzel, E. (2006). Absolute coding of stimulus novelty in the human substantia nigra/VTA. Neuron, 51(3), 369–379. https://doi.org/10.1016/j.neuron.2006.06.021

[36] Itti, L., & Baldi, P. F. (2009). Bayesian surprise attracts human attention. Vision Research, 49(10), 1295–1306. https://doi.org/10.1016/j.visres.2008.09.007

[37] Taylor, R. P., Spehar, B., Van Donkelaar, P., & Hagerhall, C. M. (2011). Perceptual and physiological responses to Jackson Pollock's fractals. Frontiers in Human Neuroscience, 5, 60. https://doi.org/10.3389/fnhum.2011.00060

[38] Hagerhall, C. M., Laike, T., Küller, M., Marcheschi, E., Boydston, C., & Taylor, R. P. (2015). Human physiological benefits of viewing nature: EEG responses to exact and statistical fractal patterns. Nonlinear Dynamics, Psychology, and Life Sciences, 19(1), 1–12.

[39] Rombach, R., Blattmann, A., Lorenz, D., Esser, P., & Ommer, B. (2022). High-Resolution Image Synthesis with Latent Diffusion Models. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR) (pp.10684–10695). https://doi.org/10.1109/CVPR52688.2022.01042

[40] Hu, E. J., Shen, Y., Wallis, P., Allen-Zhu, Z., Li, Y., Wang, S., Wang, L., & Chen, W. (2022). LoRA: Low-Rank Adaptation of Large Language Models. In International Conference on Learning Representation (ICLR). https://arxiv.org/abs/2106.09685

[41] Kodaira, A., Xu, C., Hazama, T., Yoshimoto, T., Ohno, K., Mitsuhori, S., Sugano, S., Cho, H., Liu, Z., & Keutzer, K. (2023). StreamDiffusion: A pipeline-level solution for real-time interactive generation. arXiv preprint arXiv:2312.12491. https://arxiv.org/abs/2312.12491

[42] Hosale, M.-D., Macy, A., Jochum, E. A., & Overholt, D. (2024). BEAM Workshop: Biophysical Expression, Affect & Movement. In Proceedings of the 9th International Conference on Movement and Computing (MOCO '24). ACM. https://doi.org/10.1145/3658852.3661318

[43] Allen, J. J. B., Urry, H. L., Hitt, S. K., & Coan, J. A. (2004). The stability of resting frontal electroencephalographic asymmetry in depression. Psychophysiology, 41(2), 269–280. https://doi.org/10.1111/j.1469-8986.2003.00149.x

[44] Thibodeau, R., Jorgensen, R. S., & Kim, S. (2006). Depression, anxiety, and resting frontal EEG asymmetry: A meta-analytic review. In Journal of Abnormal Psychology (Vol. 115, Issue 4, pp. 715–729). American Psychological Association Inc. https://doi.org/10.1037/0021-843X.115.4.715

[45] Luck, S. J. (2014). An Introduction to the Event-Related Potential Technique (2nd ed.). Cambridge, MA: MIT Press.

[46] Oishi S, Kurtz JL, Miao FF, Park J, Whitchurch E. The role of familiarity in daily well-being: developmental and cultural variation. Dev Psychol. 2011 Nov;47(6):1750-6. doi: 10.1037/a0025305. Epub 2011 Aug 29. PMID: 21875185.

[47] Paunchev P., 4K Forest Birdsong 2 - Birds Sing in the Woods - No Loop Realtime Birdsong - Relaxing Nature Video, 25 September 2017, https://www.youtube.com/watch?v=XxP8kxUn5bc&ab_channel=TheSilentWatcher (Accessed 11.12.2024). https://www.youtube.com/@TheSilentWatcher

[48] Vakhnovsky S., SOUND OF ANTARCTICA. ASMR. 1 HOUR FOR SLEEP & RELAX, 12 February 2022, https://www.youtube.com/watch?v=M77jws5Lv3w&ab_channel=SergeyVakhnovsky (Accessed 11.12.2024). https://www.youtube.com/@vakhnovsky

[49] Bradley, M. M., & Lang, P. J. (1994). MEASURING EMOTION: THE SELF-ASSESSMENT MANIKIN AND THE SEMANTIC DIFFERENTIAL. In I. B&w Thu. & Exp. Psvchrar (Vol. 25, Issue I).

[50] Wu, H., & Leung, S. O. (2017). Can Likert scales be treated as interval scales?—A simulation study. Journal of social service research, 43(4), 527-532.

[51] Joshi, A., Kale, S., Chandel, S., & Pal, D. (2015). Likert Scale: Explored and Explained. British Journal of Applied Science & Technology, 7(4), 396–403. https://doi.org/10.9734/bjast/2015/14975

[52]PracticeReasoningTests, https://www.practicereasoningtests.com (Accessed 19.12.2024).

[53] Piferi, R. L., Kline, K. A., Younger, J., & Lawler, K. A. (2000). An alternative approach for achieving cardiovascular baseline: Viewing an aquarium. International Journal of Psychophysiology, 37(2), 207–217. https://doi.org/10.1016/S0167-8760(00)00102-4

[54] Lykken, D. T., & Venables, P. H. (1971). Direct measurement of skin conductance: A proposal for standardization. Psychophysiology, 8(5), 656–672. https://doi.org/10.1111/j.1469-8986.1971.tb00501.x

[55] Bacon-Macé, N., Macé, M. J. M., Fabre-Thorpe, M., & Thorpe, S. J. (2005). The time course of visual processing: Backward masking and natural scene categorisation. Vision research, 45(11), 1459-1469.

[56] Schielzeth, H., Dingemanse, N. J., Nakagawa, S., Westneat, D. F., Allegue, H., Teplitsky, C., ... & Araya‐Ajoy, Y. G. (2020). Robustness of linear mixed‐effects models to violations of distributional assumptions. Methods in ecology and evolution, 11(9), 1141-1152.

[57] Ferguson, C. J. (2009). An effect size primer: a guide for clinicians and researchers. Professional psychology: Research and practice, 40(5), 532.

[58] Peron, E., Berto, R., & Purcell, T. (2002). Restorativeness, preference and the perceived naturalness of places. Medio Ambiente y Comportamiento Humano, 3(1), 19-34.

[59] Ryan, R. M., Weinstein, N., Bernstein, J., Brown, K. W., Mistretta, L., & Gagné, M. (2010). Vitalizing effects of being outdoors and in nature. Journal of environmental psychology, 30(2), 159-168.

[60] Deniz, F. C., Chamilothori, K., Schoenmakers, S., & de Kort, Y. (2025). Do (not) enter? Objective visual features of indoor scenes predict approach-avoidance responses and core affect. Journal of Environmental Psychology, 102686.

[61] Halali, E., Meiran, N., & Shalev, I. (2017). Keep it cool: temperature priming effect on cognitive control. Psychological research, 81(2), 343-354.

[62] Paterakis, I., Manoudaki, N., & colleagues. (2025). Osmosis: Generative AI and XR for the real-time transformation of urban architectural environments. International Journal of Architectural Computing. Advance online publication. https://doi.org/10.1177/14780771251356526

[63] Manoudaki, N., Paterakis, I., Flatley, D., & Novak, M. (2025). Digital morphogenesis and bioaffective data: A computational framework for multisensory design ("Hydnum"). International Journal of Architectural Computing. Advance online publication. https://doi.org/10.1177/14780771251356527

[64] Tosti, B., Corrado, S., Mancone, S., Di Libero, T., Rodio, A., Andrade, A., & Diotaiuti, P. (2024). Integrated use of biofeedback and neurofeedback techniques in treating pathological conditions and improving performance: A narrative review. Frontiers in Neuroscience, 18, 1358481. https://doi.org/10.3389/fnins.2024.1358481

[65] Kosmyna, N., & Maes, P. (2019). AttentivU: An EEG-based closed-loop biofeedback system for real-time monitoring and improvement of engagement for personalized learning. Sensors, 19(23), 5200. https://doi.org/10.3390/s19235200