Design for the Psychological Habitability of Spacecraft on Extended Exploratory Missions

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Abstract: Human performance will be a critical factor in future long duration exploration missions in space, for instance to Mars. In addition to physical risks in a hazardous environment, crew face social and sensory deprivation in a confined, isolated habitat. A key paradigm affecting the mission will be the crew's autonomy. How can the spacecraft itself support psychological wellbeing through meaningful design intervention?

This short paper summarises the first phase of a current study addressing the psychological issues in extended space missions through sensory design. Based on a review of key features in crew habitation found to be psychologically beneficial, it examines terrestrial design approaches that – applied to spacecraft – could yield new insights for the design of human-centred applications.

Key words: extended spaceflight, sensory design, psychological habitability, capsule habitation.

1. Introduction

Aside from involving physical risks prevalent in all space missions, remote exploratory missions such as to Mars add further psychological challenges and stressors. These are associated with social isolation and complete autonomy of the crew in its habitation vehicle. Depression, monotony and interpersonal tension have been identified during extended orbital missions [7, 13, 16], and respective countermeasures established. Some of these, such as convenient communication with Earth, visiting crew or re-supply of fresh food, will be severely restricted or unfeasible in a mission scenario involving a 3 year round-trip with long transfer phases. However, the role of design as countermeasure supporting psychological wellbeing is acknowledged widely [1, 2, 7, 9].

This paper summarises the first phase of an ongoing study addressing psychological issues in extended exploratory missions through design. Based on a review of psychologically beneficial features in space habitation design that appear particularly feasible in an autonomous vehicle, it examines four terrestrial design approaches that can offer new insights for human-centred applications in space.

2. Psychologically Beneficial Features in Crew Habitation Design

In order to establish the value of certain design provisions, a review was conducted of all civilian operational space stations to date (Salyut 1, 4, 6, 7; Skylab; MIR; Shuttle/ Spacehab; ISS), informed by anecdotal evidence from astronauts [20], selected science-fiction production designs including unpublished material of NASA

technical consultants (Stanley Kubrik Archive), and discussions with architects of recently designed Antarctic bases (Halley VI; iTasc; Queen Elizabeth). A methodology for an evidence collection of user experiences in space habitation was then prepared at the European Space Agency, including walk-throughs in mock-ups of the International Space Station, observation of astronaut training, and discussions with ground personnel and astronauts.

Several issues appeared to be of importance, such as dimensions of privacy and territoriality associated with the habitable volume, spatial configuration and composition; and individual preferences in environmental parameters (lighting, odour, colours). However, some features with potential to be addressed through site-specific intervention stood out particularly: (i) interaction with the capsule exterior (windows, cupolas, extra-vehicular activites, external walkways, observatories); (ii) inclusion of "living" elements (greenhouses, live stock or pets, images of natural scenes, natural building materials); (iii) means to facilitate social interaction and individual personalisation (colour coding of items or places, communal leisure areas, personal sleep quarters décor, flexible furniture); and (iv) a degree of variety and personal control in onboard food and leisure items (diversity in condiments to complement pre-selected basic meals, databases, archives, immersive applications).
The question emerged which terrestrial design approaches could be employed to re-design or integrate those features specifically with regards to psychological habitability across the entire habitation system.

3. Examination of Terrestrial Design Approaches

Historically, the main driver for spacecraft design was survivability [12]. When missions became longer in duration, considerable efforts were made to "humanise" space habitation [21]. In order to ensure the success of increasingly complex and longer future missions, an autonomous crew will not only have to survive or cope in a capsule environment, but be comfortably integrated in order to thrive.
To provide a multitude of starting-points for future concept development, design approaches from a wide cultural and industrial spectrum were examined – some selected due to their historic influence, others since they had previously been investigated in a space context to some extent. This open-ended process of exploration resulted in a number of independent, convergent or nestled approaches with the following four main strands.

3.1 Paradigms of Vernacular Extreme Environment Habitation and Exploration

Extreme natural environments, such as space, polar, deep sea, high altitude, desert and jungle, are characterised by their unsuitability for humans, and demand complex physiological and psychological adaptation [7]. From an evolutionary perspective, the reaction to hostile environmental conditions has been nomadic [11], but native populations have been able to adapt to harsh conditions over millennia, using in situ resources for shelter and food. Also non-native individuals, such as mountaineers or apnoe-divers, were able to adapt within their lifetime [6]. Although paradigms can thus be shifted, it remains to be seen whether human physiology and cognition can begin to adapt to altered gravity or daylight conditions in space. While planetary surface habitation will certainly benefit from use of local building material, also the unique sensory conditions of extreme environments should be integrated and specifically addressed in habitation design. To gain practical insight into extreme habitation issues, a short fieldtrip to subarctic Lapland was conducted during the polar winter, where ambient lighting of habitable snow structures and local atmospheric phenomena were measured and documented photographically.

3.2 Value of Play

The concept of playfulness has become increasingly interesting to the product and interaction design community. Also in space, play acts as countermeasure to high workloads. A collaboration was formed with two designers currently working in space architecture and astronaut training. A review of leisure activities in space found that no games had been developed specifically for use in space habitation, while literature indicated a need for multiplayer, tactile play provisions to support crew cohesion [15]. Hence requirements for an interactive physical game were formulated. Concept development resulted in an expandable set of modular elements for strategic connection into a free-floating structure. A full-scale working prototype was presented to an international panel of experts [5], and subsequently tested with regards to play value with users in terrestrial gravity conditions.

3.3 Potential of Biomimetic (Bionic, Biophilic) Applications

Through abstraction of nature's principles, biomimetic design approaches in architecture contribute to innovative, aesthetic and situational design solutions. They are applied in the areas of material and processes but also as strategy for psychological and sensory integration [8]. In a space context, bionics are the subject of development studies for engineering applications [3] and structural solutions in habitation design [4]. There appears to be little documentation of biophilic design efforts in approaching psychological aspects of crew habitation, but seminal NASA studies investigated the geometry of spatial habitability [19] and possible application of abstract natural principles to spacecraft interiors [10].

3.4 Lessons from Traditional and Contemporary Japanese Design

During the investigation of biomimetic approaches, the texts and artefacts encountered repeatedly referenced the organic nature, the dichotomoy of simplicity and complexity, and the emphasis on the human-scale of traditional Japanese architecture [17]. Multi-use of spaces through flexible furniture, the interplay of exterior and interior through integration of natural elements into artificial indoors, and the maximisation of limited space prevalent in medieval and early modern spatial planning are qualities that a confined spacecraft could benefit from. The findings of research into perception of composition and layout of the Japanese *karesansui* garden [18] and the advanced operational design solutions of contemporary Japanese transport environments and capsule living could offer invaluable input in efficient, simple, yet flexible and complex interiors.

4. Conclusion and Recommendations

After pinpointing four key features of design for psychological habitability, an exploration of terrestrial design approaches with different anthropological, methodological, technological and cultural backgrounds indicated possible new impulses for the design of psychologically sustainable human-centred applications that could be implemented on a systems scale across the entire crew habitation unit.

The remaining phase of this ongoing study foresees the synthesis of these approaches into a design strategy, and its conceptual application to crew transfer habitation for a Mars mission. It is therefore recommended to investigate further the situational, complex, responsive, sensory and interactive aspects of these approaches as countermeasure for psychological stressors, and their potential to enhance the experience of salutogenic, or positive factors [14] in space.

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