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A large hexagonal grid pattern, similar to a honeycomb, composed of numerous hexagons. Each hexagon contains a unique black-and-white design. The designs include: starburst patterns with radiating lines and dots; 3D wireframe cubes with internal grid lines; stylized human figures in various poses (some with dashed lines indicating movement or structure); and two hexagons featuring a close-up of a human face. The overall effect is a complex, repeating geometric mosaic.



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Disruptive Ideas for Outer Space Through Design. How Design Can Play a Strategic Role Beyond the Earth

Annalisa Dominoni

Politecnico di Milano

annalisa.dominoni@polimi.it

ORCID 0000-0003-1667-9786

Abstract

The newly emerging discipline of *space design* is aimed both to enhance the research into well-being in outer space — increasing the comfort of the astronauts — and to generate innovation through the cross-fertilization between living in space and living on earth — intersecting different areas of knowledge and fields of applications that can be taken from space and translated to earth, and vice-versa, in space jargon, *spin-offs* and *spin-ins*. Space is a very stimulating world to explore for a designer who wants to deal with the new, the unknown, and who can imagine more suitable environments, extra-terrestrial habitats, and objects, which do not belong to our daily life experience on earth, but which could be very suitable, useful, and also beautiful, for a new generation of people who will inhabit and perform them. This paper presents the *disruptive role of sensory design for space* through a case study that acts as a bridge between science, technology and beauty thanks to the capacity to predict new behaviours, gestures and scenarios in conditions never experienced before by the human being.

Keywords

Space design
Extra-terrestrial habitats
Disruptive design
Behavioral design
Well-being

Why Design Is Strategic for Human Space Exploration

In recent years, there has been a growing evolution in the space field, triggered by future planned human space missions, which once again propose the desire for exploration as their main driver, now developed principally by the private sector which looks at space tourism as a propellant to increase interest and budget. With a permanent settlement on the Moon and a manned landing on Mars as goals to support pioneer ambitions and efforts, a significant boost has been given to the research, to fill the gaps that still make these perspectives impracticable. Following a trend that has become widespread in several industrial sectors, space agencies are turning to the adoption of cross-disciplinary teams as a tool to stimulate innovation. Design is, indeed, synonymous with innovation focused on human needs, and over time it developed to include knowledge from engineering, innovation economics and technology, to better interface with science as the basis for novel applications.

Design for space means redefining the task of design in this context, finding interlocutors and possible areas of convergence, methodological and operational tools to offer its expertise to space agencies and industries and contribute to solving the problems of living and working in confined environments and in conditions of microgravity with innovative projects. Design work, even if indispensable, is not sufficient for the success of the project if it is not integrated with the co-participation of these other actors. When this is the case, small and agile cross-disciplinary teams are recognized as the main drivers of innovation.

The role of the designer is to build a bridge between different disciplines and knowledge to develop new environments, products, and tools to allow astronauts to live and work in better conditions in space, and specifically on board the International Space Station (ISS). The aim is to increase comfort and well-being, facilitate human movement and improve the performance of the various activities conducted in microgravity to ensure greater productivity and quality of life on board. There is a whole new world to be built (Dominoni, 2021).

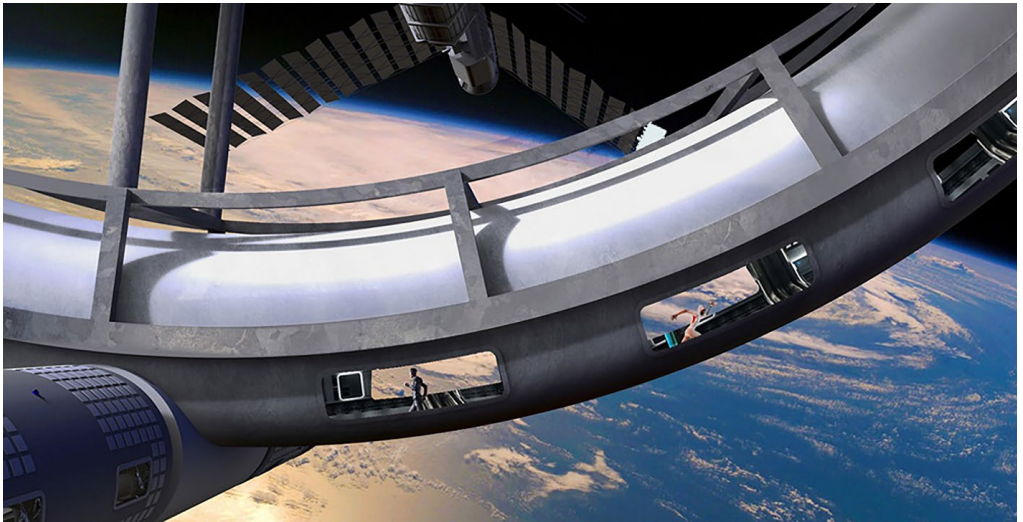
In this third millennium, human beings are definitely the protagonists of a *new space age* and have at last conquered a primary role within the scale of values that characterises a human space flight: they are no longer just professional and super-skilled astronauts with years of demanding training in preparation for the mission, they can be also scientists, researchers, and not least, tourists ready to experience space travel. So they are not trained therefore to live in an extreme environment, in conditions of permanent emergency, with limited resources and services, to the detriment of their physical and mental well-being. The *new human being* is a person who wants to live comfortably and, why not, have fun. This means that the entire environments need to be totally re-thought and re-designed based on the physiological and psychological needs of the space travellers. The same is true for objects, facilities, and tools for everyday activities (living, working, sleeping, eating, taking care of ourselves, resting, etc.) which should make life in space easier by trying to reduce the difference between living in space and living on earth. For these reasons, the role of space design is fundamental.

Design can play a role in the design process for space at various levels and scales:

- designing beautiful and functional environments to make astronauts feel better when living and working on board the ISS, by changing the internal configuration in order to increase the habitability performances;
- introducing innovative lighting systems to change the perception of space and balance the circadian rhythms that are altered in space for lack of natural stimuli;
- proposing equipment to facilitate the various activities, for example, fitness in microgravity, in order to maintain bone and muscle mass, but also to try and make physical exercise more attractive by introducing entertainment;
- creating specific tools for the preparation, consumption and conservation of food, or objects to facilitate self-care and guarantee a good level of personal hygiene;
- increasing the performance of the working instruments to support astronauts during their various tasks;
- improving leisure time, favouring both the needs of privacy and conviviality or imagining new ways to facilitate communication with family and friends.

These are only a few examples of the activities, needs and fields of applications that space design must address, which in the absence of gravity are much more complex and require the designer to pay greater attention to the human body, from the physiological, emotional, perceptive and psychological point of views, because it responds differently to the various extreme conditions, and to the interaction with objects and the environment.

Increasing the scale of the project, the role of space design is fundamental for transportation into space, such as the fleets of launchers Apollo, Shuttle and the new generation Falcon and Crew Dragon, as well as the new space stations [Fig. 1](#), Moon and Mars bases, and rovers to explore the extreme territories (Connors et al., 1985). In those contexts, the contributions of designers can include the shape of the external structure, the interior habitat for the crew and the furniture, defining all the details such as the coatings, the colours, the materials. Going into greater depth, the structures of the seats that will welcome the astronauts on the space vehicles, or the restraint systems to anchor them inside the ISS, and even clothing for living and working in confined environments and in conditions of microgravity (Souza et al., 1991–1998). At this scale, the most important aspect affecting the design choices is precisely the confinement and lack of gravity (Stuster, 1986). The designer deals with very small spaces that need to be used intelligently to allow the crew to live and work comfortably and efficiently, both individually and as a team, without bothering each other too much and with the possibility of having some private space to relax in and find their own balance.



The Capacity to Predict Behaviours and Gestures in Designing for an Unknown Environment

Designing for space means starting anew, applying a different logic for a different environment, conceiving new instruments for uses and activities that are difficult for us, who live on earth, to envisage, but which are premised on a different relationship between our bodies, objects and the surrounding environment. The impossibility of making reference to a consolidated experience built over a very limited number of human space missions, and of assessing the true validity of the designer's hypotheses until the vehicle is already in orbit, jeopardise the success of project development in the space field. For this reason, the visualisation and analysis of all the gestures and movements possible in relation to extra-terrestrial environments should be introduced as a determining factor during the design of the objects to further knowledge of the dynamics of the human body when in microgravity environments.

A designer must have the capacity to imagine life in space, even if it is not part of the normal experience of a human being, to imagine how his body could move in conditions of microgravity, how postures and gestures would change in relation to objects, and what new objects might be fittingly designed for Space.

During my experience of designing and researching for space at the Design Department of the Politecnico di Milano for more than 20 years, I have found that the most important and most interesting difference between *design for earth* and *design for space* is in the design process itself, which involves the *capacity to predict* the design of usage and gesture: visualising possible human gestures and movements in space, in confined environments and in microgravity conditions, which cannot be compared to the human experience on earth (Dominoni, 2002). This means imagining, for instance, the alteration that might be sustained by the astronauts upon assuming the *Neutral Body Posture (NBP)* and foresee what needs might be supported based on the ergonomic, physiological,

Fig. 1

Authors: Space4Inspiration (S4I) Course, 1st edition 2017.

Name of the project: Interplanetary missions. Short description: The role of *design for space* is to increase the well-being of the crew, imagining new products and habitation modules to fit the extreme environmental conditions.

Credits by Space4Inspiration (S4I) Course, 1st edition 2017, School of Design, Politecnico di Milano.

perceptive, psychological, emotional, and motor factors under conditions that are completely new and *unknown* to the human being.

To better manage the transition between the two environments and practices, design for earth and design for space, I created a specific methodology which I call *Use and Gesture Design (UGD)*, based on the simultaneous design of spaces, objects, and gestures. In other words, in tandem with developing the project, I also conduct a careful analysis of the actions, movements and gestures of the body in microgravity. This means projecting the features of the future object on the scene of its possible uses, and visualising it in action: in your hands, wearing it, in the zero-gravity environment in which the object will be used, and foreseeing how it will be used, in which ways, in which environments and with which interfaces. When I design for astronauts Fig. 2, I try to immerse myself in the ambience of the ISS and imagine how our bodies might move in microgravity, how our posture and our gestures might change in relation to the objects. And especially how the new tools could be designed to function properly in space as well, and, why not, leveraging the lack of gravity, which has always been seen as a barrier to be broken.



Fig. 2

Authors: Annalisa Dominoni.

Name of the project: IVA Integrated Clothing System for the International Space Station (ISS).

Short description: The methodology of *Use and Gesture Design (UGD)*, specific for space, is based on the simultaneous design of spaces, objects, and gestures and on the capacity to predict visualising possible human gestures and movements in space, in confined environments and in conditions of microgravity, which for us are completely unknown, and are not part of our human experience on earth.

Producer: Benetton Group with Agenzia Spaziale italiana (ASI).

Credits by the Author, Design Department, Politecnico di Milano.

The design and creation of a new object or environment for space, should take place concurrently with provisions for the use of the new object or environment. In this design process, the designer becomes a filmmaker, able to create a potential script for a new tool, which implies the relation with the environment, the movements, and the gestures of the astronaut. It is as if the formal idea and performance of a project were developed concurrently with a potential screenplay of movements and gestures of the operator (Rabardel, 1997). In the design process, the *artefact* is just as important as the *patterns of use* and the creation of an idea. A design concept for space stems from the simultaneous design of simulated actions, movements and gestures based on how the design object should or could be used, how and with what procedures, for how long and by how many *actors*.

If designing for space means projecting all the features of the new object onto the scene of its possible uses and visualising it in action — in the hands of the user, or worn in the case of garments

and accessories, and in the environment of microgravity where it will be used — it follows that the user is also the author of the object, because its performance makes it complete and fully completes the project. Every user action and gesture has in fact to be understood as an *interpretative action*.

The transverse reference to the background of choreographic ideology — which is to say the structuralist intention by which every action can be separated into a series of single movements and reconstructed as a sequence of movements — may be useful when illustrating the methodology that the designer should apply when designing for use and gesture. Like a director who must conjugate the engineering of screenplay narrative and the figurative nature of the storyboard — tracing a thread through the identification of the nodal points essential to film editing, and including and determining the geometry of actor and extra movements, as well as camera movements, connecting all of them with the soundtrack rhythms — so the designer of structures and equipment for living and working in space, following a program of uses or gestures, expresses a predefined sequence of actions that enable operators, in this case astronauts, to reconstruct designed movements for the use of new products, and therefore to reproduce them. Going back to the choreographic ideology, the designer must not only foresee the series of actions involved in the use of the object, but must enhance, at the planning stage, both the gestures and the movements that accompany the object, and the object itself, like in a dance, and must take on the role of the artifice of a series of gestures, a program of ritualistic movements.

Disruptive Ideas for Outer Spaces Through Design

The cutting edge of space design is the design of sensory environments. It is to find innovative solutions by combining industry know-how and research in universities, but also well-being and sustainability, which will allow people in the future to live in space as we live on earth today, but with more awareness and respect for our planet and its resources.

In my space architecture projects I like to go beyond the functional aspects, and consider physiological and emotional factors as well, which have a great influence on our behaviour.

In the latest concept for a new space station that Thales Alenia Space Italy (TASI) commissioned to Benedetto Quaquaro and myself, we worked a great deal on the sensory aspects of habitable modules. Indeed, everything is amplified in a confined environment: noise, light, the feeling that materials give us, the proxemics, the interface with objects, etc... The quality of the living spaces therefore takes on greater importance.

For example, the quality of light, which must be able to balance the circadian rhythms that are altered by the lack of natural light; using light I can create different areas and atmospheres in the same open environment, depending on the activities of the crew, acting on the temperature and colour of light, but also on its shape. Imagine for example light screens to divide the spaces, or light bubbles that define areas of work or relaxation.

The visual and tactile qualities of the materials are equally important to make the perception of the environment more comfortable and pleasant.

Air quality is also important, as is the quality of the odours we perceive, the acoustics and the reduction of background noise.

In addition to contributing to the planning of extra-terrestrial sensory environments, design must be an inspiration for private companies with disruptive ideas capable of proposing new visions, new applications of space technologies, but also of good practices and behaviours which we can transfer from space to earth and vice-versa, and that can inspire new projects to improve the lives of astronauts.

Design becomes indispensable to create new environments and objects designed specifically for space that can *turn constraints, such as microgravity, into opportunities*. And perhaps, it would also be advisable to think of environments for the amusement and entertainment of the crew.

This new space station, called *New Orbital Infrastructure Recreational/Habitable Configurations*, introduces for the first time the idea of *recreational space*, with more room for the astronauts' entertainment.

The *New Orbital Infrastructure Recreational/Habitable Configurations* for a space station represents the case study described in this paper as an example of the contribution of design for outer space that acts as a disruptor and a *bridge between science, technology and beauty*, thanks to the capacity to predict new behaviours, gestures and scenarios in unknown conditions never experienced before by human beings.

We applied design methodologies such as *Human Centred Design (HCD)* and *Use and Gesture Design (UGD)*, together with ergonomic aspects, to increase the comfort and efficiency of the crew in a confined environment and conditions of microgravity, optimising crew space usability and subsystem arrangement through flexibility and re-configuration.

In this design phase it is too early to describe the methodological process in detail, as the project is at a preliminary concept stage and is presented through digital models. UGD methodology becomes very useful when astronauts can interact with the physical mock-up of the habitable module. By getting in touch with the interior and equipment, we can check the quality of the design to increase habitability and performance through the analysis of the astronauts' movements and gestures.

Our proposals concerning *Concept Design Solutions* for both the external and internal configurations and the volumes of a new space station were focussed on the two tasks we were assigned: *window design* and *recreational/habitable module*.

Concerning *task 1*, our purpose was to design various solutions injecting elements of style to the existing technical solution conceived by TASI to build a strong identity for the new spaceship, focusing on recognisability (from the outside of the spaceship as well) and modifying the panes with alternative shapes and colours depending on the requirements of the materials. The goal we wanted to achieve was to transform the spaceship into a precious object, a *jewel in space* Fig. 3 in the dark sky, designing a new configuration that alternated large round and oval windows to look like precious

stones, creating a *ring* to highlight the window light as it stands out against the dark sky, if black, or the aluminium modules softly, if gold, or strongly, if red.

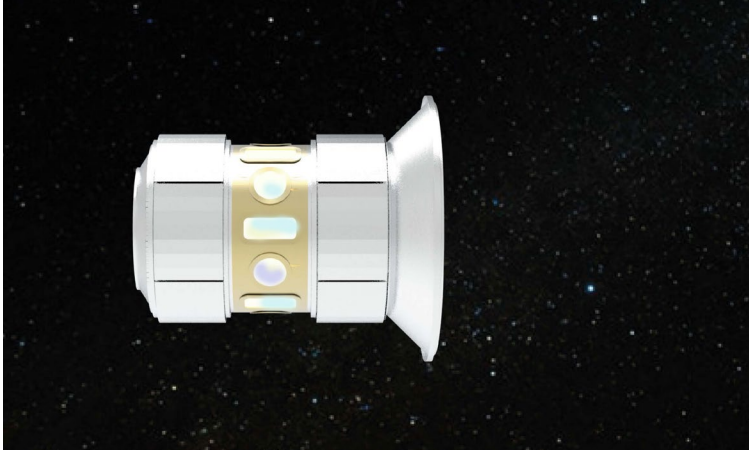


Fig. 3

Author: Annalisa Dominoni & Benedetto Quaquaro.

Name of the project: New orbital infrastructure recreational/habitable configurations for a space station.

Short description: The idea for the exterior of this new space station proposal has been to transform the habitation module into a precious object, a *jewel in space*, that could be recognizable in the dark sky as a symbol of Italian style. Moreover, the new configuration in which round and oval windows are alternated like precious stones creates a ring to highlight the window light from the outside, while from the inside, the largest surface of windows allows astronauts to enjoy a view of the earth and the deep space around it.

Producer: Thales

Alenia Space.

Credits by the Author, Design Department, Politecnico di Milano.

Our proposal to enlarge the glazed surface of the windows was discussed with the TASI engineers and considered feasible by them in the concept phase. Considering the complexity of the project and the long development time, it will be necessary to further study the structural integrity in relation to the choice of materials and technologies available in coming years.

Concerning *task 2*, the study of the internal accommodation of the recreational/habitable areas focussed on four topics: re-configurability, optimization of open spaces, lighting adaptability, stowable functional furniture (e.g. working/lunch desk, restraints); the innovative design solutions related to elements of fashion and product design in the interior habitat explored various possibilities, including a relaxing couch, the enhancement of feelings of privacy (e.g. isolation, including from acoustic noise), handrails, foot restraints and stowage solutions focusing on aspects of technical feasibility and in compliance with the constraints/requirements intrinsic to the preliminary concept provided by TASI. Imagining the *jewel in space* from the inside, it is revealed to be an immersive experience into dark space. The feeling we wish to transmit is entering the window, surrounded by glass — sliding into the interspace created by the round window — and *looking at the stars lying on the sofa*.

We have completely re-designed both the exterior skin, including the windows which alternate different shapes and create the idea of a continuous transparent surface, and the interior of the habitation module: a soundproofing textile padding able to reduce noise and increase acoustic isolation covers the structure of the windows, as well as the interior of the module, creating rings of sofas and the warm feeling of an embrace.

The project for the *New Orbital Infrastructure Recreational/Habitable Configurations* for a space station was related to the request by TASI to develop *innovative concept design solutions aimed at emphasising the Italian style through design*. The inspiration which has driven this rather difficult task relies on three key-

words: Italian Design—Sixties—Space Age.

Re-configurability was the key to gain more internal space and flexibility. The racks on the ISS are replaced by easily removable cylindrical volumes that can slide and be transformed into *tailored chaises longue* to optimise free space Fig. 4. The cylinders run on tracks serving as soft surfaces of support, as well as shelving, or removable containers. The internal space of the cylinders is intended for the storage of equipment and tools.



Flexible restraints will be included to *softly* maintain the body posture on the cylinders/chaises longue, and there will be accessories for working, having lunch, resting and so on. Female Velcro® shapes are distributed along the entire soft surface to allow the crew to move or maintain body posture thanks to male Velcro® socks.

The internal spaces were reconfigured to acquire more open volume and greater flexibility to accommodate the different activities and needs of the astronauts: working, relaxing, gathering, reading, playing and listening to music, resting, looking out the windows, organising meetings and eating meals.

The light changes in intensity and colour following circadian rhythms with the aim of changing the perception of the environment to suit the various activities, while the overall feeling is one of relaxation and wellness. We put wellness as a focal point for the entire project, creating a sensorial environment in which all senses are stimulated, to contrast the lack of natural stimuli in space. In order to achieve illumination adaptability, we imagined LED rings for diffused light that changes in intensity and colour in relation to the various activities on board, integrating the circadian rhythm system with chromotherapy: for example, white-gold light during every-day-activities, white-blue light when a relaxing environment is required, gold light for gathering, recreational activities and eating together or orange light for fitness which implies being very active and energetic. Removable personal lights to be fixed where needed inside

Fig. 4

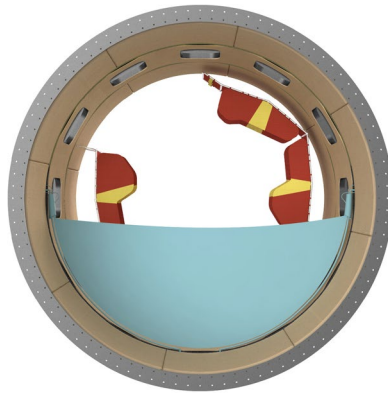
Author: Annalisa Dominoni & Benedetto Quaquaro.

Name of the project: New orbital infrastructure recreational/habitable configurations for a space station.

Short description: The interior of the habitation module is completely disruptive compared to the existing interior spaces of the ISS: the whole environment is based on sensitive materials, such as acoustic textile padding that can reduce noise and increase acoustic isolation, which covers the structure of the windows as well as the interior of the module; a chromatic lighting system based on the circadian rhythms follow the day and night activities of the astronauts, and also encourage moments of recreation; the racks on the ISS are replaced by easily removable cylindrical volumes that can slide down and be transformed into tailored chaises-longue to optimise free spaces.
Producer: Thales Alenia Space.
Credits by the Author, Design Department, Politecnico di Milano.

the space station were also included in the project. In addition, we propose introducing light walls to virtually divide the interior space of the module, introducing the use of Artificial Reality (AR) for fitness activities and immersive experiences into nature.

The entire project includes the design of the environment and the proposal of specific crew system/outfitting items and tools to be integrated into the interior with the aim of enhancing space re-configuration for crew privacy and purposes of socialisation: among them are a collapsible textile partition **Fig. 5**, made of innovative acoustic textiles inspired by the *gennaker snuffler* used in sailing competitions, and a foldable relaxing chaise longue to provide a support for rest and relaxation.



If we compare the case study of the *New Orbital Infrastructure Recreational/Habitable Configurations* for a space station with a ISS normal interior, where astronauts are used to living today **Fig. 6**, we can easily understand the *evolution of space design*, and overall, the impact of design's contribution in two directions: to increase the qualities of habitability and well-being in space (1); to create *spin-offs* and *spin-ins* between space and earth and vice-versa, involving design companies in order to find new applications and solutions for both fields.

Fig. 5

Author: Annalisa Dominoni & Benedetto Quaquaro.

Name of the project: New orbital infrastructure recreational/habitable configurations for a space station.

Short description: The whole project includes the design of the environment and the proposal of specific crew system/outfitting items and tools to be integrated into the interior, with the aim of enhancing the reconfiguration of the spaces for crew privacy and purposes of socialisation, such as a collapsible textile partition, made of innovative acoustic textile inspired by the gennaker snuffler used in sailing competitions, and a foldable relaxing chaise longue to provide a support for rest and relaxation.

Producer: Thales

Alenia Space.

Credits by the Author, Design Department, Politecnico di Milano.



Fig. 6

Author: Annalisa Dominoni.
Name of the project:
IVA Integrated Clothing
Support System
for the International
Space Station (ISS).
Short description: An
interior of the International
Space Station (ISS) shows
the astronaut Roberto
Vittori wearing the IVA
Integrated Clothing Sup-
port System, designed by
the Author, in an extreme
and chaotic environment
in which the quality of life
in space is not considered
a priority. However, the
well-being of the crew
directly affects the perfor-
mance and the success
of a human space mission,
and for that reason the
contribution of design
in space is fundamental
and strategic to improve
the crew's conditions.
Producer: Benetton Group
with Agenzia Spaziale
italiana (ASI).
Credits by the Author,
Design Department,
Politecnico di Milano.

To give a concrete example, the panels and acoustic fabrics that we have proposed for the interior of the habitation module and part of the furniture such as the textile partitions, are by an Italian company, Caimi Brevetti, who thanks to our project is testing the efficiency of the acoustic panels at NASA with the aim of inserting them into the structures of the pressurised modules of the ISS, to reduce the reverberation of the background noise. In this case, a new terrestrial technology is going to be applied in space thanks to the mediation of design, which proposes disruptive new ideas by cross-fertilising very different industrial sectors.

In the future, it is conceivable that this trend will be amplified, thanks to the role played by private companies in space, and that the contribution of design can give rise to innovations and new business models that will help encourage the development of human space exploration.

Annalisa Dominoni
Architect, designer, Ph.D.
Associate professor at
School of Design, Politec-
nico di Milano. Through her
design research, scientific
publications and teach-
ing activity she has been
responsible for affirming
the role of design for outer
space. In 2017 she created
and directs Space4Inspir-
Action, the 1st and only
MSc Course in Space
Architecture and Design
supported by the European
Space Agency.

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In the nexus of design and Artificial Intelligence (AI), the convergence of ethical, political, and creative facets demands a decentralized approach guided by data justice and posthumanism. As AI's reach expands into societal and environmental spheres, the imperative is not neutral but deeply entangled with socio-political contexts and power structures. The shift from tech-centricity to collective needs dovetails with the urgency for non-anthropocentric design, particularly with autonomous agents. This global perspective challenges "for good" narratives and raises questions about digital colonialism, while artistic experiments redefine the boundaries of creativity and aesthetics, compelling a holistic reevaluation of design's role in AI's multifaceted impact.

Flaviano Celaschi

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