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DESIGN INTO EXTREMES: EXTENDED LEARNING

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ABSTRACT
Unprecedented climate emergencies are part of everyday conversations and experiences. As students seek how to design for these challenges, some design educators are providing learning grounded in what it means to live in extreme environments. As Space Architects, the authors design suitable living conditions and life support systems for unfamiliar, remote settings. The challenge is inaccessibility to end users, their latent needs, and real-time conditions. This case study describes a student team project to design/build a habitat (Canada) for a client (Europe) and a crew of analogue astronauts who would deploy and use the habitat during an *analogue mission in a lava tube (Iceland) (*situation created/selected for its similarities to space). Design studios support students to work through a process to meet the learning objectives. Project outcomes for the curriculum presented, are functioning full-scale prototypes. However, for this case study, the process was robust but not fully functional. Extreme contexts often lead to spectacular concepts, presented as 3D-modeled concepts that never reach a built state let alone usability testing and deployment in an extreme setting. The student team's technical concepts informed a final full-scale prototype that was deployed in a lava tube and inhabited by two crews of analogue astronauts. Post-mission reports conflicted on the habitability of the concept prototype. The co-author team of analogue astronaut, student/project lead, and design educator apply an Experience-Reflection-Action model to inform extended learning through end-user engagement, contextualized methods, and survivability versus habitability.

Keywords: Habitability, analogues, prototyping, extreme environments, user-centred, life support systems

1 INTRODUCTION
The term 'extreme' is becoming part of everyday conversations and experiences and design educators are increasingly integrating extreme contexts into studio projects to introduce students to methodologies and skills for critical survival responses to unprecedented weather events. To learn how to design practical solutions for locations affected by climate change is to provide support for communities and empower design students with agency for coping with climate change and the associated anxiety of uncertainty. Hickman and colleagues documented the global prevalence of climate anxiety in young adults and its impact on their daily function [1]. They identified 'constructive or practical' anxiety as an important rational form of anxiety and response to danger that can lead us to seek more information and work toward solutions and concluded that the practice of 'solutions' is a strategy to manage anxiety arising from uncertain situations. [ibid]

Author Rebecca Solnit defines an emergency as "*a separation from the familiar, a sudden emergence into a new atmosphere*" when she writes of disasters, survival, and hope [2]. How should we design for a 'sudden emergence' into *unfamiliar* environments and what skills and competencies are needed to design and build contextually appropriate solutions. Extreme weather events bring about harsh conditions, and the most challenging factor is their unpredictability and our unpreparedness to manage the situation. Here, analogous situations are offered as a way to prepare. Learning from experiences arising from exposures to similar conditions can enhance our understanding of and resilience to terrestrial extremes and help us generate solutions for climate adaptation [3].

Extreme environments are characterized by harsh environmental conditions, beyond the optimal range for human liveability, for example, pH 2 or 11, −50°C or 113°C, saturating salt concentrations, high radiation, 200 bars of pressure, among others. These are conditions inhospitable for life. Space is one of the most extreme environments. Space architects design for inaccessible contexts and work with *Analogue astronauts* who experience life-in-space by participating in missions set in remote environments (e.g., deserts, underwater, or the arctic), living as a crew in habitats, and wearing spacesuits when performing mission-relevant roles. Learning to live off-planet requires an understanding of how to prepare for environmental hazards through analogue missions and simulators. For example, the Self-deployable Habitat for Extreme Environments (SHEE) provides a platform to conduct research into human-space activities that are distinct from living on-planet [4], including psychosocial aspects of isolation and confinement, as well as the distinctly human aspects of surviving, operating and cohabiting in a high-risk environment with a diverse set of crewmates [5]. This approach is relevant on Earth for its focus on design for remote and extreme locales, thus the authors propose design education that prepares students for unprecedented environmental events with contextualised methods, and an understanding of end-user needs and habitability design criteria.

2 HABITAT DESIGN EDUCATION FOR EXTREMES

Learning about unfamiliar settings and unpredictable situations can expand our thinking and yield innovative results [6]. A prior paper shared a 5-year evaluation of a hybrid product design education model where students design for human activity in high-risk environments [7]. The program is collaborative, explorative, and technically demanding. The students are part of a third-year studio course in designing for unpredictable and dangerous contexts. They learn from experts who mitigate risks with specialty knowledgebases and technical skills. Working in teams, they self-project-manage their way to full scale, functional prototypes that are evaluated through design scenarios, expert feedback, and site-based test protocols, to meet the following course learning outcomes:

- *Confer with user groups and manufacturers in the development of design solutions*
- *Assess the essential user criteria through observations, meetings, role-playing, ethnographic studies*
- *Formulate design criteria necessary to generate and test concepts and prototypes*

In extreme environments, humans require technical products and personal protective equipment (PPE) to survive. This curriculum focuses on both short and long emergencies for user's needs. 'Short emergency' is aligned with survivability while 'long emergency' is aligned to the liveability of conditions. While Kunstler uses the latter term to describe the catastrophic impacts of the techno-industrial phase [8], the authors apply it to design adaptations for habitability. Within this curriculum, design development requires applying user-based research insights, user criteria, and user testing to achieve a concept that is feasible, buildable, and testable. This paper shares a case study emerging from the same curriculum, but with challenges of scale and inaccessibility of the locale and the latent end-users (analogue astronauts). The case study method was chosen to capture and share the distinct elements of this project and the co-authors, including their reflections, as guided by the Experience-Reflection-Action (ERA) cycle [9]. The project was grounded in project based learning and Problem-Based Learning (PBL); both are active methods aligning to the pedagogical concepts of learning-by-doing / learning-by-discovery [10].

3 CASE STUDY: ANALOGUE MISSION IN ICELAND 2021: EXPERIENCE

A client-generated brief was provided. Figure 1 shows the setting and specific access details for a habitat to be designed and prototyped as a concept for an analogue mission set in an Icelandic lava tube (Stefanshellir, August 2021). The client brief specified that: "*the habitat needs to provide shelter for three analog astronauts for the duration of the analog mission: this involved two nights inside the habitat. As we are targeting multiple back-to-back missions, the habitat should be robust enough to be used in at least two missions. Preferably, the structure can be re-deployed for future missions.*"

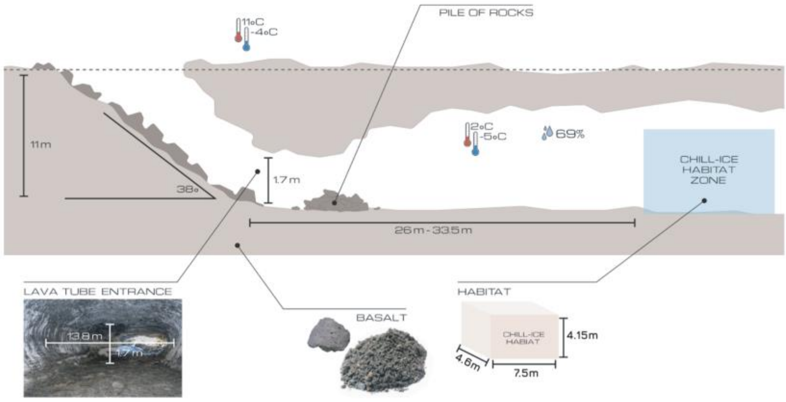

Figure 1. Stefanshellir lava tube access, geology and environment (Image Credit: B.van Rikxoort)

3.1 Design Requirements - Survivability versus Habitability

Design Educator's Experience: The "mission critical" requirement was for habitat set-up to require less than 8 hours, as that is the limit of the astronaut's portable oxygen supply. Other requirements to address include portability (load dimensions and weight) given the steepness of the terrain (Figure 1) and the need for the habitat to be freestanding within the basalt lava tube. Remaining criteria to address were the crew's use of the volume including: "*minimal living and working space for the crew of three, for which multiplexing of areas will be vital! The space will need to provide: a hygiene area: somewhat shielded from the rest of the interior, minimal work and communications area, sleeping area, EVA suit donning, and storage (EVA suits, instruments, utilities)*." The team-developed design hierarchy had eight criteria (Figure 2a);01-04 address survivability and 05-08 extended to habitability.

Figure 2. a) *Design Criteria Hierarchy and b) Design Validation process (Image Credit: B.van Rikxoort)*

Student/Project lead's Experience: With certainty for use at the core of this project combined with the fast-approaching deadline, our team was urged to deliberate what it means to design for survivability versus habitability. While additional design considerations were proposed - 'performance vs testing methods', 'availability vs cost', and 'leave no trace' ultimately, the client's specifications guided our design decisions when working through the design validation process (Figure 2b).

3.2 User testing:

In analogue missions, the function and safety of design solutions are evaluated and optimized by focusing on user-experience. The team focused on human factors (Figure 3) to support concept evaluation and development. Habitability design applies human-centred design principles at each step of the process. NASA's Habitability Design Centre stresses the importance of early prototyping and testing to save cost and to improve crew experience via 3D-modeling/prototyping mock-ups for hands-on evaluation by both their habitability design and their human factors teams [11].

HUMAN FACTORS	FREQUENCY	IMPORTANCE SAFETY, HEALTH, WELL-BEING	HIERARCHY SCORE (importance X frequency)	ESSENTIAL FOR MISSION SUCCESS	POTENTIAL FOR MITIGATION
HUMAN INTERACTIONS					
Isolation from the world	5	5	25	N	N
Time alone (being by yourself)	2	4	8	N	Y
Time with others	5	3	15	Y	Y
PRIVACY					
Changing/hygiene privacy	5	5	25	N	Y
Lack of privacy	5	3	15	N	Y
Bathroom privacy	5	5	25	N	Y
Sleeping privacy	3	2	6	N	Y
ENVIRONMENTAL INTERACTIONS					
Moving/walking space	4	4	16	N	Y
Access to natural light	2	2	4	N	Y
Breathing fresh air	1	5	5	N	N
Greenery	1	3	3	N	N
Airlock space for 2 people	5	5	25	Y	Y
Working/communal environment	4	3	12	N	Y
Temperature	4	5	20	N	Y

Figure 3. Human Factors criteria (Image Credit: B.van Rikxoort)

Student/Project lead's Experience: Using test protocols our simulations yielded insights for unpacking/packing the habitat from the transport bag, such as: ...difficult to grip with gloves, difficult to breathe (with mask on), heavy for user…putting the shell and floor into the bag was a struggle…5 min 10 seconds time to pack up (Criteria 01,02 and 06). In our final report, we stated that "User testing is focused on the users and how they understand and interact with the habitat. Looking at the human factors, we needed to determine; how all of the design considerations will be filtered for the end results, how the users will comprehend how the habitat will be put together, and how they will interact within it." [12] **Design Educator's Experience:** Design validation involved user testing, feedback and review of the design criteria against test results (Figure 2). This led to the teams' concept prototypes (Figure 4).

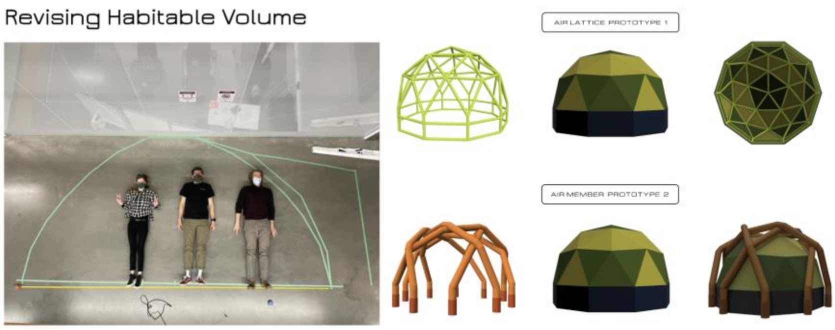

Figure 4. "FullAir' Habitat" concept development (volume, structural testing) (Image Credit: M.P. Alary)

The concepts referenced Buckminster Fuller's geodesic dome; a structural design proven to be suitable for habitability in extreme environments [13]. By week seven the team had built many sample constructions and two full-scale concept prototypes using innovative structural inflation strategies. Despite extensive prototyping, testing and revisions, neither concept was structurally testable as a habitat for the upcoming analog mission. The next section offers the co-authors (three-way) insights.

4 INSIGHTS: USER TESTING HABITATS IN EXTREMES: REFLECTIONS

The student's rigorous research and concepts informed the final construction of the full-scale concept prototype and supported documentation for the analogue crews on deployment/redeployment, care and maintenance of the habitat. The client independently documented the habitat project's contribution to research on analogues [14]. This paper sought the perspective of an Analogue astronaut:

Table 1: ***Analogue Astronaut's Experience/Reflection:*** *Daily Log Extracts, S.C. Crew Engineer*

01 / 06	DEPLOYMENT / REDEPLOYABLE
	"we had it up quite quick [within 4 hours] but once it was up we noticed a leak so this is something we need to monitor and repair. This is unexpected and will add to our tasks and workload.."
02 / 03	PORTABILITY / PACKABILITY
	"Walking up/down from the cave entrance was dangerous. I couldn't see the obstacles due to my helmet visor (limited visibility) and fog. We could only go one person at a time, and carrying heavy loads made it even more dangerous without the right safety measures."
04	FREESTANDING STRUCTURE
	"The structure was leaking on the first day (two tubes leaking) and we had shifts to keep it up. The poles help but aren't keeping the structure up. Night two: the structure collapsed at the airlock end and this meant more water entered the habitat and it affected the air flow inside"
05 / 07	HABITABLE SPACE / AIRLOCK
	"…the volume feels fine for the three of us, but more interior organization would be great. I kept my laptop dry and other items using drybags, but not everyone has these. With so much dampness (humidity and water on the floor) it's difficult to stay warm unless we're in our sleeping bags. My crewmembers are cold as their bags are not rated up to -10° C (the temperature at night was around 0 C). My sleeping bag was damaged in transport by the sharpness of the rocks... hygiene station/airlock has a bad odor - it's throughout the whole habitat because of the lack of airflow… there is no privacy and it would be good to have sound insulation too. We're a mixed gender team so the option of more privacy while getting in and out of our suits and for getting ready for sleep was lacking… we can't heat water because our electronics stopped working… repairing the leaks has affected our schedule and everyone is exhausted... two air structures failed so the habitat partially collapsed at the airlock end, which affected hygiene (that was a big problem)."
08	MATERIALS
	"...I can feel that the floor has layers but it still feels cold. It's so humid inside the habitat. I'm questioning the suitability of inflatables for a lava tube environment…the surrounding surfaces (mostly basalt) are extremely sharp."

Student/Project lead's Reflection: Reviewing the Analogue Astronaut's feedback (Table 1) led to many reflections, including these: *we overlooked the need for testing the habitat in a diverse range of temperatures, and underestimated how this can impact the success of each factor we designed; situating Team discussions in environments where comfort is reduced, (e.g. a confined space) may have helped to provide empathy into psychosocial challenges, and understanding where redundancy should be incorporated may have also been revealed to us in this setting.*
Design Educator's Reflection: This project yielded insights in user testing and test protocols for extreme, unfamiliar and remote contexts. When mapped onto the Team's Design Criteria (Figure 2) these insights include: repairability and replaceability are complex in extreme environments (01/06: Deployment/Redeployment); cultural beliefs impact habitability so there was a need to prioritize forms of privacy (05: Schedule of Use); and extending test scenarios didn't involve design for worst case scenarios and possibilities beyond the obvious. (05/07 Scenarios of Use)
Triangulated Reflections: Habitability design is a complex learning challenge. Collectively, the co-author team's insights focused on empathy, end-user criteria and scenario-based testing. Post-project, the faculty team also engaged in discussion and debate on how to [ethically] facilitate and integrate end-user testing for remote, unfamiliar and extreme contexts, and how to extend these insights into new learning approaches that can be evaluated in future project iterations?

5 DESIGNING EXTENDED EDUCATION THROUGH EXTREMES – ACTIONS

Time and experience have shown that revolutionary ideas come from extremes; extraordinary circumstances that will require design programs to expand how user testing is integrated into processes and projects. discussing the insights yielded the following three high level themes and suggested actions to extend design learning opportunities for unpredictable and dangerous contexts.

1. Technology for understanding context and end-user testing; the ethics and logistics of accessing extreme contexts preclude site visits but Virtual Reality (VR) can offer the experience of unfamiliar, dangerous contexts within ethical boundaries and is an emergent area of practice. [15] VR also allows for rapid and scalable 3D-modeling of true-to-size structures and immersion in the space, which can help in contextualizing design requirements prior to building.
2. Empathy and humanity are challenging mindsets to teach alongside technical content. Conversations are important to link studio project experiences to climate change thus having discussions of lived experiences is recommended over 'information dumps'. Environmental educators like Campbell advocate for a 'contemplative, existential perspective' to process anthropocentric emotions [16] which is relevant to designing for the 'long emergency'.
3. Analogues, end-user needs and habitability; Situational preparedness should prioritise exploration and prototyping prior to a climate emergency, since a 'sudden emergence' involves trying to adapt and design simultaneously. When designing analogues, students are trying to understand end-user needs without experiencing them directly, but seeking latent end-user needs, needs that are important yet not obvious or outwardly spoken by the average user, can address this gap [17].

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