DIGITAL ADVANCED DESIGN

TRANSITIONAL INDUSTRIAL APPROACHES FOR SUSTAINABLE INNOVATION

edited by
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Summary

DIGITAL DESIGN FOR CIRCULAR MATERIALS

DIGITAL DESIGN
FOR MANUFACTURING

DIGITAL DESIGN FOR MANUFACTURING

Within the *Digital Design for Manufacturing* research cluster, the progress of projects 1.8 *Advanced Human-Machine Interaction for Continuous Transformative Manufacturing and Robotic Systems* and 1.10 *Beyond the Space Life. Digital Living Lab for Human Life in Space*.

The contribution, "Towards Sustainable Transformative Factories with AI-based Human-Machine Interaction, Virtual Prototyping, and Industrial Orchestration," delves into human-machine collaboration, Virtual Prototyping, and software/network co-orchestration in advanced automation systems for the development of sustainable scenarios that can be enabled by a load-aware orchestrator. The second paper, "Novel Operator-Centric Digital Technologies for a Sustainable Industrial Workplace," explores predictive maintenance and reconfigurable robotic systems, with a focus on HMI technologies. It also outlines expected outcomes, including advanced tools for real-time mental load management and intuitive interfaces for interaction and programming of collaborative robots.

For project 1.10, the essay "Life Beyond Space: Responsible Advanced Design for New Balances Between Space Habitats and the Human Factor" presents methodology and actions taken to activate, in an experimental way, a process of shared knowledge among different actors and an interdisciplinary design path, open to contamination within and outside the Space domain. Finally, the essay "Advanced Design Strategies for Space Habitats: Bridging Human Factors and Digital Tools for Enhanced Living Environments" delves into one of the outcomes of the 1.10 project, illustrating the methodological process of advanced design applied to the configuration of space habitats oriented toward the psycho-physical well-being of future users and the flexibility and adaptability of environments.

LIFE BEYOND SPACE: RESPONSIBLE ADVANCED DESIGN FOR NEW BALANCES BETWEEN SPACE HABITATS AND THE HUMAN FACTOR

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1. Introduction

Designing habitats for Deep Space is considered a highly complex area of investigation, not only because it involves extreme and unfamiliar environments in which humans live under conditions never experienced in other domains, but also due to the multitude of international stakeholders, interdisciplinary approaches, and research centers engaged in the conceptualization, value chain development, and sustainment of livability for future inhabitants (Di Pippo, 2023; ESPI & CIFS, 2023).

The *New Space* economy is fundamentally reshaping the strategic assets that have historically characterized space exploration. Emerging policies within space programs now involve not only governmental agencies but also major private companies (European Investment Bank, 2019; Council of the European Union, 2024). Certainly, the planned decommissioning of the International Space Station in 2030, evolving geopolitical scenarios, and upcoming challenges are prompting, on the one hand, renewed visions of human presence on the Moon and crewed missions to Mars, and on the other, the expansion of the range of individuals able to undertake missions in Low Earth Orbit (LEO) (Leach, 2015; Rollock & Klaus, 2022; Peng et al., 2024). This shift in vision presents design, business, and research opportunities for emerging enterprises, commercial players, and diverse sectors within academia and professional practice (Meusburger et al., 2023).

As a result, design processes must increasingly address human factors, habitability, crew dynamics, the development of new in-orbit activities, the activation of new cooperative policies, and strategies for both material and immaterial sustainability (Van Ellen et al., 2023). These changes demand a rethinking of both the space habitat and crew well-being, as well as of the design process itself in terms of design accessibility and process sustainability.

As Meusburger and Bishop (2021b) emphasize, the inclusion of more numerous and diverse crews will place human factors and the experience of inhabiting space at the center of future design efforts. These concerns are echoed in NASA's assessments (Buckland et al., 2022), which recognize the risk of incompatibility between habitats and "new users" if proper attention is not paid to human well-being, performance, and the physiological limits of the body in microgravity and confined spaces. The socio-spatial and psychological dimensions of future users and crews must become part of the design requirements, focusing not merely on survival but on prosperity (Meusburger & Bishop, 2021b), and on fostering a more qualitative experience of interaction between space travelers and the space environment (Bannova, 2021; Dominoni & Quaquaro, 2023).

With regard to design accessibility, several questions are now being raised: How can this professional and entrepreneurial sector open itself more to cross-disciplinary contamination in order to design future space exploration experiences? To ensure sustainable competitiveness, how can we train designers capable of activating more collaborative design processes? And in such a complex domain, how can knowledge and know-how become more accessible and transdisciplinary?

At the international level, several initiatives are emerging in an effort to address these issues. For example, in 2021 the International Astronautical Federation (IAF) established a dedicated Space Habitat Committee, composed of experts from various disciplines, to investigate the challenges of space habitats through an interdisciplinary lens, with the goal of enabling not only survival but also well-being in such extreme environments (Meusburger et al., 2023).

Thus, the necessary ideas and solutions do not originate from a single field of expertise. In recent years, new educational and research programs have been launched at multiple levels—master's degrees, courses within architecture and design curricula, and interdisciplinary design labs—supporting the development of new skills and experiences. These initiatives aim to integrate engineering approaches with methodologies focused on human well-being and on activating meaningful relationships between environment, user, and community (Caratelli, 2020; Yashar, 2023; Iacobo, 2024). These efforts are designed both to imagine, design, prototype, and test future scenarios, and to support the development of sustainable systems and technologies that facilitate human presence in deep space.

The sustainability of the design process itself, on the other hand, can be analyzed through two key dimensions:

- Material: related to design timelines, the use of energy- and resource-intensive tools, the selection and application of materials during concept development and product design, and the overall configuration of the habitats;
- Immaterial: referring on one side to the value of local knowledge and expertise, and on the other to the psycho-physical and sensorial aspects that must be considered throughout the design process.

In the first case, the complexity of the sector leads to high resource consumption throughout the design process. Achieving a final output typically requires multiple stages of both low- and high-fidelity prototyping, which will in turn influence digital modeling and production workflows. Furthermore, time itself plays a critical role: difficulties in effectively coordinating heterogeneous designers, tools, design concepts, and product developments not only extend the process but also make it more energy intensive.

In the second case, current challenges highlight the importance of small and medium-sized enterprises (SMEs) in driving innovation within the space sector (Council of the European Union, 2024), and therefore the significance of territorial relationships and the exchange of expertise across different fields. From a design standpoint, it becomes clear that in an environment defined as *Isolated, Confined, Extreme* (ICE), achieving a successful mission, both socially and operationally, requires focusing on the "extraordinary dependency on the habitat, its technological capability as well as the sociospatial framing, i.e, the elements of the built environment that form the boundaries for the social and individual activities taking place within the habitat." (Meusburger & Bishop, 2021a, p. 2).

2. Responsible Advanced Design for Deep Space

Within this evolving landscape, design can play a key role both as a mediator of knowledge and expertise (Celaschi, 2008), and in defining a design model capable of integrating established aspects of the sector with emerging visions and future needs. This enables the activation of an anticipatory, reflective, transformative, and collaborative learning process (Celi, 2015; Celaschi et al., 2019; Succini, 2023; Gianfrate, 2024), serving the next generation of designers and benefitting new users of deep space.

These elements are embodied in the research project *Beyond the Space Life: Digital Living Lab for Human Life*, led by the Advanced Design Unit at the University of Bologna, in collaboration with the Department of Mathematics at the same university and the company Thales Alenia Space Italia.

The project, embedded in a context of high cultural and social value—that of Made in Italy—aims to respond to ongoing changes by hybridizing the space sector supply chain (Cozzi, 2024) with the knowledge and know-how that characterize the Italian territory, stemming from other supply chains and from the design discipline. Design becomes the means by which this interaction is transformed into opportunities for developing high-value-added sustainable strategies.

The main goal of this study is to construct, through a responsible and advanced design approach (Succini et al., 2024a), a model of a *Space Digital Living Lab*, which, through the integration of digital tools and physical experimentation, supports future designers, Made in Italy entrepreneurs, and professionals in the field:

1. In creating, through tools and best practices, complementary forms of knowledge and collaboration to accelerate the emergence of design ideas in the early stages of space habitat design, and to foster open and responsible innovation processes in the development of systems and products.
2. In formulating a methodological process of advanced design to develop new orbital habitat configurations aligned with sustainability criteria, particularly immaterial sustainability.

3. In conceiving a digital system for dynamic configuration of space habitats, to be used during the conceptual phase, allowing for early consideration of crew well-being, spatial customization based on psycho-relational characteristics, and in-mission spatial flexibility.

The project does not aim to create an entirely new design model, but rather to redesign specific parts of the existing process used by Thales Alenia Space Italia (TASI), introducing targeted enhancements in the early stages of the company's design process. The goal is to make extreme space environments more accessible and familiar to a wider range of designers, while also making the relationships between the various stages of design, from initial ideas to concept, more dynamic and sustainable.

In fact, TASI is not only a partner in the project but also represents the applied case study through which explore the core themes of the research, investigate specific design processes, and test new strategies. With over 40 years of experience as one of the main actors in the space sector—and having built the majority of the pressurized modules of the International Space Station (ISS)—TASI brings consolidated know-how that can validate and support the actions and outputs of the project.

As previously noted, a wide variety of professional roles are involved in the design of a space habitat. Of particular interest to this study, especially in relation to TASI's design processes, are the professionals engaged in the early stages of the project—from ideation to conceptualization. These roles can be grouped into two main macro-clusters, each containing categories with distinct needs and objectives, as described in table 1:

Tab. 1. Professional profiles of interest in the research.

	Professional Profiles	Objectives
New Designers	Designers, architects, engineers, etc.	To become familiar with the space sector, acquire a more systemic understanding of its specific characteristics, explore best practices from outside domains, and experiment with combinations of design approaches for extreme environments
Current Industry Designers	*Strategic, Conceptual, and Human Factor Design Field*: Professionals working in systemic design, layout conceptualization, and human factors expertise	To streamline design and systemic processes for concept development
	Modeling and Immersive Reality Field: Professionals involved in system-product modeling and virtual reality simulation	To improve workflow pipelines in order to reduce development time and enhance user movement dynamics within the virtual environment

A common objective shared by all designers involved in the project is to establish stronger interconnections between the various stages of the process: knowledge acquisition, conceptualization, and immersive design experience.

To investigate in a multidisciplinary, anticipatory, and inclusive manner what is available on the market, the variety of international policies and visions, and the emerging needs related to increased attention to the well-being of future users, the applied research methodology is *Responsible Advanced Design* (RAD) (Succini, 2023; Succini et al., 2024b). RAD is employed as an analytical framework, a design attitude, and a guide for evaluating the impact of the various design strategies implemented. The factors of this approach are: *anticipation, reflexivity, inclusiveness, responsiveness, care, and transparency* (Succini, 2023; Succini et al., 2025), which are translated into:

- Design practices guided by an open innovation model, where all stakeholders are involved collaboratively and ethically;
- The dissemination of responsible knowledge through open and adaptable tools tailored to the type of designer and the research objectives;

- The development of new behaviors and sustainable processes through future-oriented design that anticipates the needs of both humanity and the planet;
- The application of technology with consideration for designer well-being and its role as an enabler for learning and increasing design accessibility.

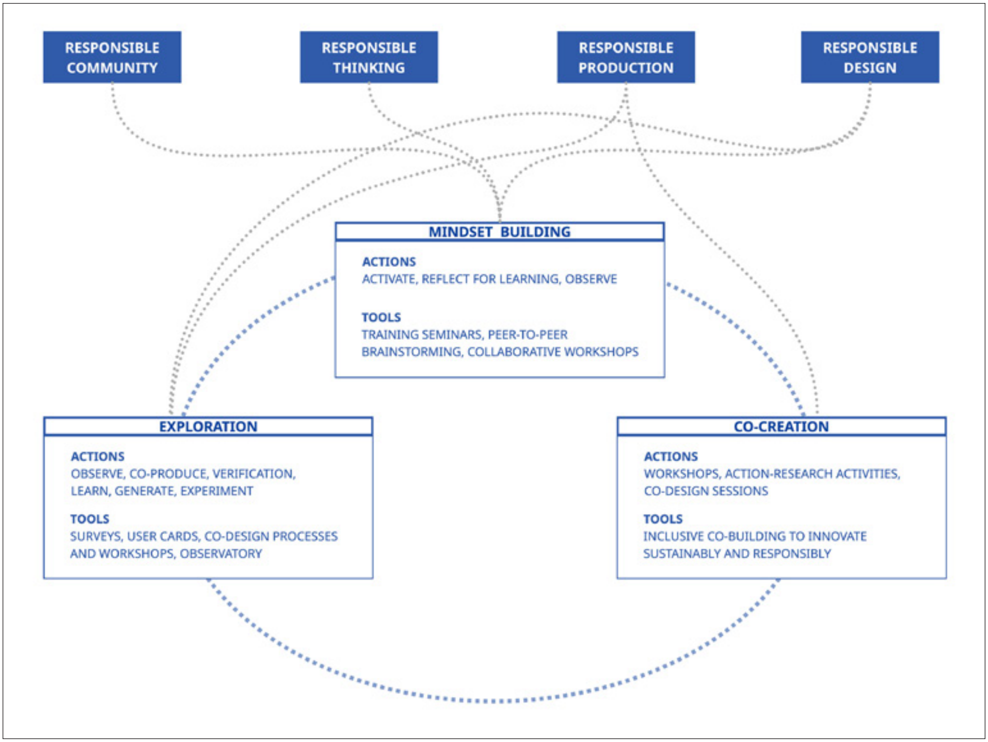
RAD is structured around macro-actions that translate the concept of responsibility across four key areas of design: *Responsible Design*, *Responsible Thinking*, *Responsible Production*, and *Responsible Community*. Each area is defined by a set of actions, insights, and design tools aimed at fostering responsible innovation (Stilgoe et al., 2013).

Given the highly interdisciplinary, multi-level, and multi-stakeholder nature of this context—along with strict design constraints such as safety and survival—the RAD methodology required integration, particularly in the knowledge and design phases, with both the Human-Centered Design approach (Norman & Draper, 1986; Long et al., 2022) and Human System Integration (NASA, 2010, 2014; Boy, 2021; Silvia-Martínez, 2023). This integration ensures the inclusion of human factors from the very beginning of the investigation and design process, not only addressing functional ergonomics but also psycho-perceptual dimensions.

In practical terms, RAD was articulated through three interconnected lines of action: *Mindset Building*, *Exploration*, and *Co-creation*. These areas are closely related, as certain actions are shared across them to achieve the project's objectives (see fig. 1). They also serve a dual purpose: first, to foster dialogue among project stakeholders and support collaborative design; second, to provide development and testing channels for the research's proof-of-concept outputs.

3. The design methodology applied to the TASI case

Each line of action was understood and employed both in the relationships among project partners and other system stakeholders, and as a set of tools and strategies used to define the project outputs.



1. Relationship between the Responsible Advanced Design approach and the three lines of action within the research project.
All images are reproduced in color in the online edition of the book.

3.1. Mindset building

Tools: Training seminars, peer-to-peer brainstorming sessions, collaborative workshops
Actions: Activation of flexible learning processes, construction of design responsibility, cross-disciplinary observation to foster change

Activating Collaborative Knowledge Within Working Groups

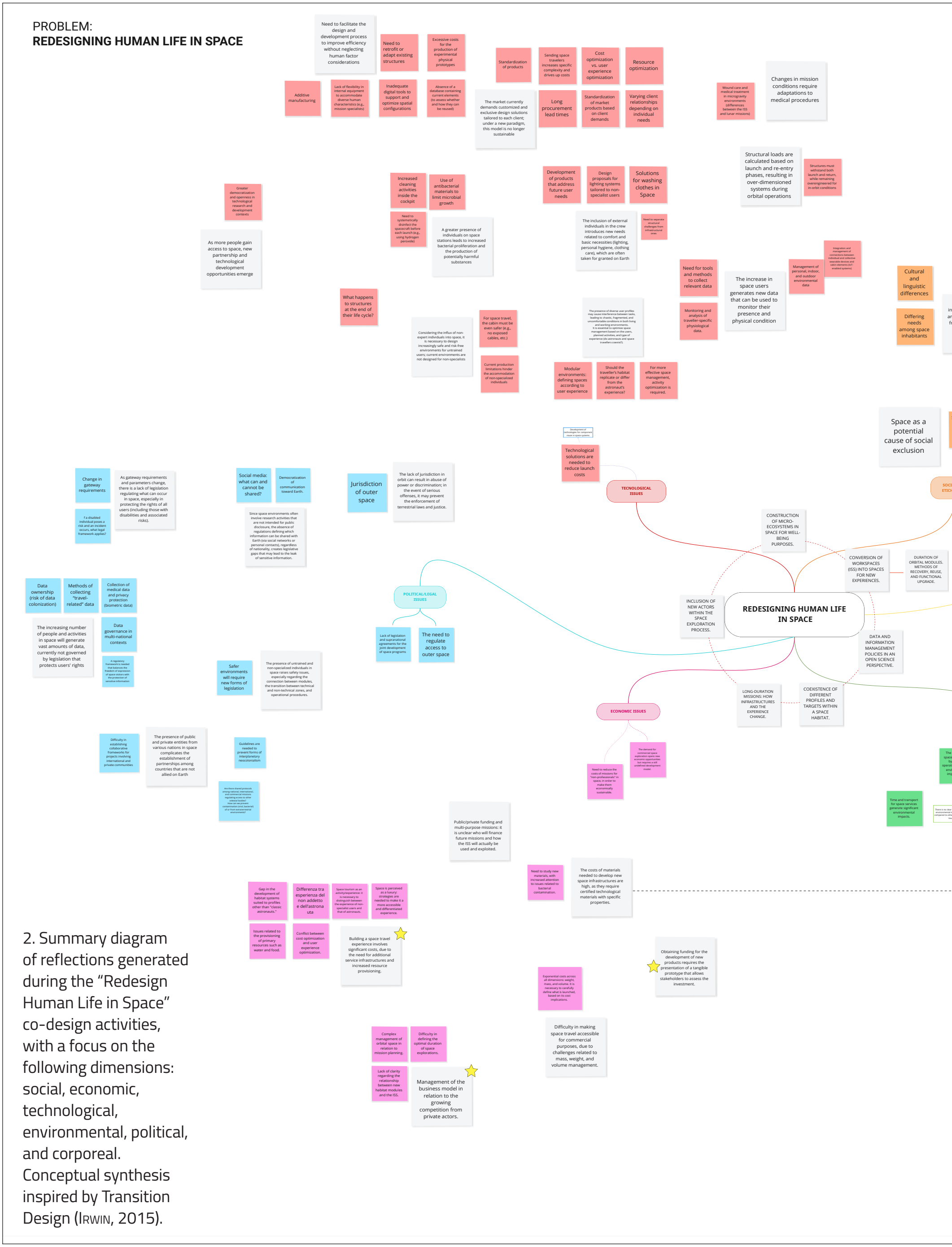
To foster a form of collective intelligence among the research team, a series of knowledge exchange and reflection activities took place between September 2023 and April 2024, focused on identifying values and critical issues to consider when redesigning human life in space.

These activities alternated between peer-to-peer training seminars, conducted by the project partners themselves, and collaborative brainstorming sessions. The seminars explored technical and engineering aspects of space habitats, the role of human factors in design, how training affects the psychological traits of crews and how design can enhance the experience of future users. These flexible learning formats allowed all participants to contribute and encouraged dialogue between academia and industry.

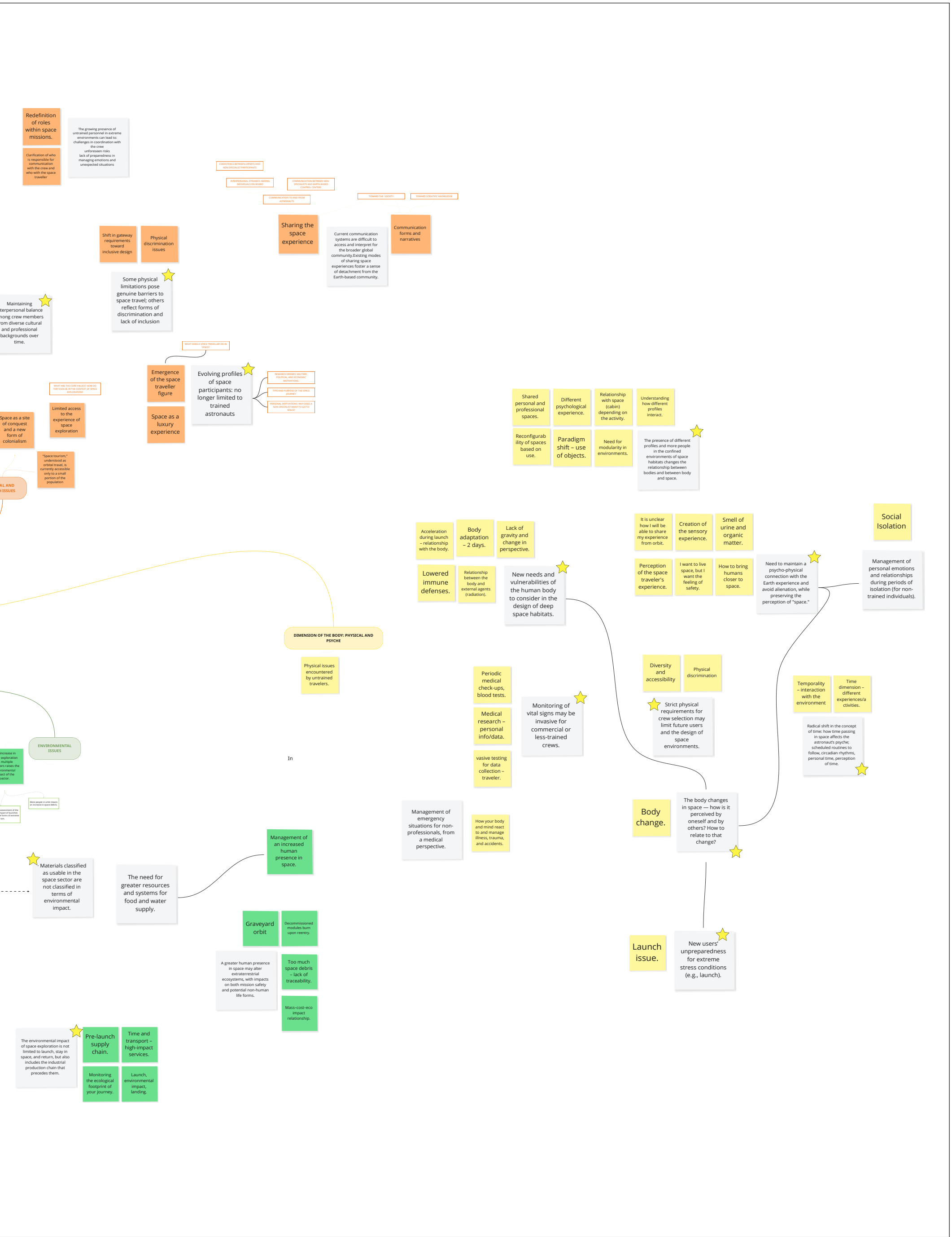
The brainstorming sessions, guided by the principles of Advanced Design and Transition Design (Zannoni et al., 2024), aimed to construct a shared vision of the future of life in space, examining the relationship between habitat, person, and community in scenarios more complex than those currently known. This challenge was analyzed through multiple dimensions: social, economic, technological, environmental, political, and corporeal.

The co-design activities engaged a broader group—including human factors experts, virtual reality specialists, researchers, engineers, and young designers—to reflect on the potential impacts of this transformation on people, policy, and communities in the medium and long term. Together, they identified a set of shared research *must-haves* to be considered throughout the project (see fig. 2). For example, the research was deliberately narrowed to focus on Low Earth Orbit, as designing for the Moon or Mars would require addressing a very different set of challenges.

The group's reflections extended beyond potential future users to include the evolving relationships between today's astro-



2. Summary diagram of reflections generated during the "Redesign Human Life in Space" co-design activities, with a focus on the following dimensions: social, economic, technological, environmental, political, and corporeal. Conceptual synthesis inspired by Transition Design (Irwin, 2015).


Redefinition of roles within space missions.
Clarification of who is responsible for communication with the crew and who with the space traveller
The growing presence of untrained personnel in extreme environments can lead to: challenges in coordination with the crew unforeseen risks lack of preparedness in managing emotions and unexpected situations
Shift in gateway requirements toward inclusive design
Physical discrimination issues
Some physical limitations pose genuine barriers to space travel; others reflect forms of discrimination and lack of inclusion
Maintaining interpersonal balance among crew members from diverse cultural and professional backgrounds over time.
Sharing the space experience
Current communication systems are difficult to access and interpret for the broader global community.Existing modes of sharing space experiences foster a sense of detachment from the Earth-based community.
Communication forms and narratives
Emergence of the space traveller figure
Space as a luxury experience
Evolving profiles of space participants: no longer limited to trained astronauts
Limited access to the experience of space exploration
Space as a site of conquest and a new form of colonialism
"Space tourism," understood as orbital travel, is currently accessible only to a small portion of the population
Shared personal and professional spaces.
Different psychological experience.
Relationship with space (cabin) depending on the activity.
Understanding how different profiles interact.
Reconfigurability of spaces based on use.
Paradigm shift – use of objects.
Need for modularity in environments.
The presence of different profiles and more people in the confined environments of space habitats changes the relationship between bodies and between body and space.
Acceleration during launch – relationship with the body.
Body adaptation – 2 days.
Lack of gravity and change in perspective.
Lowered immune defenses.
Relationship between the body and external agents (radiation).
New needs and vulnerabilities of the human body to consider in the design of deep space habitats.
It is unclear how I will be able to share my experience from orbit.
Creation of the sensory experience.
Smell of urine and organic matter.
Perception of the space traveler's experience.
I want to live space, but I want the feeling of safety.
How to bring humans closer to space.
Need to maintain a psycho-physical connection with the Earth experience and avoid alienation, while preserving the perception of "space."
Social Isolation
Management of personal emotions and relationships during periods of isolation (for non-trained individuals).
DIMENSION OF THE BODY: PHYSICAL AND PSYCHE
Physical issues encountered by untrained travelers.
Periodic medical check-ups, blood tests.
Medical research – personal info/data.
vasive testing for data collection – traveler.
Monitoring of vital signs may be invasive for commercial or less-trained crews.
Diversity and accessibility
Physical discrimination
Strict physical requirements for crew selection may limit future users and the design of space environments.
Temporality – interaction with the environment
Time dimension – different experiences/activities.
Radical shift in the concept of time: how time passing in space affects the astronaut's psyche; scheduled routines to follow, circadian rhythms, personal time, perception of time.
ENVIRONMENTAL ISSUES
Management of emergency situations for non-professionals, from a medical perspective.
How your body and mind react to and manage illness, trauma, and accidents.
Body change.
The body changes in space — how is it perceived by oneself and by others? How to relate to that change?
Management of an increased human presence in space.
Materials classified as usable in the space sector are not classified in terms of environmental impact.
The need for greater resources and systems for food and water supply.
Graveyard orbit
Decommissioned modules burn upon reentry.
A greater human presence in space may alter extraterrestrial ecosystems, with impacts on both mission safety and potential non-human life forms.
Too much space debris – lack of traceability.
Mass-cost-eco impact relationship.
Launch issue.
New users' unpreparedness for extreme stress conditions (e.g., launch).
The environmental impact of space exploration is not limited to launch, stay in space, and return, but also includes the industrial production chain that precedes them.
Pre-launch supply chain.
Time and transport – high-impact services.
Monitoring the ecological footprint of your journey.
Launch, environmental impact, landing.

nauts and new crew members, and how these dynamics might influence habitat design and the types of activities that will take place within space stations.

In parallel, through desk research and collaborative workshops, the team explored the astronaut's life in orbit from an experiential perspective. Drawing on both scientific and divulgative sources, a journey map of the current astronaut was developed, highlighting their interactions with the environment, needs, and daily activities. This representation became the foundation for a collaborative analysis and reflection process, through which additional feedback, implicit actions, current pain points, and future insights emerged areas where design can intervene to begin imagining who the next users might be and what their more implicit needs could look like (fig. 3).

Building a new design mindset

The interaction between academia, industry, and various disciplines made it possible to identify the difficulties that new designers may face when approaching such an extreme design domain, as well as the concerns of seasoned professionals in the field toward less conventional design approaches. This ongoing dialogue between domain and out-of-domain led to the adoption of one of the core action areas of Advanced Design—*Extreme Design* (Celaschi, 2018)—not only as a direction for innovating products and systems, but also as a channel for exchange and advancement within the research framework.

As defined by Celaschi (2016), *Extreme Design* encourages designers to look beyond their immediate disciplinary boundaries to discover "stimuli for change" (p. 68). In this phase of the research, it played a key role in shaping the interaction dynamics between future designers, current professionals in the field, and the processes of knowledge-building and project development for the space sector.

Relationships between different domains were outlined to make this interaction more inclusive and interdisciplinary:

- Field observation linked to gaming experiences;
- Scenario-building for short, medium and long-term futures connected to anticipation and future studies;

3. Collaborative construction of the astronaut's journey map.

- Innovation in product-service systems aligned with open innovation models;
- Validating ideas through physical prototypes in dialogue with virtual or mixed reality.

These relationships and needs are part of the project's overarching goals and, as we will see in the next intervention line, have been explored through several practical experiments.

3.2. Exploration

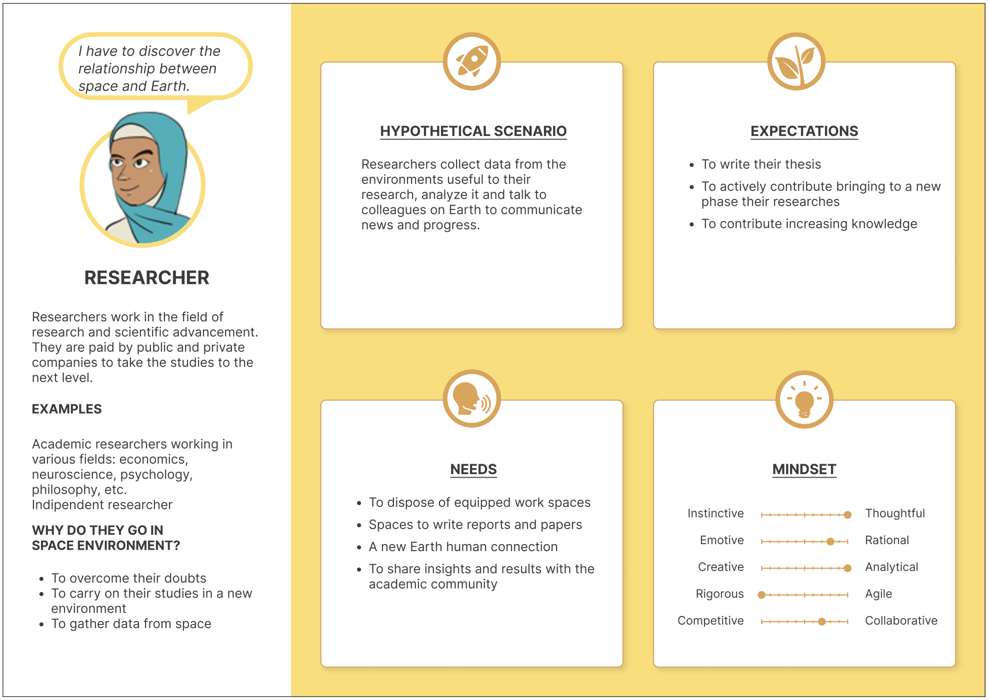
Tools: Questionnaires, user profiling templates, co-design processes and workshops, observatory
Actions: Observe to innovate, co-produce future scenarios and processes, validate through collective experimentation, learn digitally and in the field, generate new ideas, and test new formats of knowledge and design

Building a shared, sustainable, and open imagination for space exploration

Before identifying trends, relationships, and interdependencies that may arise within future habitats, it was first necessary to imagine who the potential users of near- and long-term space stations might be. The process of creating these archetypes was collaborative and open to public participation. The initial tools used were a future user profiling template and research based on scientific and divulgative sources. Cross-referencing primary data collected from TASI experts with secondary data led to the creation of initial proto-personas, which were later refined through an open questionnaire distributed to the digital community.

This approach resulted in the creation of nine archetypes, each with specific goals, expectations, and needs. These include: the Pioneer, the Researcher, the Artist, the Designer, the Mission Specialist, the Patient, the Space Traveler, the Content Creator, and the Station Manager (fig. 4).

This continuous exchange between internal and external perspectives highlighted several insights about potential future users: increased need for private personal spaces, the development of new work and leisure activities, and the requirement for dedicated workspaces, among others.



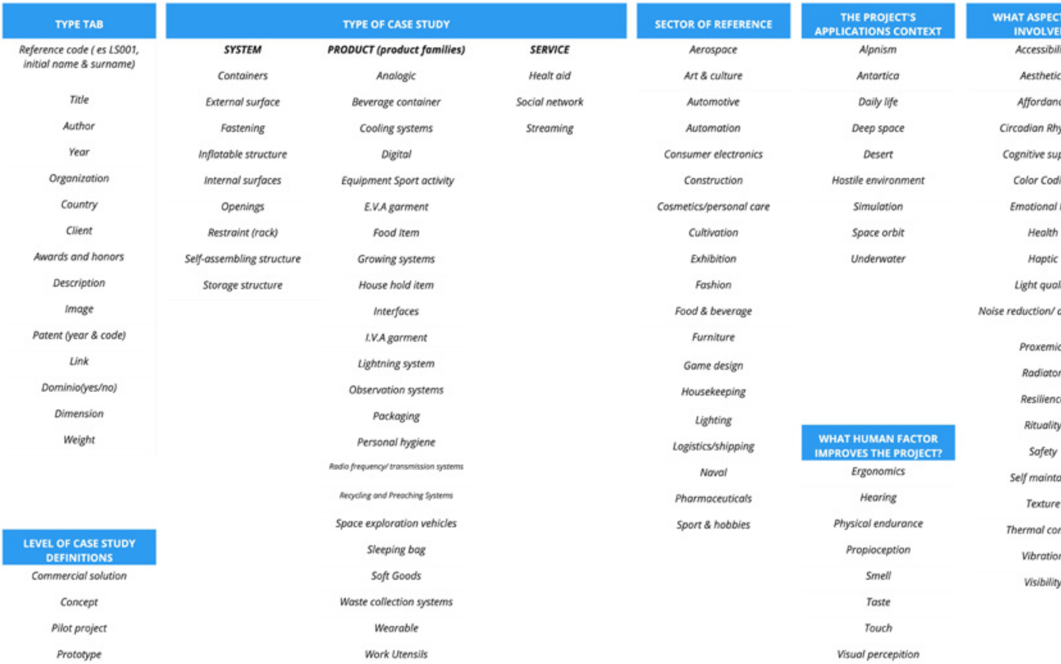
4. An example of a user archetype profile developed through the various research activities (image elaborated by Luigi Vella).

The exploration phase concerning the composition of future crews was accompanied by the observation and collection of products, concepts, services, best practices, and methodologies, both within the domain and from other extreme environments and adaptive experiences attentive to relational factors. The focus on lived experiences made it possible to center attention on the user as a person composed of both physical and emotional dimensions, and to view products and spaces as points of interaction.

This analysis led to the development of a case study cataloging template designed to be accessible and understandable to a wide community of designers (fig. 5). It became the foundation for formulating the advanced design methodology used to develop new habitat configurations, as described in the following paper.

Lastly, several formats for collaborative workshops were designed with the aim of:

- Validating the initial research findings (archetypes, actions, and needs) with designers and industry experts;



5. Basic cataloging template for case studies within the domain, outside the domain, and for methodological best practices.

- Building a cross-disciplinary design mindset related to extreme environments, informed by the contributions of professionals with different backgrounds and knowledge bases;
- Learning, designing, and validating through action-in a "learning by doing" mode.

An example of the latter is the *Space Workshop* held in April 2024, which involved 25 young designers and researchers (with backgrounds in product design, service design, and anthropology) guided by the project team and company representatives. In the first phase, participants approached the design domain through a virtual reality–guided gamified experience, which allowed them to observe and inhabit the environment, identify challenges, and collaboratively analyze them through co-design sessions (fig. 6).

The second phase, dedicated to conceptualization, introduced new users, new factors related to psycho-physical well-being, and new actions to consider within future habitats. This led

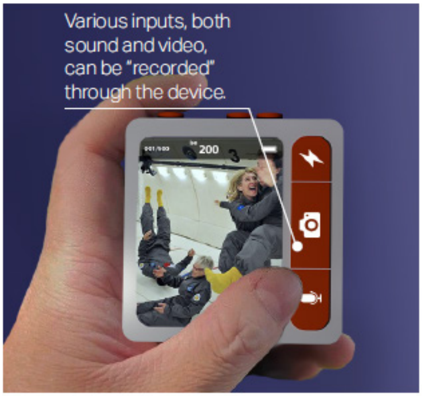
to initial reflections on design solutions that take into account these emerging users and the evolving spatial and relational affinities within space habitats.

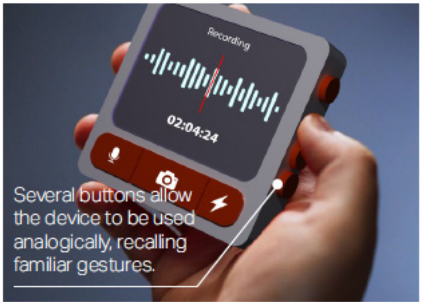
Building knowledge through a sustainable observatory

The various learning, validation, and collaborative design actions converged in the creation of an observatory model, drawing inspiration from the ADU experience (Celaschi et al., 2021) and reinterpreting it in the form of a new tool: the *Sustainable Innovation Observatory for Life Beyond Earth*. This digital space is designed to support designers in acquiring knowledge and developing new concepts, while also offering design strategies from an open innovation perspective. Its specific domains are:

- Far Future: offering long-term projections and visions to anticipate future challenges (Formia, 2017);
- Extreme Design: activating cross-fertilization between sectors and transferring knowledge across fields to promote sustainable innovation (Succini et al., 2024);

6. Space Workshop: learning process and early development of meta-design concepts (concept memory theme of Bastoni, Bologna, Fabbretti, Faceto, Pasini).





- Shelf Innovation: using the repository as a source of design projects and semi-finished solutions ready to be improved and adapted to meet emerging market needs (Celaschi, 2016).

3.3. Co-creation
Tools: Workshops, action research activities, co-design sessions
Actions: Inclusive co-construction for sustainable and responsible innovation

The final line of action focused on experimenting with the various tools and fine-tuning the proofs of concept.

The objectives of these ongoing or planned experiments—at different scales of the project—can be summarized as follows:

- Developing a multi-stakeholder action research protocol that uses the observatory as an initial learning tool and, subsequently, as a launchpad to expand future space habitat scenarios, stimulate new supply chains, and foster new collaborations;
- Activating continuous innovation processes that, through interaction between academia, young designers, and entrepreneurial players, can scale design processes from Earth to space—and vice versa—enhancing their sustainability;
- Facilitating interaction between product prototypes and the digital system for dynamic habitat configuration. The conceptualized products are intended to become a bridge between the virtual model, the initial strategic design process (users and needs), and the first touchpoints related to user well-being and spatial flexibility;
- Emphasizing designer responsibility;
- Creating synergies between the systemic design processes used during the ideation phase by TASI, the design-driven systems developed through this research, and TASI's own digital simulation systems (a topic explored in the next paper).

4. Conclusions: Space as an extreme context for rethinking terrestrial design practices

The aim of this research project is not to define a perfect, standardized solution to universally improve the well-being of future space habitat users or the learning paths of future stakeholders in the field. Rather, it seeks to propose a more interdisciplinary and contamination-friendly approach to design open to both domain and out-of-domain inputs. "Thus, it is apparent that the human is the most fragile and variable element in the system" (Meusburger & Bishop, p. 180), and each person reacts and perceives extreme, confined conditions differently. However, enabling a degree of spatial variability, even through small product systems or experiential adjustments, can support adaptation and prosperity in extraterrestrial environments.

For designers or entrepreneurs, confronting constraints far beyond their usual scope—such as limited mobility, zero gravity, breathable air confined to enclosed systems, or lack of access to resources beyond those already present in the station—forces a shift in design approach. It calls for a focus on factors of survival, uncertainty, emotional response, and well-being, while imagining what cannot yet be experienced firsthand. This design mindset can also be transferred to other temporary or permanent extreme or confined contexts (Inglese et al., 2024).

In fact, the research is now expanding to address additional aspects: designing for the space sector through an open innovation model rooted in sustainability and Made in Italy know-how (from both space and non-space sectors) is revealing strategies and experimental approaches that may be transferable to other complex challenges on Earth, such as those stemming from natural disasters (floods, desertification, etc.) or other emerging crises.

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This book presents ten innovation fronts developed in parallel through research funded within Spoke 1 of the MICS (*Made in Italy Circolare e Sostenibile*) Partnership. Set within the framework of Digital Advanced Design, the project explores the role of design and digital innovation in promoting sustainable and circular transitions across various *Made in Italy* sectors, bringing together knowledge and expertise from academic, industrial, institutional, and professional fields.

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