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Leveraging Empathic Strategies: Prototyping for Commercial Space Vehicle Design

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Abstract: When designers are tasked with the role of future forecaster, they engage in speculative acts that can be aided through prototyping. These tangible analogues act as a platform for building ideas as well as empathy in an effort to approximate the future activities and experiences of end users. The emergence of space tourism as a viable industry in the near future, will require designers to develop prototyping strategies that emulate these future experiences. To that end this paper reports on the development of a modular prototyping system for the design of space vehicle interiors. As a means of evaluating the effectiveness of this experimental prototyping platform it was deployed in a student class studio setting where designers utilized these elements throughout a team project. The results from this experiment indicate that a modular structure has several advantages across multiple phases of the design process that can translate to future space vehicle design.

Keywords: prototyping; empathy; speculative design; space travel

1. Introduction

1.1 Rise of Commercial Space Travel

The rise in interest and new business development surrounding commercial space travel presents a new area that designers will need to increasingly address. Historically space travel was a significant technical endeavour and still is but the potential for tourism flights introduces an increased focus on the user-centered approaches of vehicle design (Tovey, 2012). Early missions into space were large government funded initiatives that supported the efforts of a select few individuals to go into space and report back about their discoveries. Recently, there has been a surge in interest in the private space sector producing such visible players as Virgin Galactic, SpaceX, and Blue Origin (Prosser, 2018). Boeing and Space Adventures have planned to offer a commercial passenger options to the ISS aboard the new CST-100 Starliner capsule (Experiences: Space Station, 2018). These shifts mark the rise of

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commercial space efforts (Hammond, 1999) and space tourism where humans will be able to stay in space hotels, travel to the moon, and beyond. This also represents a shift towards an area of tourism that has no historic examples to draw from and subjects tourists to environments and experiences that no designer has ever had, nor has the ability to directly reflect upon. The highly technical, scientific, or military nature of past space missions had quite different interior spaces than the new wave of space tourist will expect. Astronauts were trained to deal with more harsh living conditions and experiences than an average tourist will withstand or tolerate. As Mary Roach said in *Packing for Mars*, “To the rocket scientist, [humans] are a problem. [They] are the most irritating piece of machinery he or she will ever have to deal with.” (Roach, 2010). Much like the vehicle design of military equipment and naval architecture, the human is often considered after all other constraints have been met. Ultimately, the facilities for the actual crew are developed to meet the bare minimum of accepted codes and complete the mission. Space missions are no exception. With the added constraint of incredible fuel costs, reducing payload is always a top concern. That being said, tourism operating under these conditions will introduce a need to address comfort as will the overall emotional experience of the trip. Tourists will experience a combination of extreme circumstances such as microgravity and confinement with unfamiliar people while disconnected from the earth. Space travel has been shown to consistently produce many undesirable cognitive and physiological effects (Williams 2002). For, example, even five days in microgravity can lead to a loss of muscle mass (Tischler, et al. 1985). This design endeavour represents challenges as well as opportunities as these experiences are future ones that are tough to replicate on Earth and have limited means for developing a direct or empathetic understanding of.

1.2 Space Travel as Future Scenario

Designers have long embraced uncertainty as a profession. Increasingly, these problems may not be address through new and novel material objects but may result in a myriad of possible designed services, systems or social solutions. These wicked problems (Rittel, 1973) are compounded by planning for current problems as well as future ones. Historically, designers have leveraged lessons from other precedents when developing new concepts but in some cases, these precedents and past best practices are not enough to inform future designs. Iterative approaches to problem solving and a desire to develop these alternatives into a final concept are the underlying structure of the design process. Based on that, designers are increasingly taking on the role of future forecaster. The future of space travel continues to evolve from the visions of the mid-20th century and once again, designers will need to develop concepts that address these futures. Balancing between elements of Design Fiction (Sterling, 2005), and Speculative Design (Dunne A. a., 2013), this activity requires designers to develop scenarios and prototypes that will facilitate concept exploration as a means of making the intangible more accessible. To aid in this process, prototyping strategies need to allow for a range of possible iterations that accommodate potential use cases beyond the traditional government funded space mission.

1.3 Building Empathy through Prototyping

As researchers continue to explore frameworks for empathizing for future scenarios (Evans, 2015), prototyping remains a critical tool for designers. As many of the aspects of the problem space are not completely understood, 'experience prototyping' (Buchenau & Fulton Suri, 2000) has been a proven strategy to "understand, explore or communicate what it (product / interaction) might be like to engage with". By extension this strategy could be leveraged to support designers need to develop empathy around an experience like space travel as most if not all designers are void of directly experiencing this activity. A platform for engaging with the reality of space tourism is needed to facilitate the designer's reflective practice and promote knowing-in-action (Schön, 1983) through analogue experiences. This new prototyping approach not only needs to accommodate some forms of empathic research but needs to address some functional concerns that arise. Habitats being designed for space tourism require flexibility. This is dependent on different factors such as length of travel, tourist type, etc. Additionally, the platform needs to be scalable and modular. Designers will have to be able to easily grow or reduce the size of the platform as well as change its orientation to reflect how one might move between units in space. This will allow the mock-up to accommodate a variety of specific use cases. Additionally, this will allow experimentation by designers that may eventually drive engineering solutions. By allowing the designers to gain some measure of empathy for the experiences future tourists will have and by providing some realistic functional constraints and encouraging designers to prototype early and often within analogue environment, new and unique habitation designs can arise.

1.4 Approaches to Vehicle Prototyping

Due to the fact that transportation design is such a broad field, this work is limiting its scope of comparison to transportation efforts that deal with similar problems of mobility, specifically the transportation of small groups, for short to medium length durations. The most direct space travel analogue would be the prototyping that NASA has used historically. Most strategic approaches to aerospace transportation design mock-ups can be divided into the same categories defined by the "Design Research Matrix". (Cohen, 2012). These are 1. Concept evaluation 2. Design research 3. Engineering integration 4. Operations simulation and development and 5. Crew Training. Additionally, transportation design often employs mock-ups of an even higher fidelity than those mentioned in the Design Research Matrix. These would fall within a sixth, higher-fidelity category of marketing mock-ups. For the purposes of the research outlined in this paper, most of the speculative prototyping activities centred on categories 1 and 2.

Within the category of 'concept evaluation', the process by which designers have traditionally approached prototyping was to use a full-scale drawing techniques by drawing with traditional media or to use pieces of tape to draw which is heavily relied upon in the auto industry (Starting Out: Car Design Glossary, 2008) (The Language of Tape: Ford Designers and Moders Use Tape to Communicate Throughout The Development Process, 2014) This full-scale

drawing technique allowed the designers to work quickly and directly with the actual scale. Small scale sketch models (PEI, 2011) (Starting Out: Car Design Glossary, 2008) have also been utilized in transportation design to quickly validate concepts in 3D before moving to larger and/or full-scale models. Full-scale models are used for both surface validation and interior validation. In those cases, the full scale mock-ups and prototypes are often direct representations of a low or high fidelity but limited to a specific design concept. Whether it is clay modelling as an exterior form or structural modelling, many of these are standard methods don't address the need for a modular and flexible system that can be deployed in a range of configurations. This is particularly important when a designer is exploring a speculative concept such as space tourism and vehicle interior design. To that end, this research reports on a different strategy focused predominately on the interior space of the vehicle and the outer portion was represented for context only. The interior of the new Scaled Section Platform was intended to facilitate low to medium fidelity prototyping with an emphasis placed on iterating concepts, testing human factors, and integrating findings into new prototypes over attempting to achieve a high fidelity look and feel.

2. Prototyping Approach: Scaled Section Platform (S.S.P.)

2.1 Prototyping Strategy

In an effort to address several of the challenges around the future of space vehicle design, this research project developed a prototyping platform aimed at flexibility of use as its primary goal. The prototyping platform needed to allow for a wide variety of designed outcomes, while on providing some constraints to help focus design work in such a speculative area. The largest constraint was the inner diameter representing the inner sidewall, an outer diameter representing the outer structure of the space vehicle, a space reservation for functional systems, and some representative structural elements to introduce the real-world challenge of navigating systems and structure (see figure 1). Similar to real-world design within large vehicles, these systems and structural "stay out zones" could be compromised if a design solution should require it but would necessitate discussions about how this would be accomplished. Some examples that could be foreseen to arise might be portholes/windows, domes, new doorways, access hatches, or the attachment points of proposed design concepts. To develop the dimensional constraints around this prototype structure, a series of workshop exercises were conducted with the industry sponsor utilizing 1 to 1 taped out floors spaces and a group of seven individuals. These individuals examined common positioning of potential dining, sleeping and group egress between spaces and other individuals. Based on that exercise and combined with secondary research on other transportation spaces such as train sleeper cars and aviation vehicles this information was combined to generate a minimal inner diameter of 2.3m and the outside diameter was the result of structural requirements in addition to studio ceiling height limitations which resulted in an outside diameter of 2.5m. The length of the individual sections was directly impacted by the standard construction material used (plywood) resulting in lengths of 2.43m.

As a result of these constraints, the prototype platform is not a direct reflection of any specific space vehicle but instead a speculative platform developed so design teams could explore early concepts and scenarios. This platform was intended to facilitate open-ended speculative outcomes rather than to produce design solutions for known current scientific missions as a result idealized interior arrangements and specific requirements for necessary equipment were not given. The main objective was to understand how microgravity and being confined in a small space with other people might affect individuals and ultimately their design.

Figure 1 Mock-up cross-section constraints

While a set of functional constraints were introduced, the ultimate configuration and scale was not set. Given that this space vehicle would be operating in a low gravity atmosphere, the orientation, based on our earth directions, as discussed in section 4.2 below, might very well end up as some unknown combination. Designers might decide that modular units could attach end-to-end, at right angles to each other, or some other configuration entirely. In order to facilitate this modular adaptability, and to accommodate the fact that some designers might not be experienced with the fabrication and installation of such a structure, some design considerations were given to the mock-up. Thought was given to hardware, modular adaptability, component complexity, component size, and accessibility.

Hardware was standardized and integrated to reduce complexity. All hardware was utilized the same size bolts for the main structure and the nut portion of the bolted construction was integrated into the structure. This greatly reduced part count and improve the ease of disassembly and reassembly. This also allowed for one size of wrench or socket.

The entire Scaled Section Platform (S.S.P.) could be seen as one main mock-up that was created out of two modules. These modules were in turn comprised of eight components. Each module was designed to be easily separated, rotated, and reattached. The placement of hardware attachment points on the structure was mirrored so that these points would align in any position. This feature was also implemented on the four individual components that make up the modules as well. In this way, even if all eight components were separated, they could be recombined in any order to avoid confusion and add to the ease of adaptability. The individual components were all identical which further reduced complexity and they were designed to be a size that could be easily lifted, manipulated, an attached to the mock-up.

The mock-up was designed to be free standing and structurally sound enough to support the weight of designers walking throughout its interior or, if necessary, support the weight of designers applying forces to the sidewalls, or suspended from the top portion of the mock-up. An outer support lattice (See Figure 2 quadrant D) was designed to facilitate climbing on the outside of the structure should installation of prototypes require it. This lattice was divided into removeable sections should access be necessary (figure 3).

By reducing the number of parts, complexity of components, and creating components in manageable sizes, there were also benefits to project cost and installation. Addressing the part complexity meant that only 1/8th of the parts needed to be programmed by CNC machinists. These initial programmed parts could be copied and re-run, greatly reducing billed hours. Standardized parts allowed for a price break for ordering a larger quantity of one type of hardware rather than small batches of many types. The size of the components allowed for ease of transportation in a small truck, easy movement by two people, fitting within the confines of a standard freight elevator, and could be easily handled by designers. The individual components would be pre-assembled before being delivered to a studio location and were ready to be configured as needed.

2.2 Configurations

Some intended configurations (see figure 2) were A. One full-length, full cross-section longitudinal orientation intended to represent the entire constraints of the habitat module, B. One set of a half-length, full cross-section longitudinal orientation and one half-length, full cross-section vertical orientation, C. Multiple half-height sections and/or, D. Multiple quarter sections. These mock-up design features were all intended to allow a variety of possible experimentation by designers.

Figure 2 A range of mock-up configurations (CAD model).

Figure 3 SSP individual sections (built platform)

2.3 Empathic Research Platform

Normally, a similar vehicle design project might first progress through several stages before a mock-up is developed. However, being that this project dealt with such an unknown area of transportation design, it was hypothesized that having a realistic representation of the space from the very beginning would provide some context. As well as becoming a platform for prototyping, it was intended to become a platform for research and gaining empathy.

Working within the mock-up would begin to give designers a sense of the confinement and isolation experienced by astronauts (Stuster, 2010) and by using some of the configurations shown in figure 2. Designers could begin to understand some of the human factor challenges imposed by low gravity environments.

3. Scaled Section Platform (S.S.P.) – Course Experiment

3.1 Basic Application

In an effort to explore the implications of a sectioned approach to prototyping, these prototype elements were utilized in a University of Washington Industrial Design studio class setting that was designing for the topic of commercial space travel. Students were asked to utilize these Scaled Section Platform (S.S.P.) prototypes in both the initial research portion of their team projects as well as later in the actual ideation and design refinement phases. The aims of this experiment was to observe and evaluate how students leveraged these platforms throughout the class. A total of eight modular units were deployed in the studio space where four were preassembled and the remaining four were left as independent units. Particular focus was on the use of these prototyping structures as a flexible system of components that might promote a range of applications throughout the entire design process instead of just supporting one portion of the design visualization.

3.2 Course Structure and Implementation

This studio course was unique in that it explored the future of commercial space travel in the year 2030 but was also an industry collaboration between the University of Washington Industrial Design program and aviation industry sponsor, TEAGUE. This collaboration was instrumental in establishing a strong grounding and professional context for designing for transportation needs. With decades of experience in this field, the TEAGUE's contribution helped to guide several of the parameters of the course as well as some of the prototyping platforms that were utilized in this studio class. As a leader in aviation design field, TEAGUE was interested in exploring possibilities in this emergent form of travel. For over 70 years TEAGUE has worked with Boeing to envision the future of flight [9].

The actual class structure was based on a single project and team work spread across the quarter with individual deliverables contributing to the overall performance of the group's work. To best support the various research and design activities over this 11 week term, the 20 industrial design 4th year students in the class were broken into teams of four. The class met in a studio style format twice a week for three hours each meeting. These two meetings were initially split each week between a range of activities including studio tours, lectures, and workshops as a means of accelerating students into the research collection phase. The overall design project was initialized with a secondary data research portion coupled with primary research. This then advanced into a range of generative design activities exploiting various sketching and prototyping methods with the ultimate aim of designing a unique

vehicle interior and focused touchpoint (bed, lavatory, galley, etc.). Teams were asked to conceive a seven day space journey within the cislunar area that started from Earth orbit, travelled out and past the Moon and returned to Earth orbit for the year 2030. This journey would be supported by three crew members and four passengers (tourists). Additionally, the envelope of the vehicle interior was defined for teams and the key connection point to the Scaled Section Platform (S.S.P.) prototype elements.

3.3 Prototype Usage in Studio Course

IMMERSIVE AND EMPATHIC RESEARCH

The student teams did not have direct contact with anyone that had spent time in space, which required them to explore other research methods outside of traditional user-centered observations and interviews. A portion of this was supplemented by secondary data but the other main component was a series of student designed immersive and empathic research experiments (Germany and Lund 2019). As many researchers have reported on the importance of introducing empathic methods into design curriculum (Malins & McDonagh, 2008) (Feng, 2017), the goal of these initial experiments was to speculate and ultimately emulate some of the experiences that future space travellers might experience. To that end, students were tasked with examining the effects of isolation and physical constraints on social and emotional wellbeing. To explore these elements, student teams utilized portions of the S.S.P. prototype structures. They positioned these structures in full and partial configurations in that allowed for a set of experiments. Team constrained tasks ranged for group exercises like the ‘human puzzle’ or other games where individuals had to coordinate their efforts to a single goal inside the closed space provided by the S.S.P. structures (figure 4).

Figure 4 Student immersive studies in S.S.P. structures

IDEATION AND CONCEPT EXPLORATION

After collecting research and synthesizing their findings, teams then moved on to exploring a range of interior design concepts. Initial methods of exploration were done in sketch form but these ideas were then advanced to 1/10th scale section mock-ups (figure 5). These scale mock-ups were constructed from tubular forms and cardboard elements to represent

an abstract interior concept. These section pieces of tubular cardboard worked in a conceptual parallel as being analogous to the $\frac{1}{2}$ section pieces (2 unit) of the full scale S.S.P. prototype structures. In starting with this small platform, students could quickly explore and reconfigure their mock-up concepts and couple those design concepts with their direct experience in the full scale S.S.P. structures.

Figure 5 1/10th scale team mock-ups

The 1/10th scale mock-ups were evaluated and a down selection was made. The advancing designs were then enhanced through additional rounds of sketching. The next aim was to begin working at full scale as quickly as possible to explore specific components of their interior designs. To make this transition from reduced scale (1/10th) to sketch to full scale mock-up, teams utilized 2D full scale wall drawings (figure 6) to generate starting templates for their larger mock-ups. Beyond the direct template aspects of this wall drawing approach, these were used to ideate around cross-sectional volume and to build an understanding of the relationships between individual design components within the interior concept.

Figure 6 Wall drawings to templates to component mock-ups

From wall drawing to paper template teams then utilized foam core and card board to generate volumetric elements that were positioned within the Scaled Section Platform structures (figure 7). The interior of the S.S.P. was most commonly skinned with a single layer of foam core to act as a smooth wall and doubled as a pinnable surface for quickly moving mock-up pieces in and out.

Figure 7 SSP structure and volume mock-ups

Students repositioned these structures as 1/4, 1/2, and full sections in both horizontal and vertical configurations depending on the mock-up elements they were exploring. One team exploring the sleeping units utilized a horizontal configuration where another team that was designing an observation bay positioned the S.S.P. After several rounds of prototyping, each team narrowed down the final elements of their overall concept. Again, teams returned to utilize the S.S.P. structure elements as their platform to display the final interior concept. Using a mixture of foam core, paper, and fabrics, teams assembled their primary interior touchpoints as a final presentation and exhibit (figure 8).

Figure 8 Final interior mock-ups (sleeping pods concept)

FINAL CONCEPTS VISUALIZATIONS

The S.S.P. proved to be an affective platform for all phases of the design process and greatly aided the visualization for the final outcomes of this experiment. Each of the student teams advanced the physical prototyping on the S.S.P. by developing a series of renderings and visualizations that combined their speculative scenario with the primary touch point that they focused on. Some teams identified flexibility in sleeping spaces as critical in their design (figure 9) as other teams found that the shared open spaces in the vehicle were the key driver in their concept (figure 10).

Figure 9 Final concept example 1

Figure 10 Final concept example 2

4. Discussion

The results of the studio activities were primarily collected by faculty observations as well as input from liaison designers from the industry sponsor, TEAGUE. Observations and interactions occurred during regular class meetings throughout the quarter; specifically, twice a week for three hours each meeting. The primary objectives were to observe how student design teams utilized the Scaled Section Platforms (S.S.P.) from initial research activities through iterative concept development all the way to final visualizations. The main points based on these observations are highlighted in the following section.

4.1 S.S.P. and Research Activities

As previously outline, the premise of the studio was focused on commercial space travel in the year 2030 and the speculative topic presented underlying challenges. One of those challenges was devising a strategy for collecting insights about an activity (space travel) that students could not directly experience and where there were no end users (astronauts) that could be interviewed or observed within the scope of the class time. To that end, teams leveraged the Scaled Section Platforms for several of their initial immersive research studies. In providing an enclosed volume that was a full scale representation of the vehicle, the students began to develop an understanding of some spatial orientation issues, limits on personal space, as well as coordinating team movements inside a confined environment.

4.2 S.S.P. and Design Activities

The rough full scale explorations using the S.S.P. structures provided a direct understanding of the constraints exhibited inside the confined vehicle and allowed teams to empathize with the future space travellers they were designing for. Accelerating their understanding of the challenges and providing a feedback loop to the next round of prototyping. This appeared to be particularly important when they were trying to achieve three main activities in the design process. The first was translating sketch based concepts to full scale volume mock-ups, the second was addressing the 3 axis layout of their design components where there was no defined ceiling and floor and the last activity was the coordination of human movements through the design interior. The last two were of particular importance in the feedback and refinement of the team designs.

Beyond the research and design related activities, the overall performance of the S.S.P. units was accessed throughout the studio course. The key take-away from those observations was that the prototyping platform (S.S.P.) showed significant benefits in that it was a modular, flexible and easy to deploy and redeploy tool that could be utilized not just at the terminal portion of the design project but throughout the class. The modular aspects allowed for design teams to explore interior design sections ranging from 1/4, 1/2 and full tube configurations as well as stacking these full tubes in horizontal modules. This point leads to its flexibility as students utilized the S.S.P. structures in both vertical and horizontal orientations depending on their need. Lastly, because of the ribbed construction, units were light enough that 2-3 students could move them around quickly. The remaining benefits observed in this studio experiment were that the S.S.P. proved to be far more durable than previously thought leading to their reuse over and over throughout the project.

4.3 Limitations

Although Scaled Section Platform prototyping structures appeared to support a range of design activities in addition to their utility applications, there were several areas where improvements could be made to future iterations. The first pain point was related to 1/4 and 1/2 section supports. When deployed in these configurations, the structures had stability issues depending on the volumetric foam core models that were hung on them in the vertical orientation. The work around to this issue proved to be the addition of secondary plywood ground stabilizers or to anchor the section to a wall. The second issue exhibited during the studio was related to the application of skinning materials to the inner ribbed surfaces. The primary skinning material was white 1/4in foam core that required perforation cuts on the back to accommodate the curved interior and mounted with wood screws. This was the least resilient portion of the whole platform and required continued maintenance or replacement as mock-ups were added and removed from the interior space or where foot traffic impacted the surface. Future applications of the S.S.P. would require a more durable surfacing sheet material like styrene or masonite. The last issue to this prototyping platform was that it was modular and scalable but limited to a fixed diameter.

For the studio class experiment this was a problem but if applied to a wider range of vehicle applications, this could be a defining constraint.

5. Conclusion

When designers are tasked with the role of future forecaster, they engage in speculative act that is aided by tangible analogues. These analogues can act as a platform for building ideas as well as empathy in an effort to approximate the activities and experiences of end users. The emergence of space tourism as a viable industry in the near future, will require designers to develop concepts for experiences that are not readily replicated. The challenge in developing a prototyping strategy for these experiences is to allow for enough flexibility and adaption to facilitate a range of concept explorations. The Scaled Section Platform (S.S.P.) prototyping structured outlined in this paper aimed to support this range of explorations from initial immersive research to concept iteration to final visualization. This effort is in alignment with other 'experience prototyping' strategies (Buchenau & Fulton Suri, 2000) which focus on user understanding, exploring and communicating as the primary activities. In the context of aerospace design, the S.S.P. prototype structures targeted the first and second columns of Cohen's (Cohen, 2012) "Design Research Matrix", namely concept development and design development but also allowed for primary immersive research which precedes the concept development phase. The primary benefits of the S.S.P. system is that it allows for a modular, flexible and easy to deploy and redeploy set of structures that can accommodate much of the front end prototyping needs of vehicle interior design. Additionally, these structures are reusable thus reducing time and money needed to move to full scale mock-ups. The constraints to this strategy are limited to its fixed diameter and challenges associated with developing a durable and reusable skinning surface. That being said, the underlying strategy of the Scaled Section Platform is one that could prove to be a promising solution to future spatial and space vehicle oriented design efforts. This is particularly true for design teams that are still at the front end exploration phase of a project as this acts as a relatively standardized platform much like a pencil and paper are for other design activities.

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