Chapter 4
Space Design Between Research, Project and Education

4.1 Five Case Studies of Space Design

In this chapter I have chosen five case studies from my work of designing, researching and teaching Space Design to support the previous three chapters with the aim to demonstrate the advantages to integrating the Design discipline in the Space industry. The case studies are very different, but follow a chronological order; according to the development of my research path, and overall, they are all first pilot projects of Space Design, and are pioneers of a discipline and a methodology that I have tried to affirm throughout my career, now more than twenty years.

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In addition, all the case studies demonstrate the importance of a multidisciplinary approach in which Design emerges as a bridge between science and beauty, able to speak the various disciplines’ languages as well as manage working groups, made of different backgrounds and know-how according to the nature of the projects, which could not only embrace the area of a clothing support system to perform activities in microgravity, but also equipment and tools to facilitate the various activities on board, lighting systems, lunar or orbital bases and so on.

The designer should interpret—by means of the formal and symbolic qualities of its projects—people's needs, expectations and desires in relation to the environment, and at the same time elevating the degree of their general well-being, the functionality of the activities and the usability of interface’s facilities and instruments for astronauts, to achieve better goals that directly affect the success of human space missions. Not last, these projects show how fundamental is the involvement of the companies, both in the space industry and in the private sector,
to design objects, equipment and habitable systems that should be at the same time innovative and feasible.

4.1.1 VEST. Project and Experiment on Board the ISS

The first case study describes, in fact, two case studies, but joined by the same topic, an innovative integrated system of garments designed for the crew activities, VEST and GOAL, that were born by a project research financed by the Italian Space Agency (ASI) in 1998, and that I developed as a feasibility study with the aim to design models and prototypes to be tested for two experiments on board the International Space Station (ISS) in which I was the Principal Investigator: VEST, Clothing Support System for the International Space Station, was performed during the Italian Marco Polo Mission, in April 2002, and GOAL, Garments for Orbital Activities in weightLessness, during the Eneide Mission, in April 2005.

The two experiments VEST and GOAL are the tangible results of my intuition of an innovative integrated system of garments to be used during the human space flight missions with dedicated Space items, for microgravity conditions and confined environment, when performing Intra-Vehicular Activities (IVA), that increase comfort, efficiency and wearability.

Aim of the experiments was to demonstrate that the provision of a new integrated system of garments to the crew would not only increase their well-being through the use of specific fabrics for confined environments, able to improve thermoregulation and body hygiene, but also tailored models designed for the Neutral Body Posture (NBP), assumed by the human being in microgravity, that integrate particular repositionable pockets and restraints to move better through the interiors of ISS as well as to fix the body when settlement activities are required.

Also, not expecting to use additional time for the experiments, the clothing were worn during normal daily activities, work and rest, allowing to collect useful data with less impact on the crew schedule, and to prove that in general with VEST and GOAL equipment less mass and less volume were assured.

This case study also describes an example of spin-in, in which I applied cuts and seams taken by the Earth snowboard clothing (Dominoni 2002) that then I translated to the new integrated system of garments because I found the posture performing this sport is very similar to the compact NBP assumed by the body in microgravity with knees towards the shoulders.

I am very proud to affirm that VEST and GOAL are the only two example until now in which a space agency, in this case ASI, sponsored and supported the realization of a fashion design project, and overall, accepted to collaborate with a private company, Benetton Group, that I had involved in the project because they specialized in sport and technical garments. It was my first gesture to demonstrate that also the private sector, if well driven, could be involved in the space programmes. We could consider that gesture as one of the first strategic action driven by Design that now we would call it new space economy.
4.1.2 Couture in Orbit. A Capsule Collection for ESA

The second case study presented is the project *Couture in Orbit*, an experience of research and teaching that I led with a group of selected students at the School of Design, Politecnico di Milano, on the invitation of the European Space Agency (ESA) in 2016, with the aim to create a *capsule collection* inspired by Space scenario, using *ESA technologies*, and designed to be worn every day on Earth.

Compared to the two previous case studies, in which *VEST* and *GOAL* are both projects of a new integrated system of garments designed to be worn by astronauts on board the ISS, and in which Design serves space environment (*Design for Space*) generating a spin-in, *Couture in Orbit* is the reverse case study, in which Design is inspired by Space, and is pushed to imagine new applications for space technologies to integrate into terrestrial garments (*Space for Design*) generating spin-offs.

Working together with the Italian partner of ESA for the Technology Transfer Solutions, Rina Consulting, we have carried out extensive research into ESA space technologies patents to try to interpret and transform them looking at the social needs, with the aim to induce new behaviours driven by technology.

*Our principal aim was to find relations between life in Space and life on Earth connecting the two environments and considering not only technological spin-offs or spin-ins, but also emotional language and usability.*

We transformed inspirations into shapes and textures by looking at astronaut postures and movements in microgravity and considering their activities in Space in relation to the objects they use and the environment they live, in order to imagine new gestures, interpret new needs and generate new ideas.

*Couture in Orbit* today remains the first and only case study in which a space agency, this time ESA, decided to use the design and fashion language to communicate to a huge public its role with the aim to celebrate space exploration and research exploitation and their impact in many fields of our life.

4.1.3 Space4InspirAction. A Space Design Course with ESA

The third case study is *Space4InspirAction (S4I)* that I created in 2017 together with Benedetto Quaquaro and now is at its 4th edition 2020. *S4I* is the 1st and unique international Course of *Space Design* in the world, recognized and supported by the European Space Agency (ESA) through experts and scientists who suggest and then deepen with us the project themes in line with the objectives of the space agencies’ strategic programmes. The Course *S4I* is the principal design laboratory in the second semester, inside the Master of Science in Integrated Product Design, at the School of Design, Politecnico di Milano.

The collaboration between the *S4I* Space Design Course and ESA is not a spot project, but the beginning of an ongoing agreement about an *academy—research—*
design process to ensure the development of innovative ideas in which the contribution of design discipline is recognized by ESA as fundamental and strategic to generate disruptive visions of habitability in extreme environments and equipment solutions to increase the wellness in Space.

Thanks to ESA, we are able to compare our design vision with real conditions and requirements and find innovative solutions designed for Space, but that can be also transferred to daily life on Earth becoming spin-offs.

Space allows students to develop creativity with intense visioning activities by confronting their projects with confined and microgravity environment, that is not part of our common experience. The unusual and extraordinary environment offers the students the possibility to think out-of-the-box, like astronauts experience looking at the Earth from another point of view, outside the atmosphere, together with the chance to increase the creativity and the ability to imagine and design new objects and tools starting from a perspective completely unknown.

Through a new methodology that I have developed and called Use and Gesture Design (UGD), the Design role is not limited to creating objects, environments, architectures, but also new behaviours and gestures of astronauts in relation to the use of designed objects, environments and architectures.

4.1.4 Fashion in Orbit Versus Space Fashion Design

The fourth case study is the unique spin-off generated by Couture in Orbit. Looking at the extraordinary results of the project presented at the London Science Museum on May 2016—during an event including a catwalk and an exhibition of the materials and technologies used for the capsule collection—which have generated over 20 million media feedback responses, and we decided (Benedetto Quaquaro and I) to continue the experience together with ESA, creating a specific Higher Education Course, called Fashion in Orbit, at POLI.design (the Consortium of Politecnico di Milano) in February 2017, based on the same idea of Couture in Orbit: a capsule collection of garments to be worn on Earth that integrates Space technologies and innovative materials.

Fashion in Orbit was not a curricular Course scheduled inside a Master of Science like Space4InspirAction, but was open to young professionals who wanted to develop innovative products in fashion tech and smart textiles, inspired by space and technology research, in order to find new applications and spin-offs for materials and textiles driven by attractive solutions of garments, which are able to increase the value of the technology itself. Fashion in Orbit pillars included fashion, technology and space inspiration.

We involved specific companies of technology focussed on sensor systems and data collection, together with many other companies of the private sector coming from smart textiles and luxury fashion fields. Colmar, an Italian brand of sportswear, very known for the ski clothing, was our main sponsor, while the other companies—Alcantara, Caimi Brevetti, Coats, Limonta, Luxury Jersey,
OmniaPeg, Sitip, Soliani, Thermore—supported our projects supplying materials, fabrics, accessories and fabric processing systems to realize the capsule collection.

Our strategy was to put together companies coming from distant fields of application and know-how, as the new acoustic textiles product made by Caimi Brevetti—which integrates a strong scientific research on the sound propagation—with OmniaPeg—which is dedicated to producing pleats of haute couture fabrics in silk—with the purpose to create innovation. This strategy of putting around a table distant knowledge—observing products and productive processes which coming from areas that we never imagined integrating and trying to generate new connections and thoughts asking ourselves *what if?*—we found it is a very good methodology to produce disruptive ideas and innovative products.

All the conceptual works emerged at the end composing the capsule collection of *Fashion in Orbit* represented different identities and backgrounds, as the companies involved, and shared an intimate relationship with the cosmos, which was expressed through garments with new languages full of emotion, feeling and poetry, mixing fabrics, materials and technologies in unusual and surprising ways.

A year later, in 2018, we extend the area of application of fashion to product design, to give more possibility to innovate crossing different fields, and we called the 2nd edition *Space Fashion Design* transforming the formula of the Course for professionals to a contest in which we worked focussed on a unique brief defined together with the private company and ESA.

### 4.1.5 Moony. A Lunar Base in Lava-Tubes for Igluna

*ESA_Lab@*

The fifth and last case study I present in this book confirms the overture and the interest of the European Space Agency (ESA) to improve cooperation across Europe by building an international and multidisciplinary platform through the collaboration between different disciplinary perspectives developed by different universities and research centres. The principal aim of this new project is to create an educational environment able to inspire a potential *future generation of Space experts* and to analyze the future development of technologies being tested to discover possible new potentialities for human space exploration.

I was invited in September 2018, together with Benedetto Quaquaro, to be part of *Igluna*, the pilot project of *Esa_Lab@* coordinated by the Swiss Space Center and supported by the European Space Agency (ESA): a multidisciplinary platform to create a *space habitat* with the aim to demonstrate how to sustain life in an extreme environment using space technologies for disruptive innovation and cross-fertilization. Teams of students from all over Europe, supervised and supported by their academic institutions, were called upon to develop a series of modular demonstrators inspired by the context of a lunar habitat.
The Politecnico di Milano was represented inside Igluna project only with our Design Department. Having the role of designers we were asked to give shape to the whole lunar base—that was to be built in the lava tubes, under the Moon surface, to protect the human settlement principally by cosmic radiations and meteorites—integrating into the internal configuration of all the other projects (a part of robotic arms to help the realization of the lunar base in situ, greenhouse systems for extreme environments as well as boxes containing experiments for life science) that should have converged in a final exhibition of the results.

Particularly, our Moony project, being a link between the actually built habitat and its vision on the Moon, tried to picture a habitat and mission development that could appeal imagination, but restraining creativity to plausible technologies and operations, based on solid case studies. There are several issues addressed, such as how to build and place a housing module safely in an extreme context—responding to requirements that can encourage the adaptation and comfortable stay of the human beings—or which king of technology to use to build the base—integrating in situ materials, as regolith, with collapsible inflatable structure—that requires research, experimentation, tests and in which demonstrators result to be very useful.

The analogue, as the demonstrators of space environments reproduced on Earth in territories with similar characteristics are called, was completed inside the swiss glacier of Zermatt, the Matterhorn Glacier Paradise, and has been inaugurated at the end of June 2019 to test all the prototypes that belonged to the various experiments. The 1st edition of Igluna 2019, brought together 19 teams from 13 universities in 9 different European countries.

The multidisciplinary nature of Igluna project covered a full range of topics, going from the habitat conception and construction to life support systems, communication, navigation, power management, as well as science and human well-being. If we imagine to build a livable environment—especially one far from the Earth—we should take into account all aspects of human life, that includes food production, energy and oxygen, the construction of shelters, the provision of instruments and the enabling of communications. Teams from different universities were either mono-disciplinary or cross-disciplinary, but they worked in the context of a multidisciplinary project where different contributions required to be integrated developing oxygen and electricity production processes, a mechanism to cultivate algae, a system to use urine to fertilize plants, sports facilities, a laboratory, a system of communication and control, a robot for digging paths in the ice and more. Expertise involved ranged from a different kind of engineering, from aerospace, biologic, electronic, robotics to computer science, geology, architecture and design disciplines.
4.2 VEST. Projects and Experiments on Board the ISS

In April 1999, the area for scientific research of the Italian Space Agency (ASI) organized the national workshop on the Scientific Use of the International Space Station (ISS), which was attended by about 200 participants from the Italian scientific and industrial community. On that occasion, the opportunity was created for a better knowledge of the resources and support that the ASI could provide and it was clear that there was considerable interest from the scientific community in terms of programmes and proposals, although not evenly distributed across the four thematic areas. One year after this initiative, also in the light of the restructuring of the ASI, the workshop on Scientific and Technological Use of the ISS was organized at the astronomical observatory of Capodimonte in Naples on 17, 18 and 19 April 2000. The aim of the workshop was to stimulate and address scientific and technological proposals and projects, national and international collaboration, and verify the needs of the community in the different stages of proposal, design and implementation of programmes, also in view of the initiatives of the ASI, for the development of operational and engineering centres in support of the scientific community. The participation of those interested in the technological use of the International Space Station (ISS) was one of the innovative elements of this workshop and represented a moment of better integration between scientific and technological programmes in terms of future collaborations.

The achievement of these objectives has been through presentations in plenary session followed by debates and meetings of working groups on the four thematic areas—science of engineering, science of Earth, science of the universe, science of life—during which it was possible to discuss the status and requests of all ongoing projects selected within the European Space Agency (ESA) or international for human space missions on ISS, Shuttles, rockets, parabolic flights, etc., so as to allow room for a final discussion.

I participated in the science of life’s thematic area with my VEST project, an innovative integrated system of garments, selected for an experiment on board for the ISS, in which I proposed the development of a new clothing system designed for life and work in Space that which foresaw tailored made garments, included the search for new cuts, seams and tissues suitable for confined environment and microgravity, and the integration of prostheses in the garments to facilitate movements and Intra-Vehicular Activities (IVA) of the crew and make them more comfortable for the benefit of greater overall well-being.

Considering that the state of the art of the clothing on ISS does not provide specific garments designed to be worn in microgravity and confined environment, and VEST project represents a unique case study in which astronauts have been able to experience to feel more comfortable, efficient and clean—thanks to the use of antibacterial and thermoregulating fibres as well as the attention I have given to new parameters of functionality and wearability according to the Neutral Body Posture (NBP) assumed by the body in Space.
4.2.1 Proposal for the Development of an Integrated Clothing System VEST

The VEST project gives me the opportunity to report in this book a testimony, quite rare in the field of Design, of how the various phases of development of the project took place: from the first proposal, the feasibility study, up to the realization of the prototypes1 of the garments collection, and the subsequent experiment conducted in orbit on board the International Space Station (ISS). During the design and development process, the importance emerges, which I stress several times also in the other case studies, of creating multidisciplinary groups made up of experts and companies, both in the space and private sector, to complete all the parts that make up such a complex project.

For a designer, it becomes essential to be able to build a network of interlocutors: starting from space agencies, the Italian Space Agency (ASI) and the European Space Agency (ESA) in this case, which are a fundamental reference for the sponsorship and the support of the project; continuing with an industry specialized in habitable pressurized modules such as Thales Alenia Space, which is fundamental for the spatialization of the projects, and which has dealt precisely to spatialize my prototypes; and finally integrating companies that possess a great know-how, specific for terrestrial products, such as in this case Benetton Group – which I chose for its international recognition as a fashion manufacturer, in particular sportswear, and for the research and development center within it, specializing in advanced textiles and nanotechnology, which could support me in the development of the most suitable fabrics and garments for the confined environment and microgravity—as well as Sorin Biomedica Cardio, for the development of monitoring systems made of micro-sensors and external tools to manage signals and collect data.

For the Italian Space Agency (ASI), it was the first time in which a proposal integrated industries of the private sector, instead of Space industry and they appreciated the innovation in the process, and the strategies related to the design thinking approach that I applied, from the beginning of the first ideas to the realization of the experiment on ISS with the astronaut Roberto Vittori, who was involved both in the VEST and GOAL projects, the second one the implementation of the first project, following the results I achieved.

4.2.1.1 Aims of the Project

The principal purpose of the project VEST was the development of a new integrated clothing system designed for life and work in Space, which involved the search for new tissues, and the integration of prosthetics tools in the garments to facilitate movements

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1In the Space industry, usually the prototype coincides with the first product of the series considering that we produce only unique pieces realized by engineers’ teams which we can consider high tech artisans.
and Intra-Vehicular activities (IVA) of the crew. The clothing system, already presented in the paper *IVA Clothing Support System, ExploSpace, Workshop on Space Exploration and Resources Exploitation, ESA* (Dominoni 1998) provided the development of a collection of clothes for the different activities to be carried out on board the ISS: clothes for work, for rest and for physical activity, in addition to underwear.

The main objectives were to improve the overall well-being of the crew, but also, which at the end it is the same thing, to reduce the logistical demand caused by the number of astronauts and the duration of the human space missions, which requires or have many changes or to be able to wash dirty clothing. The clothes could have then been used to help reduce some unpleasant effects of the presence on board, such as absorbing unpleasant odours and helping the skin to release its dross, both as liquids (sweat) and as solid products (skin flakes). This would have also led to an improvement from the point of view of reducing microbiological contamination on board. The project pushed to increase.

1. **the level of comfort and efficiency** currently achieved, facilitating the movements and the operational activities of the astronauts through a range of equipment and prostheses, incorporated in clothing, which allow the anchoring of the crew to the internal structure of the modules of the International Space Station (ISS) and the transport of tools and objects that are fixed on clothes;

2. **the aesthetics and wearability** of the garments, currently, astronauts wear clothes that they bring to Earth and that are not suitable for the particular environmental conditions on board. I was convinced that the concept should be changed and that it was important to design **style, cut and fabrics suitable for microgravity**, considering the particular movements and postures, not static, which are created inside the pressurized modules. In addition, a study of smart and performing fabrics was needed—to meet the needs of the confined environment with technical garments—an in-depth analysis of shapes and colours—in order to diversify the items and provide a wider choice for astronauts, while taking into account environmental requirements and physiological changes related to microgravity—for the benefit of a higher level of well-being and a better quality of life and social relations on ISS.

3. **body hygiene and thermal stability**, through the use of fibres and tissues we are able to perform the function of thermoregulators, absorbing excess heat and releasing it when the body cools, but also able to limit the harmful effects of perspiration by transferring excess sweating to the outside of the garment;

4. **the integration of prosthetic elements in garments** able to amplify movements in microgravity and facilitate anchoring, ensuring the stability of posture during the various activities on board, and solutions to fix **small tools** directly on the body;

5. **control of the vital, biological and physiological functions** of the crew, through the monitoring of body values such as temperature, heart rate, circulation, breathing, physical stress, fatigue, etc. without requiring the active participation of astronauts. In particular, this project area provided for the presence of sensors inserted inside the garments, but also a study on the possibility of miniaturizing the sensors to insert them into the same fibers of the fabric.
4.2.1.2 Reasons for Using the ISS to Test VEST Project

The project of the new Integrated Clothing System VEST provided the indispensable condition to be tested on the International Space Station (ISS) to verify the objectives described above (Dominoni 2001a, b):

1. *equipment and prostheses incorporated in clothing*—which allow the anchoring of the crew to the internal structure of the modules of the International Space Station (ISS) and the transport of tools and objects that are fixed on clothes—required precise and detailed experiments and verifications that cannot be replaced nor with the tests with Neutral Buoyancy Facility (NBF) in the pool—the water being more viscous than the air does not allow a correct assessment of the stability obtainable: in water, it will be more and more stable—neither with parabolic flights, because the microgravity conditions are excessively short;

2. *the style, the cut and the fabrics suitable for microgravity cannot return the same effect in the pool*—in the presence of water it creates adhesion and the fabrics become heavier—and the parabolic flights’ results, as in the previous case, are too short to verify the various postures and movements that are determined by the zero-g conditions;

3. *the thermoregulation and drainage characteristics of clothing fabrics* must be tested on board the ISS to verify, for example, the ability of the garment to carry liquids on the outer surface, without causing them to disperse into the environment in the form of water, but also that the transport phenomenon is repeatable in the absence of weight, obviously impossible to verify, for example, in the pool;

4. *the sensors* should be tested on board the ISS, during physical and work activities, because in the pool would create problems of data transmission from the skin to the sensor itself—little adherence of the sensors to the skin due to the presence of water—and with parabolic flights, there would be no time to monitor the various functions described above. This is a problem that is not easy to solve even in orbit, given the difficulties with a similar concept during the mission EUROMIR ‘95 for experiments in human physiology and respiration.

4.2.1.3 Technical and Technological Aspects

The project consists of several parts, each of which requires specific research and technological insights to meet the objectives in relation to the particular conditions of microgravity as well as the internal configuration of the pressurized habitable modules of the International Space Station (ISS).

For fabrics (I involved Benetton Group for the expertise in textiles and sportswear collections), natural and synthetic fibre technologies would have been used with applications of Thermolife (thermoregulator), Purelife (antibacterial), Sunlife (ceramic material), Drylife (rapid evaporation of water), anti-slip, anti-rip inserts, Easy Care (anti-wear treatment), in different percentages and shapes depending on
the garment. The characteristics of softness, lightness, elasticity and breathability of clothing were obtained, thanks to the type of construction of the mesh and the resulting weight.

The absence of seams, obtained through a new technological process, further improves the fit of the garment eliminating the problem of differentiated sizes. The development of sensors to monitor the various biological and physiological functions of the crew (Sorin Biomedica Cardio participated to the project researching the most suitable solutions) provides technologies related to stimulation catheters, electronic design (both hardware and software), miniaturisation of electronic circuits and mechanical components.

4.2.1.4 Applications, Spin-Offs, Market Prospects and Evaluations

The potential technological repercussions of this research project in terrestrial fields of application are many. Just remember the Gore-Tex designed for the inside of the overalls for the Extra-Vehicular Activity (EVA) and now very popular throughout the sportswear. The experimentation of new fibres and fabrics for the clothing of astronauts that I led with Benetton Group has had immediate spin-offs in the sectors that concern sportswear (extreme, competitive, but also mass) and helped to elevate the comfort and performance of clothing, not only sportswear. Nowadays, it is normal to buy underwear and clothing which integrate thermoregulating systems and antibacterial properties, but at the beginning of 2000s, it was an extraordinary innovation.

The research and application of new chemical and physical micro-sensors (Sorin Biomedica Cardio), but also the development of monitoring systems have had technological repercussions in the research activities of cardiac micro-sensors and external tools (programmers) that have been used to receive and send signals and commands to implantable prostheses.

4.2.1.5 Preliminary Development Plan of the Entire Project

The project development plan, as required, has been divided into a feasibility study and an implementation phase. While the feasibility study was entrusted with the phase of consolidation of the concept and identification of detail of what to try on board the ISS, obviously avoiding to carry out verifiable experiments also on the ground, the next part was entrusted with the task of implementing and producing in detail what would have been defined during the feasibility study. Then, at the end of the feasibility study and on the basis of the detailed proposal of experiment defined in that interior, the implementation phase would have been developed on two parallel, but well distinct lines, the experiment development and the design development of the Integrated Clothing System VEST that allowed its implementation.

In this approach (already followed by Alenia Aerospazio Division Space during the EUROMIR ‘95 mission), the two parallel lines of development guarantee a dialectic between who designs the experiment, and therefore requires certain
equipment, and who designs the equipment, and therefore provides the tools for the feasibility. This approach was defined during the feasibility study with all the partners already involved. The pre-mission development part was evaluated in a period of about 14–16 months and preceded the mission of about 6 months (as it is thought to be the time required in the programme for the ISS), an interval where the activity is reduced to small adjustments. This is a conventional choice due to the impossibility to know in detail how the equipment and the times connected to these procedures will be launched and installed on board.

The design development of the Integrated Clothing System VEST was foreseen achievable within one year, including component verification and acceptance. For the launch and the integration on board of the ISS, for which it is thought possible the use of a part of a standard rack, it has been used the knowledge of Alenia Aerospace Division Space, and especially of the programme European Drawer Rack (EDR) developed on contract by ESA.

Collections of astronauts’ data were foreseen, both before and after the mission, for checks of comfort and fit. During the development phase of the experimental protocols, and the biomedical research group discussed and obtained the necessary permissions to operate with human subjects, although no data collection technique used was intrusive. It was expected that the activity on board within a mission (3 or 6 months), even if once tested the efficiency and comfort of the clothes, nothing prevented the crew to continue to use them. It was also thought possible to carry out the experimental part during the normal course of the various activities, using for some periods to be defined by the clothing proposed by us instead of the traditional one used on board.

In order to demonstrate the best efficiency of the proposed Integrated Clothing System VEST, a programme dedicated to each of the two principal parts of the capsule collection (work clothes and clothes for physical activity) would have been appropriate for one or two astronauts within the space mission.

4.2.2 Plan of Activities for the Feasibility Study

The feasibility study phase was foreseen for a duration of 10 months and begun with a detailed analysis of the mission scenarios of the ISS. This part was divided into three sub-parts, namely

1. the analysis of the scenarios proper, which would allow us to identify where, how and when to enter the experimental phase on board, what to provide and how to provide the necessary equipment and also what time and documents were required for access to the on board phase;
2. the analysis of the requirements to be met by the on board equipment and those imposed by possible transporters (see EDR or MPLM);
3. the analysis of the scientific requirements that would allow us to correctly validate both the concept and the equipment.
After the analysis of the mission scenarios we started the development of the *concept design* that was divided into two sub-parts: the *integrated concept* that identified the various components and the *detail of the various components*, both specific to the experiment and necessary to support it, considering the interfaces with the transport system, and then with the International Space Station (ISS). When the definition of the equipment had reached a stable stage, it would have been possible to define how to perform its *validation* in more detail; then the *experimental part* would have been developed (this activity was also intended to involve external experts in order to ensure full scientific correctness).

In the *experimental part*, we would also define which data should have been used for the validation of the *concept design*, in order to allow the completion of the definition of the *Integrated Clothing System VEST* with data collection systems. In fact, the last phase of the *feasibility study* proposed to define, on the one hand, *which materials and which data collection techniques to use*—also identifying if and what technological developments would have been necessary—and on the other hand, to prepare the final proposal for the actual testing phase. The proposal for the *experimental part* would have been dedicated to identify, with the support of the ASI, the possible points in common with other proposals to see if there were possibilities of optimization between experiments, or if we could have expanded the use of the information collected. This because it was believed that the development of the proposed equipment could have also been useful to disciplines of the human sciences. At the end of the *feasibility study*, it was expected to be a report of the work carried out both in the form of a document and as a presentation to the ASI. Especially at the beginning of the feasibility study, they were foreseen as a series of working meetings between the various partners, although only three of the formal meetings have been planned, namely, the *start-up meeting*, the *consolidation meeting* and the *final presentation of the results*.

The plan foresaw also a complete project regarding the organization of the *works packages* to describe the organizational structures of the complete project and that of the feasibility study. From this, we could see how the two parts were organized and who were the various responsibilities, even if the *multidisciplinary group* of the project acted as much as possible as an integrated group having to share very different experiences and know-how.

### 4.2.2.1 Design Goals of the Integrated Clothing System VEST

The core of the *feasibility study* was the development of the concept of a collection of garments specific for Space, that I personally created and developed, and of which I report here the results entering in a more detailed description of objectives and design hypotheses from the Design point of view. The new clothing system is designed for life and work on board the ISS so as to increase the comfort of the crew through the search for new fabrics and clothing specific to the confined environment and microgravity. It also provides integration of sensors in the clothes, for the monitoring
of biological parameters, and prostheses, to facilitate the movements, and consequently, the Intra-Vehicular Activities (IVA) of the astronauts.

The principal aim of this project is to identify the main requirements of fabrics and clothing to be used on board the International Space Station to develop a new integrated clothing system able to enhance the body and make it more comfortable and efficient crew activities.

The state of the art does not provide for any type of specific clothing that takes into account the many inconveniences caused by living in a confined environment and in conditions of microgravity: significant variations in internal temperature, biological and postural alterations, lack of privacy, the need to do many hours of exercise every day to maintain muscle mass and tone and to counter bone decalcification, resulting in increased perspiration, are just some of the problems astronauts face without having adequate and diversified outfits to carry out the various activities comfortably. In addition, equally important is the pleasantness that comes from wearing a dress that does not necessarily resemble a military uniform, but rather that enhances the personality and identity of the astronaut. Having a good sense of self means feeling comfortable with your body and your second skin, to the benefit of an overall improvement in on board social relations which inevitably result in greater operational and performance efficiency (Dominoni 2003a, b).

The study of fabrics, cuts, shapes, colours and accessories to diversify the garments and provide a wider choice for astronauts is essential to increase the level of well-being and improve the quality of life and social relations on board. A second skin could satisfy the functional needs of the body and spirit.

The objectives of the project are, therefore, aimed at increasing the degree of well-being and efficiency of the astronauts by improving their psychophysical condition through the wearability of the garments, the aesthetics, thermal stability and body hygiene, and the monitoring of the biological and physiological vital functions of the crew, thanks to the use of sensors integrated in the garments without being invasive. The project provides for the possibility of prefiguring different types of clothing for the various activities on board, such as work, rest, physical activity and underwear. The design of the clothes also considers the problems related to the storage of the material on board, with particular attention to the packaging and the minimum size of the same, and provides treatments that facilitate maintenance and possible washing (for the time being not yet resolved, since the clothes are packed and brought back to Earth dirty). For this specific problem I was exploring new possibilities, as a system of washing the clothing to be integrated onboard the ISS, in which washing technologies were closely related to the chemical characteristics of the fibres and detergents that would have been identified during the project.

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2At the same time, I was designing a system to wash clothes in Space without water, using vacuum, in which I involved Electrolux Zanussi in a Pre-Feasibility Study along with ASI, but then, unfortunately, the lack of funds did not allow the project to get to prototyping and verification on board the International Space Station (ISS).
4.2.2.2 Project Researches and Hypothesis

1. Increase the Level of Comfort and Efficiency

The absence of gravity is generally considered an advantage for movement in Space. Once accustomed to microgravity, the body moves with minimal efforts and is able to perform acrobatic maneuvers with extreme ease. However, in order to exert forces, the body must be anchored so that the opposing force can be developed for the active exercise of the force-vector. One problem that occurs widely during the first few days in the absence of gravity is the decrease in motor performance.

The astronaut finds it difficult to accurately estimate the amount of physical work required for certain operations and also takes longer to perform the various activities due to the lack of landmarks and strength based on gravity. After a few days in microgravity, the movements and activities of the astronauts become more precise and the perception of the difficulty level decreases. When the crew returns to Earth, after a long stay on board, the vertical stability decreases along with the reduction of muscle strength. It should also be noted that astronauts tend to drop things for the first few days, believing that they can float in the air as in microgravity. These problems disappear after about a week of stay. It is not yet predicted how long it will take to recover the effects of a 1/3G environment like Mars.

Microgravity has a decisive influence, as well as on the human being, on the strength-weight of objects, increasing the difficulty in use and control. The use of Velcro® is in fact the only current efficient and less invasive system to fix objects to the structure of the station or to the body of astronauts, mainly thanks to the ease of use and the minimum size, in terms of volume and weight. The increase in comfort, to the advantage of greater well-being of the crew, directly affects the operational efficiency and performance in carrying out the activities on board.

The Integrated Clothing System VEST aims to facilitate the movement and physical and operational activities of astronauts through a series of equipment and prosthetics, incorporated in clothing, that allow the anchorage of the crew to the internal structure or parts of it and the transport of tools and objects through their Velcro® fastening on the clothes worn (Fig. 4.1).

2. Provide New Parameters of Wearability

Currently, astronauts wear clothes that they bring to Earth and that are not suitable for the particular environmental conditions on board. In Space, there is a substantial change in the posture and size of the human body. If relaxed, the body assumes a semi-harvested position, in which the angles of the knees and elbows are about 130 degrees, changes the pelvic angle and flattens the curvature of the spine in the lumbar and thoracic section, giving rise to a body extension of over 10 cm. The head and spine bend forward and the upper limbs fly upwards to the trunk 450°. The new Neutral Body Posture (NBP) to which crew members are subject in microgravity conditions is similar to that taken by the body underwater and seems to result mainly from a new balance of muscle forces in relation to the tension of the
tissues acting on the various joints. While the NBP in Space does not in itself have contraindications, apart from the inconveniences that can occur by bending forward or trying to sit or stand upright as on Earth, it is necessary to carefully consider the new implications between operator and instrument.

The design of a space clothing system must take into account in an essential way the Neutral Body Posture in Space and consequently provide new parameters of fit, weight and fall of the fabric, cuts and seams of clothes, adhesions and elasticity in relation to the postures and movements that are created in the absence of gravity. Adhesions should be carefully considered at the joints and ends to prevent excess tissue from becoming entangled in structural parts within the ISS.

3. **Consider Aesthetics as Fundamental**

The study of fabrics, shapes and colours and accessories, to diversify the garments and provide a wider choice for astronauts, is essential to increase the level of well-being and improve the quality of life and social relations on board. The pleasantness that comes from wearing a garment that is able to enhance the identity of each astronaut is a very significant parameter if we think of the condition of confinement to which the mixed and multi-ethnic crew is subjected. The *Integrated Clothing System VEST* should be able to differentiate the various specificities of astronauts and backgrounds while considering the new wearability parameters.

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**Fig. 4.1** A rendering made for the concept design of the *Integrated Clothing System VEST* created by the author shows removable textile pockets to transport various items and tools through their Velcro® fastening on the clothes worn. Credits by the author
During the second technical meeting, a particular need emerged for astronauts to wear garments in orbit that do not differ much from those used during training on Earth, to facilitate the adaptation of the crew on board. So sci-fi style is not recommended because the crew prefer very normal clothing. What a pity for me!

Recreating a home and family environment seems to be the most useful and attentive design choice to the requests of the users who will use the clothing system living and working on the ISS.

The Integrated Clothing System VEST can then consider the opportunity to design garments for both ground activities and those in orbit, differentiating the wearability, and then the cuts and fall of the fabrics, in relation to the different environments, but maintaining unchanged comfort, aesthetics, with the same types, variations in colours and accessories, and thermoregulatory treatments, breathable and antibacterial on the fabrics (Fig. 4.2).

4. Ensure Thermal Stability and Body Hygiene

The temperature inside the ISS, under normal conditions, has a variation between 18.3 and 26.6°, while in emergency conditions, the variation expands between 15.6 and 29.4°. It is, therefore, important to be able to wear garments that are able to counteract external thermal changes, while maintaining constant body temperature. The confined environment and the scarcity of renewable resources, such as water...
and air quality, pose problems that inevitably affect the hygiene conditions of the crew. Limiting the contraindications due to excessive sweating, especially during physical activity, becomes a considerable advantage that is extremely effective when applied on the second skin. The use of thermoregulatory fibres and fabrics, which absorb excess heat and then release it when the body cools, breathable, were able to limit the harmful effects of perspiration by transferring excess sweating outside the garment, and were antibacterial, thanks to silver particle finishing, which can help to improve the thermal stability and hygiene of the astronauts on board. In addition, tissues and garments should help to reduce skin flaking by retaining particles.

5. **Allow the Control of Vital, Biological and Physiological Crew’s Functions**

Monitoring of body values such as temperature, heart rate, circulation, breathing, physical stress, Fatigue, etc., is currently carried out with equipment that requires long application times of sensors and limits astronauts in movements and in the performance of activities. One area of the design of the *Integrated Clothing System VEST* involves the inclusion of sensors in garments that will allow the detection of astronauts’ bio-signals without interfering neither with the subject nor by its activity, and without requiring a direct and conscious application. An essential condition is that the sensors are in direct contact with the body, or in any case inserted into tissues adhering to the body.

### 4.2.2.3 Concept Design Development

The concept of the *Integrated Clothing System VEST* provided different types to meet the requirements (identified by the technical note NT1) and the study, included in this activity, for the monitoring of biological parameters (technical note NT3). The need to position the sensors in direct contact with the skin, combined with the need for greater comfort that facilitates the activities of the crew, has directed the design choice towards the creation of a specific underwear that is able to integrate the sensors, while giving the astronaut complete freedom. The underwear consisted of two pieces, differentiated for men (t-shirts and shorts) and women (brassiere and briefs), and allowed the monitoring of biological parameters. The garments packaging also uses technological processes that allow to obtain a seamless tubular mesh, for greater comfort and a more snug fit. The other types of clothing include specific garments for the three most important activities and incidences with respect to the allocation of time identified in the technical note NT1:

- the work
- the rest
- the physical exercise
All types of the *Integrated Clothing System VEST* were foreseen made of antibacterial, anti-odour, thermoregulatory, breathable and antistatic fabrics, in different percentages depending on the specific characteristics of each garment.

**The Work Clothes**

(t-shirts, long pants, short pants)

Privilege the wearability, in relation to the environmental conditions dictated by microgravity, and the comfort and consequent operational efficiency, to facilitate the movements and activities of the crew.

The garments are equipped with tools (slings) that are able to anchor the astronauts to structural parts (rail-straints) and between them; they provide Velcro® inserts to attach tools to the body during routine maintenance operations to be carried out on board, and integrate small light sources to facilitate various activities, which often take place in very narrow and poorly lit areas of the ISS.

**The Sleeping Clothes**

(t-shirts, long pants, short pants)

Privilege comfort, to provide more freedom of movement to astronauts during sleep, but also entertainment services.

The garments also integrate small light sources to allow you to read or send emails; they provide the ability to listen to music through speakers fixed on the garments at the shoulders.

**Clothes for Physical Exercise**

(t-shirts, short pants)

Privilege comfort, thermal stability and body hygiene to counter excess sweating during movement.

The tissues of the garments for physical exercise are foreseen, therefore, to have a higher percentage of antibacterial, anti-odour and thermoregulatory treatments compared to other types of the collection.

### 4.2.3 **VEST Clothing Support System on Orbit Validation**

The experiment was scheduled during the Italian *Marco Polo* space mission in April 2002 about which I was the Principal Investigator. Aim of the experiment was to demonstrate that the provision of a new *VEST Clothing Support System* to the astronauts would increase their well-being, would allow to collect useful data with less impact on the crew schedule and to prove that in general with *VEST* equipment less mass and less volume are required for the clothing system. The results of *VEST* experiment (Dominoni 2005) have allowed to obtain specific requirements for a specific clothing system in microgravity and confined environments that had not
been proposed by any research group before. At this regard, it follows a brief description of the garments used by the astronauts on board the Shuttle and the International Space Station (ISS) with technical requirements.

4.2.3.1 Garments Used in Human Space Missions

During human space flight the crew members worked inside the Space Shuttle in shirt-sleeve comfort. Prior to a mission was outfitting from a selection of clothing including flight suits, trousers, lined zipped jackets, knit shirts, sleep shorts, soft slippers and underwear. Today things are more or less the same. Nothing is changed. The crew wear the same clothing that they use on Earth without specific requirements for the space environment. There are only some characteristic with small adaptation of the garments to microgravity such as closable pockets for storing some objects as pens, pencils, data books, sunglasses, a multipurpose swiss army knife, scissors or a flashlight as well as Velcro® attached to the shorts and trousers where a Nomex pocket attaches to carry their items. The materials are supposed to be flame retardant even if not all the clothing because underwear, shirts and polo or rugby type shirts are made of cotton 100%. Shorts, trousers and flight jackets are made of Nomex, which is a rude fibres very uncomfortable. For their feet they either wear 100% cotton socks, slipper socks made of wool and leather or Polartec fleece socks. Because the lack of space and the necessity to limit weight, or a 7-day flight, a crew member had one shirt per day, 2 or 3 pairs of socks/slippers, 2 pairs of shorts and 1 or 2 pairs of trousers, 1 sweater or jacket.

With the International Space Station (ISS) NASA could collect some crew’s preferences from the experiences of the previous missions: both shirts (long sleeve and short sleeve) are off-the-shelf clothing items and must be made of 100% cotton. Long and short sleeve shirts are selected and then procured from a vendor. They are limited to a few styles to select from. The colour and size vary according to each choice. They may have monogramming, a mission patch, or NASA logo sewn on. They are available in sizes small for females to through extra-large for males.

The **incremental innovations** compared to the Space Shuttle was first to try to make more comfortable the clothing in Nomex with finishing on cotton fibres to make the cotton fire retardant and allow astronauts to wear more soft flight jackets, trousers and shorts. The original cotton twill material was treated to enable the assembly to comply with flammability requirements in a 30% oxygen-enriched atmosphere. The flight jacket was proposed royal blue colour, with multiple pockets, featuring a Nomex knit waistband and cuffs. It ranges in size from small/regular (chest/sleeve) to extra-large/long, and maybe worn with or without the jacket liner. The crew preference flight jacket liner was a natural coloured vest made from flame-retardant treated cotton cloth that zips-out from the jacket assembly. The line exterior had a layer of Nomex batting quilted to it for insulation.

The second suggestion by astronauts was on wearability to have a wide range of sizes to accommodate either male or female, and flight trousers feature an adjustable waistband, two side and hip pockets, a zippered pouch on the left calf, and several
strips of Velcro® across the legs to allow for mating with the removable pocket. Featuring an elastic and drawstring waistband, the crew preference was flight sleep shorts which had two side pockets, one flap hip pocket, Velcro® across each leg for pocket mating and a white liner.

On ISS were introduced also synthetic materials in clothing as the Lightweight Kit consisting of a zippered shirt and a pair of shorts. The shirt was made of thick cotton. The shorts were made of polyester and feature a zippered fly, elastic waist and two zippered pockets. Lightweight clothing colours are crew’s preference with some limitations. This clothing kit is usually worn during periods of interaction. Such as crew exchange, TV interviews and casual times. Another example is the Operator Suit, a sleeveless, multi-pocketed and zippered coverall with stirrups. It is composed of an antistatic, synthetic outer layer with 15% Lycra, paired with a cotton lining. The Lycra in this garment provides a feeling of forces being applied to the body. The suit features two zippered chest, thigh and rear pockets, along with a zippered left calf pocket. This coverall comes in a variety of colours, which are crew’s preference, and 2–4 sizes (accommodates 24 sizes).

4.2.3.2 Fibres and Fabrics Innovations of VEST Project

The Clothing Support System VEST introduces important innovations which increase the well-being during Intra-Vehicular Activities (EVA) as the use of thermoregulating fibres and fabrics, which absorb excess heat and release it when body temperature falls and are capable of curbing the noxious effects of perspiration by transferring excess sweat to the outside, and enables one to fight bacterial proliferation and body odour, thanks also to a special small silver particle finish. All this contributes to improving body thermal stability and overall hygienic conditions on board. The basic principle informing the search for materials, production procedures and crucial technologies for the realization of the new items of clothing—as developed in the course of the project—was that any item of clothing or accessory is to be considered a multi-composite product, which stems from the interaction of a number of technological parameters. The research of fibres and fabrics was carried out in four main areas of technology:

1. **yarn technologies**: yarns with phase-changing microcapsules for active control of body temperature, silver-coated yarns so as to control germs and fungi due to perspiration and elimination of ensuing any body odour, and yarns containing micro-particles of organic compounds so as to kill off bacteria and fungi due to perspiration and ensuing body odours;
2. **weaving technologies**: orthogonal weaving is carried out with shuttle looms with yarn weft and warp orientation, respectively, at 0° and 90°, circular weaving is carried out with circular looms for the creation of tubular knitwear;
3. **fabrics technologies**: considering that one of the primary goals in the feasibility study of VEST was to choose garments capable of reducing paying load at take-off as compared to standard paying loads, the researches I led have
highlighted how, in relation to the 100% cotton fabrics currently used in a number of garments, mixes of cotton and acrylic fibres allow for a substantial reduction in the mass of the garments (provided one compares two items of clothing made the same way). By way of example, a 40% Cotton and 60% Thermoregulating Outlast Acrylic would allow for the creation of a fabric weighing at least 15%;

4. **treatment technologies**: compatibility between the fabrics treated and the user’s skin owing to the peculiar conditions on board. The research of the best technology was also addressed to the garments manufacturing with a special attention being devoted to accessory design and the choice of the most suitable materials as well as to the packaging which foresaw vacuum-packed, and the best solutions adopted in space flights.

### 4.2.3.3 Tailoring and Wearability Innovations of VEST Project

As far as aesthetics is concerned, the clothing wearability for Space environment is built on the Neutral Body Posture (NBP) which the crew members adopt in conditions of microgravity and is similar to that adopted by the body underwater and seems to result above all from a newly found balance between muscular and the tension of fabrics acting on the different joints. During the project research, I
discovered that this particular posture is very similar to that adopted by snowboarders—with limbs bend, knees and elbows upwards and head bends forward—and therefore, some functional details as cuts and seaming designed to adhere to the body of the snowboarder for a better wearability have been directly applied to the Clothing Support System VEST. The whole clothing system VEST is based on the concept of flexibility so as to answer the project requirements identified, and notably the two that most influence the design and style of clothing: comfort—and, as a result, operative efficiency—and wearability, and therefore aesthetics. The integrated clothing system foresees specificities and solutions ensuring that, once the garments have been put on, the adherence and elasticity of sleeves and trouser legs and of the waist may be adjusted, thanks to strings threaded through the single items of clothing, which may be widened or tightened up and secured with Velcro®. This makes it possible to adapt single garments to the changes the body undergoes in conditions of microgravity, be they physiological (fluids tend to shift to the upper part of the body, causing it to swell), morphological (atrophy of the lower limbs and lengthening of the spine) or postural (when in orbit one assumes a neutral semi-curled position). Moreover, the possibility to modify adherence and elasticity in relation to the 1G environment enables the astronauts to wear the same kind of clothing also on Earth, during training and in the preparatory stages of human space missions (Fig. 4.3).

Fig. 4.4 In this picture it is easy to observe the gap between the wearability of the Integrated Clothing System VEST designed by the author, and the normal clothes used both on Earth and in Space without to consider the effects of microgravity. Credits by NASA
4.2.3.4 Aesthetics Reflections of VEST Project

When I was asked to design a collection of clothing for astronauts, my first wish was to create clothes with a strong identity that would make people immediately understand that the person who wore them was an astronaut who was living on board the International Space Station (ISS). Such an extraordinary role, in my opinion, required garments with a strong aesthetic value, which, while not compromising comfort and functionality, were similar to superhero costumes that recalled the collective imagination of sci-fi and future scenarios. But during the various meetings of the feasibility study and then for the preparation of the experiment and, above all, the briefings with the astronauts, I realized that there was a certain resistance, mainly due to the fact that having to live in an environment already very different from the terrestrial one they wanted certainties that made them feel at ease, at home. Contrary to my expectations, as regards the formal and aesthetic choices of the Integrated Clothing System VEST, astronauts feel the need when in orbit to wear clothes not all that dissimilar from those used during training on Earth, so as to facilitate their adjustment to life on board. As already underlined previously, to recreate a domestic and family environment seems to be the best approach and the one best answering the requirements of the astronauts wearing the new Integrated Clothing System VEST. Banal garments for them was a way of feeling normal, very normal. I should have looked for innovations in other fields, in the search for materials and fabrics, in the wearability of garments, and in their adaptability according to the various activities to be carried out on board. I was, however, intrigued by the idea of making some reflections on the aesthetics in Space and on the value of wearing clothes in such extreme living situations, which concern not only the effects of microgravity, but the fact of living for a long time in a restricted and confined environment, without the possibility of leaving, and where they create forcibly group dynamics in which, I think, it is important to affirm their identity while they maintain a strong group spirit (Dominoni 2003a, b).

The choice to explore the behavioural dynamics with regard to aesthetics aspects in an extreme environment as Space allows me to get into focus the human problems and the psychological and social implications that could derive from it. The conditions of constant emergency of the crew’s members on board the ISS, the confined environmental and the microgravity effects cause heavy stress that made astronauts more sensitive and vulnerable: the interpersonal relationships are altered and the harmony of social sphere—the cultural and ethnic peculiarities of the different crew members—is seriously compromised. In this context, each behaviour is increased, and the actions are laden with meanings that on Earth could be of secondary importance. The aesthetics in microgravity doesn’t escape from this principle: the extreme conditions in which astronauts live require a particular attention to aesthetic values to encourage a high level of personal satisfaction, and therefore a more quiet acceptance of one’s self. It has to be said that if in common earthly conditions to have a positive perception of one’s self means feeling at ease with one’s body and its second skin—which leads to an overall improvement in such social relations, and therefore, of increased efficiency in terms of both
operation and performance—in Space; the aesthetics values are essential for the well-being of each individual and have to be considered fundamental for the success of the mission. On board the ISS the performance equipment must be extreme, the clothing inclusive, and it is necessary to study a high technological level of materials and production’s processes compared to products used on Earth. This means that the clothing worn by astronauts should improve the aesthetics and comfort through innovative technological and suitable choices to take advantage of the environment (Fig. 4.4). To study in depth the aesthetics meaning of the crew’s clothing could provide interesting research tools with application in different contexts as technological solutions selected for spatial environment that could foresee important spin-offs on Earth, from extreme to domestic contexts. It should be borne in mind that the study of life in Space is still in its early stages and that Space itself is after all a relatively new environment for human beings. Its effects have been recorded by collating the experiences of a few people, most of whom have spent but a few days in Space, while just a few have spent several months in Space.

Where do designers draw inspiration from when creating styles for Space closing totally unrelated to the unimaginative one—a far cry from the kind of clothing described in books and science fiction films—used during space missions? What does the industrial designer deem to be of paramount importance when setting out creating a new and aesthetically pleasing Integrated Clothing System VEST? The solution consists in striking a balance between functional needs—related to comfort and the countermeasures called for by the microgravity environment—and subjective needs—which include personal taste and the pleasure to be derived from wearing a given item of clothing (Dominoni 2003a, b). If we then wish to analyse the issues of style and aesthetics, like most users, astronauts do not seem to have any clear ideas. It is instead the task of industrial designers to come up with a number of solutions, and just as many variables, by giving shape to the needs expressed by the users, but also by embodying potential ones in real and usable products. The study of fabrics, of shapes, of styles, of accessories and of colours aimed at the diversification of garments, and at providing astronauts with a wider choice is essential if one is to improve the level of well-being, the quality of life and social relations on board. Just as important is the pleasure that is to be derived from wearing clothes that do not necessarily smack of military uniforms but to enhance instead the personality and identity of the astronauts. This parameter becomes very important if we consider the confined environment the mixed-sex multi-ethnic crews have to live in. To increase the degree of well-being and efficiency of the astronauts, to ensure garment wearability, bodily thermal stability, hygiene and the monitoring of biologic and physiologic functions are the project requirements adopted to counter the adverse effects in Space and to improve living conditions within confined spaces, which have to be shared by a number of individuals living under mental and physical stress. Such project requirements fully respect NASA indications as to fabric composition, weight, volume and storing, and therefore, greatly influence overall project aesthetics.
4.2.3.5 The Experiment Sessions

*VEST* experiment was specific for the *Marco Polo* mission of the Italian astronaut Roberto Vittori, scheduled in April 2002 on the Soyuz Taxi Flight. The scope was to validate the on-orbit functionality and concept innovation of *VEST Clothing Support System*, consisting of a complete garment set. Aim of the experiment was to demonstrate that the provision of a new integrated system of garments to the crew would increase their well-being, which would allow to collect useful data with less impact on the crew schedule; and to prove that in general with *VEST* equipment, less mass and less volume are required for the clothing system. Diversified items of clothing, more than the underwear garments included, foresaw the three most important and most significant activities—in terms of time management—as identified in the mission analysis: work, night rest, physical exercise. The requirements foreseen for the crew are very simple: to wear *VEST* clothes and to provide opinions concerning their psychological and physiological well-being, therefore, to provide comfort, garment wearability, aesthetics and efficiency of thermal stability and bodily hygiene on board. I used specific questionnaires. No pre-flight training was necessary for the *VEST* experiment to be put in practice. Astronaut Roberto Vittori was informed about the garments set to wear for each session, about timing and procedures to follow on board. He was aware of the experiment purpose and he was willing to give his opinion answering to the questionnaires.

The experiment sessions, apart the first one dedicated to physical exercise, was extended during normal work and sleeping activities on board the ISS. For the other two session types, the astronaut wore *VEST* provided clothes while performing mission planned activities. In addition, also the time devoted to remove clothes from *VEST* bag, astronaut dressing, astronaut cloche removal, clothes re-stowage and questionnaire filling in was considered as astronaut time allocated to the *VEST* experiment. During work and physical exercise sessions, *VEST* experiment required also the part-time involvement of another cosmonaut for taking pictures and video recording.

Data have been collected and analyzed by questionnaires, video and still images. Fundamental topics as *usability* and crew *well-being* have been checked taking into account the astronaut’s opinions wearing the *Integrated Clothing System VEST* during the various activities on board. Body postures, movements and clothes *wearability* in microgravity were the principal parameters for questionnaires, photos and video recording. The four questionnaires—one for each three activities plus underwear described before and one testing the wearing easiness—was based on questions with multiple answers. Questionnaires submitted to astronaut’s opinion included also to consider reports of negative impressions. Several questions foresaw a comparative analysis between *VEST* clothing system and usual garments on board with the aim to verify the *efficiency* of the new garments.

*VEST Clothing Support System On-Orbit Validation*’s experiment has been based exclusively on Roberto Vittori experience, and therefore his opinion is not representative of any statistical result, as are most of the experiments conducted on
the ISS. Even so, the experimentation results were extremely significant for the validation of VEST clothing considering the study’s development in the future. Vittori’s opinion was important in order to help garments design concept for a longer and more complex mission where several crew members of different gender, race and size could have worn a new designed set of VEST clothing. I am grateful to Roberto Vittori who shared with me the interest and the enthusiasm for the innovative garments during the experiment activities. The results of the questionnaires demonstrate the full success of the experiment and the importance of having clothes dedicated to Intra-Vehicular Activities (IVA) that make more comfortable and pleasant living and working in Space. Thanks to VEST project, Vittori has known the Design meaning and appreciated the ability to shape the needs of astronauts following their needs and finding solutions more favourable to the confined environment and microgravity.

My role of designer, in this case, consisted in mediating the needs of the user-astronaut with the peculiarities of the space environment, and consequently, in considering the opportunity of designing garments both for ground and in-orbit activities, by differentiating wearableity, and therefore tailoring and fabric drop in relation to the different environments, but without renouncing comfort, and aesthetics, or favourite typologies, shades of colour and accessories, and the same thermoregulating, anti-perspiration, antibacterial, anti-odour and antistatic treatment for fabrics. At the end, the task of Design is to translate project requirements into opportunities that can be expressed through aesthetic values.

The proof of the success of the experiment VEST was the request that was made to me personally by Roberto Vittori to continue in the implementation of the project providing other garment sets for his subsequent Eneide Mission, scheduled in April 2005, on the Soyuz Taxi Flight: with the experiment GOAL I had the chance to affirm again the value of new requirements and items to make comfortable and more efficiently his on board activities during human space flight.

### 4.2.3.6 Meaning and Spin-Offs of VEST Project

The development and completion of the VEST research project and experiment open up extremely interesting opportunities of generating—both in the short and in the long term—meaningful technological spin-offs both for the clothing textile industry and for other fields of production. In recent years, the textile sector for both leisurewear and sportswear has been undergoing meaningful changes and companies have increasingly been focusing their attention on innovative fabrics and technologies. VEST introduced new product technologies which address the issues of the user’s comfort, well-being and safety as well as ensuring energy saving and being environmentally friendly. As a rule, new technologies have higher costs than already consolidated ones, especially when first introduced onto the market, and the support of a high profile scientific activity, such as that developed in Space projects, capable of ensuring the quality and performance of the new product, which cannot but be beneficial for the promotion of that self-same technology with the end-user.
For example, the *Integrated Clothing System VEST* for confined environments and conditions of microgravity—which foresees the use of antibacterial and thermoregulating treatment for fabrics capable of counteracting the former the effects of body perspiration, the latter the variations in temperature of the ISS—might prove to be extremely effective also here on Earth in the course of sports competitions and, by dilating the sphere of application, also in the course of any given individual’s normal physical exercise. Spin-offs will be recorded in the use of fabrics specifically developed for use in Space but also in the solutions of increased comfort and flexibility adopted for casual and sportswear. Apart from the far-reaching effects to be recorded in the field of textiles for clothing, one can easily picture the spin-offs to be had in the field of furnishing fabrics for the automotive industry, where the functional problems related to active thermal regulation and the killing of bacteria can be just as important. When the *feasibility study* of *VEST* started, in the years 2000, the use of antibacterial and thermoregulating fabrics was a remarkable innovation. The spin-offs I foresaw have shown that these technologies have extended to many areas of applications and productions, and now many garments, from underwear to competitive sports, use these fabrics and textiles that were born for our project in Space, as basic requirements for active textiles and clothing.

### 4.3 Couture in Orbit. A Capsule Collection for ESA

I believe the project *Couture in Orbit* is the first important step to communicate to a huge public the role of the European Space Agency (ESA) in developing innovation and inspiring people through the design and fashion language, that celebrates space exploration and research exploitation and their impact in many fields of our life. Thanks to this initiative, ESA has experimented the value of Space Design in finding disruptive solutions to apply in many fields on Earth to increase the well-being of our society looking at Space as a booster of creativity.

The idea of *Couture in Orbit* was aimed to mark the missions of five European astronauts—from Italy, the UK, France, Denmark and Germany—who flew on board the International Space Station (ISS) between 2014 and 2016 organizing an innovative project of a *capsule collection* which was presented during an event on 25 May 2016, at the London Science Museum, involving five fashion design school from each of the astronaut’s home countries. ³ I was invited by ESA to lead the Italian side of *Couture in Orbit ESA POLIMI* involving my students of the School of Design, Master of Science in Design for the Fashion System, at Politecnico di

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³*Couture in Orbit*, ESA, Taking Technology and Fashion to Higher Levels, 25 May 2016, https://couture-in-orbit.tumblr.com/ (accessed 10.09.18).
Milano, with the aim to create a collection of garments inspired by space scenario, using ESA technologies, which were designed to be worn every day on Earth.4

Working with *Couture in Orbit* was a great challenge for us to explore fashion in the age of technology and understand better how we can be more conscious of the transformation technology brings. I was very excited because I believe space innovations will have a strong influence on how people behave and perform in the next future.

Before to go into the description of this case study, I think it is necessary a short excursus on the interaction of Space and the fashion design industry before the project *Couture in Orbit* to demonstrate the strong link between Fashion Design and Space, starting with *Space Age*, which has redesigned a future creating a new style inspired by colours, shapes and space materials, and which evolving in technological research integrated into garments, led to the development of intelligent fabrics, smart textiles and wearables that are part of our daily life.

### 4.3.1 Space and the Fashion Industry

Space and fashion industries often influence each other with spin-offs and spin-ins. The most famous spin-in, from Earth to Space, is surely the use of Velcro® by NASA’s astronauts during their human space missions to fix objects easily in microgravity: it is a patent registered in 1958 thanks to the intuition of the swiss engineer George De Mestral who, observing the alpine thistle properties consisting in micro elastic hooks, tried to apply the same principles to facilitate assembly operations creating Velcro® which became immediately very common in the clothing system all over the world. There are many examples of spin-offs, from Space to Earth: innovations that have become more than familiar, common objects of everyday life, such as Gore-Tex® of the astronauts’ suits (De Monchaux 2011) that—thanks to the light weight, waterproof protection, breathability and cold resistance—has gone from Space applications to those of technical clothing and sportswear industry, becoming a basic component in thermal insulation.

One of the most fruitful and lasting collaboration with NASA is the industry DuPont, whose advanced materials and thermal protection systems have made possible human and unmanned space missions for nearly half a century. DuPont is the owner of brands such as Nomex® and Teflon®, the two fibres used in astronaut suits for their heat resistance performances, which guarantees security and protection to the fire brigade during fire impacts and first-aid operations. NASA developed recently Aerogel (the first molecules of Aerogel date back to 1931) to insulate space probes sent to Mars, and the first Earth application regarding fashion is Italian. Corpo Nove, a company specialized in technical clothing, used Aerogel to

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4 *Couture in Orbit*, ESA-POLIMI, European Space Agency & Politecnico di Milano make Fashion, 19 February 2016, https://couture-in-orbit-esa-polimi.tumblr.com/ (accessed 10.09.18).
design and develop the jacket *Absolute Zero*, that exploits the extraordinary thermal qualities of this material; it can insulate at temperatures between 50 and 3000 degrees Celsius, and with regard to its lightness, it is composed of 99% of air and is the lightest solid substance in the world.

With the support of ESA Technology Transfer Programme (TTP), Grado Zero Espace (the research and development laboratory of Corpo Nove) has developed another project using shape memory alloys to obtain Oricalco®; a textile having a content of Titanium of 45% and characterized by the extraordinary ability to recover any shape pre-programmed upon heating. With this fabric was made a shirt with long sleeves. The sleeves could be programmed to shorten immediately when the room temperature heats up. The shirt can be screwed up, pleated and creased, then, just by a flux of hot air, even a hairdryer, it can pop back automatically to its original former shape. ESA innovations were recently used in thermal underwear for the manufacturer Björn Borg as well as an Italian motorcycle-clothing manufacturer, Dainese, tailored ESA’s Skinsuit to alleviate astronaut back problems.

Space exploration could become today a driver for growth and competitiveness involving industries and companies not strongly related to Space, as it has been its policy until now. The European Space Agency (ESA) is looking into novel ways to advance its strategic goals for space exploration that can include private sectors with the aim to create new products and services which are able to answer to the emerging needs of the society constantly changing and reach a wider audience. It is for that reason that, together with the traditional areas of interest for ESA consisting in user-driven exploitation of Low Earth Orbit (LEO) infrastructures, lunar and martian exploration, and research and development, we find, for the first time, the word inspiration: how could we consider this keyword’s choice?

### 4.3.2 Taking Inspiration by Space to Innovate

How many times Space has inspired the human being? All the worlds of thought have looked at the universe: science, philosophy, religion, technology, literature. And also, all the disciplines related to art and practice: design, cinematography, communication, music and many more. Sky and stars continue to exert a strong fascination on every one of us beyond the ages and fashions. There are different kinds of innovation that can reflect Space: style innovation, meaning innovation or technology innovation, including spin-offs and spin-ins, transferring by Space to Earth and vice versa.

#### 4.3.2.1 Innovation of Style

The fashion designers have been inspired by Space envisaging new scenarios explored by the first human space missions and the astronauts’ experiences. The microgravity effect, with the possibility to fly and move without to feel weight, and
the possibility to look at our planet from another and external point of view are the two most innovative and extraordinary conditions which are able to generate visual suggestions that can be translated into shapes, colours and materials: rounded volumes, optical white, and silver nuances as brilliant moon powder, mirroring metals and synthetic fibres.

The visions of the future of Pierre Cardin, André Courreges (Fig. 4.5), Paco Rabanne started during the 1960s with the Space Age (Topham 2003) which implied a great research on experimental fashion based on space styles white and lunar colours, and innovative materials, with the aim to foresee a new way to living and dressing capable of suggesting dreams and inspiring people. Paco Rabanne was at the helm of the Space Age fashion movement thanks to his use of unconventional materials, making clothes from plastics and metals. Indeed, his inaugural 1966 collection was titled *12 Unwearable Dresses in Contemporary Materials*, and his signature dresses comprising plastic discs or aluminium plates strung in a way that was reminiscent of chainmail. Paco Rabanne extended his research to popular science fiction when he designed the costumes for the classic cult *Barbarella* in 1968, which is set in the 41st century. As for today, under the direction of Julien Dossena, the fashion house has been returning to its futuristic roots with chainmail skirts, sheer Nylon® and Perspex® wedge boots. Many fashion designers have often turned to science fiction and its associated futurism for inspiration. The distinctive costumes from cult science fiction flicks have proved lasting influences, from Jean Paul Gaultier’s looks in *The Fifth Element* to the punk-rock garb in *Blade Runner* and the robot from 1927 silent film *Metropolis*, which has been embraced by the likes of Karl Lagerfeld and Thierry Mugler (Dominoni and Quaquaro 2017a, b).

And this trend is continuing until now. *Star Wars* saga is the inspiration of the new fashion show for men of Versace in 2016: tracksuit in optical fibres, shirts with luminescent piping as in astronaut suits, outwear with embroideries like space debris, leather jackets decorated with crystals, jeans with imprinted entire constellations, and sneaker with lunar landing sole. The most surprising action inspired by space scenario was performed during the fall 2017 show by Karl Lagerfeld who organized a catwalk for a Channel at the Grand Palais in Paris simulating a C-branded spacecraft launch in the final part of the catwalk dominated by silver glitter garments and accessories as space helmets worn by the models. It was a powerful way of updating the space style in our contemporary world which looks at space tourism as a close and feasible opportunity.

### 4.3.2.2 Innovation of Meaning

So, not only technology innovation but shape, scenario and narration can suggest us new ideas and products destined to revolutionize the world of production and become best sellers on the international market: from the lunar exploration and Neil Armstrong’s lunar boots derive the sneakers, with strong power of absorption thanks to the technology transfer. At the same time looking from another point of
view, the Moon landing has had also the ability to inspire great ideas, like the Venetian entrepreneur Giancarlo Zanatta, who in 1970 wanted to clone the footprint of Armstrong’s foot to make the mythical snow boots Moon Boot, an interesting case study of spin-off related to innovation of meaning, innovation of emotional language, and innovation of usability of the product, and not just to innovation of technology (Fig. 4.6).

“The America is thrilled and celebrates itself for the conquest of Space. Before me—tells Giancarlo Zanatta in an interview—a giant poster of Neil Armstrong walking on the Moon. It’s beautiful, it is strong: the man seems to come out from the image. I cannot take my eyes off those boots so special and from that imprint. Well, it happened at all of us if we think about it: the world’s attention was not directed precisely at the foot of the astronauts? If we strive to remember, each of us will think of Armstrong descending the ladder, the gait clumsy and bouncy, the famous phrase a big step for mankind, witnessed by a so wide and clear footprint on the dust from between the craters. Everything is focused on those feet. Here the bulb lights up. Why not copy those funny boots and make snow boots that leave a similar imprint on the snow? I come back to Giavera del Montello, in my factory,
and decided to try it. We are in three on this product and rely on a designer for the logo. The only complication, if I may say so, is the sole that will have to reproduce the footprint on the Moon effect, actually later modified to make it more adherent to the slippery surface of the snow. Not everyone in the company believes in this attempt. Someone says: but where do we go with this slipper? Resoundingly contradicted. A few days after the launch at a trade show in Germany, begin to rain orders. Hundreds. Thousands. Forty years later, and that is today, they come to count 23 million pairs sold. Thanks to the *Moon Boot*, Tecnica Group has risen to worldwide fame” (Trabona 2009).

In the new snow boots, the evocation of the great conquest is a very strong appeal to consumers; it is not only a result of an unaware marketing, but also of a strong product innovation because the *Moon Boot* was released using nylon fibre, the maximum in terms of modernity during the Seventies, in a time in which all the mountain shoes continue to use traditional raw materials: the skin, the fur of animal origin. And another big innovation is the introduction of the colour, with a brilliant colour palette, and this is revolutionary. Those are the times of Pop Art and Andy Warhol, who spread a new vision through presenting and valorizing consumer
goods as powerful visual communication signs, so important to become privileged subjects of the art system; in this international context, a company which proposes a new shoe coming out from the eternal brown leather is a striking thing! But that’s not all: with ambidextrous footwear and without size constraints customers feel more free and light. The Moon Boot can be considered also one of the first examples of democratic design: it is at the feet of movie stars and queens, but also of all of us, thanks to the simple construction and relatively low costs. This case study is an example of a brilliant idea that makes the enterprise, in the sense of economic activity, an adventure almost poetic, and a product of a museum piece: in 2000, the Louvre has chosen Tecnica’s Moon Boot as one of the hundred objects of twentieth century which is most representative of the history of world costume. And Moon Boot is one of the few trademarks which is mentioned in the Italian dictionary: a so successful product able to become a common name, a word in current use.

The inspiration from Armstrong’s footprint (Jenkins 2012) is a transfer of a unique image that reminds us to an extraordinary human challenge, and for that reason, this shape assumes an evocative meaning and a strong power on our emotional choices. The spin-off concerning the emotional language and the usability are harder to identify because they are often based on different factors that need to be integrated together, giving a new interpretation of their meaning.

I experimented this kind of spin-off about usability transfer during the feasibility study carried out for the project VEST, described previously in this chapter, retrieving and making use of operating schemes that already exist in familiar clothes on Earth, and transferring them to new garments for Space, which have different needs and requirements hard to imagine considering confined spaces and micro-gravity conditions, as those connected with body alterations and new kinds of postures and movements on board. I began identifying new wearability parameters to cater for the astronauts’ discomforts, creating a collection of garments specifically tailored for the Neutral Body Posture (NBP) that astronauts assumed in Space, which is very similar to a person’s posture underwater, with their limbs bent, knees and elbows tending to move upwards and head tipped forward. My surveys carried out during design research have shown that the NBP is, in fact, very similar to the posture adopted by snowboarders, and so I decided to transfer certain functional adjustments designed to make clothing more comfortable for snowboarders—in terms of the cut, stitching and tailoring of garments—to the clothing system for astronauts (Dominoni 2005). In this case, the language of usability allows to transfer conventional outfits that are easier to handle, in another field, in this case, Space, unfamiliar and difficult to manage.

The fashion designers have been inspired by Space envisaging new scenarios explored by the first human space missions and the astronauts’ experiences. The microgravity effect, with the possibility to fly and move without to feel weight, and the possibility to look at our planet from another and external point of view, are the two most innovative and extraordinary conditions able to generate visual suggestions that can be translated into shapes, colours and materials: rounded volumes, optical white, and silver nuances as brilliant lunar powder, mirroring metals and synthetic fibres.
4.3.2.3 Fashion in the Age of Technology

The languages and meanings of products do not only derive from research into applications, but they also follow the same kind of workings as the world of technology that cuts across various different sectors to generate spin-offs. Studies into technology management have shown that innovation often comes from a recombination of existing pieces of knowledge. Henri Poincaré talks about creativity as the ability to create useful new combinations of existing elements and claims that the intuitive way of recognizing the usefulness of a new combination is that it is beautiful. Of course, he is not talking about beauty in a strictly aesthetic sense, but as something related to elegance as mathematicians understand it: harmony, simplicity of signs, practical correspondence to purpose (Dominoni 2008).

This definition applies to the sciences, arts, technology and also Design. Indeed, it seems to overlap with the design specific capacity to create innovation through transferring of contexts, possible uses, technology and materials into a range of different sectors. This familiar practice among designers is generally referred to by the expression spin-off to indicate the design process leading to the creating of useful new combinations by combining existing elements. Hussein Chalayan, Alexander McQueen and Iris Van Herpen are certainly the contemporary fashion designers that have better explored the iconic world of Space looking at technology and smart materials as a plus value to enrich their design proposals and translate them into science experiments. British cypriot fashion designer Hussein Chalayan is the master of metamorphosis.

The designer views technology as a way of pushing the boundaries of what’s possible, and his dedication to sartorial innovation was particularly evident in his fashion show in 2007: he presented a suite of computer-operated Transformer Dresses which morphed through over a century of silhouettes reminding to solar panels of satellites. Worn by models stood on the runway, the micro-motor-powered garments creeping across their wearer’s bodies as sleeves shortened and hems lifted. In a poetic paradox, the actual aesthetics of these innovative pieces were inspired by Space mixing old-fashioned, with Victorian styles morphing into flapper silhouettes. Hussein Chalayan paid homage to the digital era with his video dress, which was made from led lights and played pixel cityscape scenes. Another british fashion designer, Alexander McQueen, has caused a stir when reflecting and prophesying about the future. During his time at the helm of Givenchy in 1999, he presented in the fashion show an art performance with robots spraying colours on the white dress of the model in the centre of the space, who was turning on herself. The techno revolution of Alexander McQueen takes inspiration from Space, science fiction and robots: his models are like cyborgs with their bodysuits covered in neat configurations of multicolour led lights mounted on artificial skin made of moulded transparent Plexiglas® to create body-hugging bodice, which conjured visions of a human circuit board, with each model wearing a 12-V battery pack on her back. Iris Van Herpen, the celebrated fashion alchemist who was the first designer to create a 3D printed dress, has long explored the dynamic relationship with science and the digital world. Her visionary brand of
Sartorialism reached a climax with her human installation *Biopiracy* in 2014. In an uncomfortable voyeuristic display, models were vacuum-packed in plastic, similar to a piece of sous-vide supermarket meat, and suspended several feet above the ground. It wasn’t the first time the Dutch fashion designer had turned fashion show into a *science experiment*: her haute couture show *Voltage* in 2013, began with lightning like electrical flashes emanating from a model standing on a pedestal.

Always more often the fashion system looks at innovation as a big challenge and a great opportunity to experiment new ways to create garments and new language’s codes that could be inspired by the technology transfer. Fashion designers try to interpret this new dimension where all living with managing how to integrate these new notions of digital, virtual and cyber with our real life. If traditionally the distinction between the haute couture and prêt-à-porter was based on the handmade and the machine-made, recently this distinction has become increasingly blurred as both disciplines have embraced the practices and techniques of the other. Today we can choose several handmade couture items, featuring techniques such as embroidery, pleating and lacework, but also machine-made dresses, tailored as handmade, thanks to new technologies like laser cutting, thermo-shaping and circular knitting, or items digitally produced by 3D printing: Chanel couture collection 2015 proposed the prime examples with rich tweed suits woven through 3D printed lattices, and at the Metropolitan Museum of Art in New York the Costume Institute exhibition theme for 2016 was *Manus x Machina: Fashion in an Age of Technology* focused on the dichotomy between handmade haute couture and machine-made fashion.

### 4.3.3 Project Development of Couture in Orbit

**ESA-POLIMI**

The project *Couture in Orbit ESA-POLIMI* was initially developed inside my course at the Master of Science in Design for the Fashion System, at the School of Design, Politecnico di Milano, where I worked six months with the students to arrive at the definition of many concepts of garments inspired by space scenario and enriched with space technology and materials given by the European Space Agency (ESA) and its technical partners.

During this first phase, we were constantly in contact with the leader of *Couture in Orbit* in ESA, Rosita Suenson, who came to Milan for the kick-off of the project to give us information and contact to develop the project. We have been the go-between, with the students on one side and the industries involved by ESA on another, among which Rina Consulting, the Italian partner of ESA for Technology Transfer Solutions, and Extreme Materials, a small company specialized in textile-related technologies, which has in the past included such innovations smart materials embedded in textiles and composites. At the end of this first phase we presented the concepts at the Science & Technology National Museum *Leonardo*.
Da Vinci in Milan to ESA experts, and we selected together with Rosita Suenson the three best ideas to implement for the capsule collection. For each project we had to design and complete two outfits, a total of six outfits, to present at the fashion show at the London Science Museum on 25 May 2016 (Fig. 4.7).

The second phase of the work continued as a research project with the support of our Fashion Lab, for the realization of the whole garments, and finished with the photo shooting at the Immagine Lab, both to support the activities of our School of Design at Politecnico di Milano.

ESA provided space-certifies textiles for the students to use in the project, which was supported by the companies 37.5, Bionic Yarn, and Sympatex. The company 37.5 produces fabric technology invented in the 2000s by Cocona, Inc. to make use of the waste of coconut husks from the food-service industry, which would otherwise go to a landfill. The manufacturer burns the coconut, and the activated charcoal fibres are embedded in yarn to increase the material’s surface area, thus creating a moisture-wicking effect. Bionic Yarn is focused on recycling resources we consume on Earth in order to have a positive impact on society and our natural environment. Turning things we discard into raw materials we can be proud to use in our everyday lives. They make high-performance yarns mixing naturals and synthetics fibres made with recovered plastic (RPET). As one of the world’s leading suppliers, Sympatex® Technologies has been a byword for high-tech functional systems in clothing, footwear accessories and work-wear for decades. In addition to its standard functions (optimal breathability, 100% water-proofness, 100% wind-proofness), the Sympatex® membrane is also 100% recyclable, PFTE-free and PFC-free as well as Oeko-Tex® Standard 100 certified and Bluesign® approved. At Sympatex®, superior quality and well-thought-out technology are essential building blocks for optimal performance and comfort. With this in mind, Sympatex® developed a non-porous membrane consisting of billions of hydrophilic molecules which uses a physiochemical process to rapidly transport moisture from the inside to the outside. It ensures that the body always remains dry—even in extreme situations. Not only that the membrane also provides effective protection against rain. Unlike standard micro-porous structures, the Sympatex® membrane retains maximum functionality even after activity in continuous rain or washing as there are no pores that can become blocked.

In addition, we received from ESA other materials made of Multi-Layer Insulation Film (MLI), space blanket of heat-reflective foil in aluminium, very light with low-weight, used for many applications on the spacecraft, such as structural members, instrumentation, antennas, radiators, wiring harnesses and sunshield covers.

Studying product design from the viewpoint of fibres and textile’s structures draws attention to the fact that material is one of the key factors in any project, capable of stimulating structural, formal and aesthetic experimentation, and also of generating spin-offs and applications in a range of very different sectors. Characteristics of lightness and flexibility derive directly from research projects and applications in the aerospace industry, where the cost of transporting material into orbit (and hence weight) is incredibly high for the amount of energy used.
4.3.4 Learning Goals

The Space imaginary offers fantastic experimental scenarios that can be transformed and reinterpreted by the language of fashion, so apparently distant from the scientific world that revolves around Space, for example, by finding new applications of clothing technology that can improve the comfort of the people who wear them. The fashion system plays an important role in this spin-off process, because it is a catalyst of trends, lifestyles and behaviours, and at the same time is open to the use of new materials, intelligent fabrics and wearables. In this context, Couture in Orbit was also an opportunity to reflect on the role of technology in relation to fashion that increasingly considers innovation as a value to be integrated into their production processes, especially if tailoring matrix. Wondering how technological innovation can influence people’s behaviours and performances, and how we could become more aware of this process of transformation is the task of Design, and it is characteristic of our School of Design of Politecnico di Milano to create for our students important opportunities for research and comparison with the real world, such as this prestigious project with the European Space Agency (ESA).

Fig. 4.7 The final catwalk of Couture in Orbit collection at the London Science Museum, which integrates space technology into garments to be worn on Earth. Credits by ESA
Our principal aim was to find relations between life in Space and life on Earth connecting the two environments and considering not only technological spin-offs or spin-ins, but also emotional language and usability. We transformed inspirations into shapes and textures by looking at astronaut postures and movements in microgravity and considering their activities in Space in relation to the objects in order to generate new gestures and ideas for our projects. From the aesthetic point of view, we were inspired by space images, choosing colours like silver and white in all the lunar nuances, looking at materials such as aluminium and reflective surfaces, selecting curved shapes and imagining textiles printed with wonderful pictures taken by astronauts looking out of the International Space Station (ISS) towards Earth as well as by satellites, with marvellous colours, patterns and phenomena of light (Dominoni and Quaquaro 2017a, b). But we pushed even further, trying to imagine new uses of space technologies that they do not yet have applications other than the original, but they could in the short period of time become very interesting. Translating high fashion concepts into the language of technology was an essential skill for an endeavour like the project Couture in Orbit.

Fig. 4.8 Couture in Orbit ESA-POLIMI. Could a wearable Cooling Technology be modified to gradually deliver fragrances through steam instead of water? Credits by Politecnico di Milano
4.3.5 Design Methodology

We started to develop the project considering the aesthetic fascination of Space, the technological and functional aspects of the garments, the emerging scenarios in our society and the new needs, the possible spin-offs between Space and Earth and the most suitable expressive languages to be applied to fashion. We were inspired by the confined environment and microgravity that astronauts live on board the International Space Station (ISS), analyzing their activities in orbit and the relationships with objects, which without weight generate new behaviours and gestures following the Use and Gesture Design (UGD) methodology.

The materials that attracted us the most are reflective and very light, made of pure aluminium plywood alternated with white nets similar to gauze (but much more resistant) that are used to make satellites. The lunar colours of white and silver alternate with colourful prints inspired by the images of the Earth, thanks to the satellite network that, depending on the size scale, change patterns and assume both geometric and organic configurations.

We chose technologies developed by the technology transfer system ESA Technology Transfer Program (TTP), such as the Cooling Technology used to keep the temperature constant in astronaut suits, and subsequently chosen as a spin-off from McLaren company for protective mechanics suits. But we went even further, trying to imagine new uses of space technologies that do not yet have applications other than the original, such as some ESA Patents of antennas, but that could in the short term become very interesting if printed with conductive ink directly on fabric.

The attention to technological aspects did not divert us from the goal of also focusing on aesthetic qualities: I am convinced in fact that innovation and beauty are the most important keywords to create a collection of clothes able to integrate space technologies with a glamour vision of fashion.

We consider multidisciplinary a great value in which each student collaborated in a unique teamwork with different backgrounds, knowledge and talents to achieve the same goal. The greatest opportunity was to research and work for such a prestigious client as ESA and all the students were thrilled for this experience. The students have sought a clear explanation of how these technologies are used in practice, and in other cases consulted with the companies involved into the project to find original solutions and developments to the problems they have posed. We wanted to encourage the students to come up with apparently crazy applications—to stay as crazy as possible—while we were the ones with our feet on the ground, to take into consideration the feasibility of implementation of ideas in a concrete, workable way. For instance, could a wearable Cooling Technology be modified (Fig. 4.8) to gradually deliver fragrances instead of water? And could an innovative ESA Patent for a 3D antenna can be printed directly on textiles with conductive ink?
4.3.6 Couture in Orbit Projects

The three winning projects *Therapic Garments 23.44°*, *Tourist in Space* and *Food Keeper* were selected by a jury composed by Rosita Suenson by ESA together with other experts and project managers of the European Space Agency, the responsible of the industries Rina Consulting, the Italian partner of ESA for Technology Transfer Solutions, and Extreme Materials, Benedetto Quaquaro and I. Our team followed the students from the first ideas to the realization of prototypes and declared themselves very satisfied with the results. The research group that created the capsule collection was international, made up of students from all over the world—England, Brazil, France, Argentina, Serbia and Colombia, as well as Italy—who share and exchange cultures, different ways of living and thinking, enriching the quality of the projects.

4.3.6.1 Therapic Garments 23.44°

The number 23.44° corresponds to the inclination of the axis of the Earth that determines in the inhabitants of the northern regions a biochemical disorder called Seasonal Affect Disorder (SAD) caused by the lack of sun—and able to generate anxiety and depression—and which can be compared to the alteration of circadian rhythms of astronauts confined aboard the International Space Station (ISS) without natural light (Moore et al. 1996). The concept of this project focuses on body alterations and the study of therapeutic essences. The principal aims are to respond to these needs by acting on the possibility of stimulating the mind and body and restoring the biochemical balance with fragrances inserted in tubular structures integrated into the clothes that spread in the air through steam.

The idea is inspired by space *Cooling Technology*, developed by ESA Technology Transfer Programme (TTP) and originally used in the astronaut’s Extra-Vehicular Activity (EVA) under suits to keep the temperature constant thanks to heated water that flows in a system of tubes sewn on the inner fabric of the garment. The most famous case study is McLaren mechanics’ suits, made by the Italian fashion manufacturer Karada together with the fashion designer Hugo Boss. The challenge was to produce a thermoregulating garment, offering fire protection and a comfortable working temperature for the whole team servicing the car, whose overalls have the same safety standards as the pilot’s. The ESA TTP offered the solution: 50 m of plastic tubing, 2 mm wide, developed for astronaut’s suit by the Canadian company Med-Eng, and installed by Karada in 55 overalls. The result is a miniaturised air conditioning system, offering maximum comfort when working under extreme heat.

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5 The project 23.44° Therapy Garment was developed by R. Fustinoni, G. Presti and S. Ward under the supervision of professors Annalisa Dominoni and Benedetto Quaquaro of Politecnico di Milano, and with the technical support of Andrea Ferrari by Rina Consulting, the Italian partner of ESA for Technology Transfer Solutions, and Ettore Rossini by Extreme Materials.
In the 23.44° project it is foreseen a plastic tubing structure, surrounded by a tubular knitted structure and integrated into garments, which releases substances through steam, instead of water like in the traditional Space Cooling Technology, and distribute themselves on the surface of the garments. The tubular circuits—made of flexible plastic and wrapped in a tubular 3D coloured mesh of Extreme Materials company—create strong and recognizable organic signs on clothes and provide micro-holes that allow fragrances to envelop the body. The substances are inside small tanks in a solid form. Together with pharmaceutical substances, it is possible to join perfume essences as orange and eucalyptus to increase dopamine levels making the wearer feel more alert and energetic, but also essences of vanilla, anise and lavender that help the release of hormones such as oxytocin, serotonin, and norepinephrine, for relaxing effects.

Sculptural and organic volumes define dresses that invite those who wear them to experience an intra-body transformation in which smell plays the main role to stimulate mind and body, reactivate memories and stimulate emotions. The choice of white colour is inspired by the essential white of the Extra-Vehicular Activity (EVA) suits that astronauts wear in Space, while the tubes are coloured and in accordance with the performances induced by the essences.

This project introduces also another important aspect using Design approach in Space: the value of the beauty beyond the technology described in 1st chapter The Strategic Role of Design for Space. In addition to the choice to make the technology visible, by putting the tubes out of the dress and not inside, as in the space Extra-Vehicular Activity (EVA) under suit, we made sure that the tubes flowed on
the dress of the *Therapic Garments 23.44°* creating a drawing, an *arabesque*, that would have had a strong visual impact, and that paradoxically could have had an identity even without the technology in use (Fig. 4.9).

This is a case study that shows how through Design we can transform technology inputs in beauty driving both the languages of science and style (Fig. 4.10).

### 4.3.6.2 Food Keeper

This capsule collection is inspired by the food in Space and the types of packaging specific to the confined environment and microgravity that contain foods often in the form freeze-dried and unattractive.⁶ Astronauts are forced to eat in almost perpetual motion, floating on board the International Space Station (ISS) without having the possibility to remain motionless, if not anchoring to the structures provided on board the habitable modules. *Food Keeper* offers clothes that allow you to carry and store your food carrying your meals wherever you go and to find the pleasure of eating it, even if on the move, when we walk and move in the city.

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⁶The project *Food Keeper* was developed by A. Laurentin and C. Martinez under the supervision of professors Annalisa Dominoni and Benedetto Quaquaro of Politecnico di Milano, and with the technical support of Andrea Ferrari by Rina Consulting, the Italian partner of ESA for Technology Transfer Solutions, and Ettore Rossini by Extreme Materials.
Each dress has a different function determined by various types of compartment pockets in very large compartments: some are designed to store food and others to carry water in the amount necessary to not have to skip meals. The space style of the clothes recalls the 1960s Space Age by Pierre Cardin and André Courreges, the shapes and volumes of the pockets are reminiscent of lunar craters and are made of insulating material padded and lightweight—Multy Layer Insulation Film (MLI) aluminium used by European Space Agency (ESA) for various applications in spacecraft, instrumentation, wiring, structural elements and reflective parts of satellites—to be able to contain, transport and store food in the best possible state. The use of 3D knitted fabrics by Extreme Materials has allowed to create garments with strong and defined volumes (Fig. 4.11) that alternate with transparent and light crinolines on layers of MLI making glimpse the reflections of silver and gold light of the material.

Another silver tubular mesh covers the pipes that carry water to drink and maintain the constant temperature—inspired by the ESA Cooling Technology—creating at the same time aesthetic and structural decorations on the clothes. In this case, the space Cooling Technology is interpreted in another opportunity: the idea is to drink water through the tubing structure that decorates the outfits with a double intent: aesthetic and functional. A small tank can be filled and carried in a very light way. MLI aluminium film substrates are perfect to conserve food qualities in the pockets while moving across the city.

Fig. 4.11 Couture in Orbit ESA-POLIMI. The lunar craters of the Food Keeper capsule collection are made by 3D knitted fabric that allow to create garments with strong and defined volumes. Credits by Politecnico di Milano
4.3.6.3 Tourist in Space

The project looks at the need to carry payloads and equipment in orbit on the International Space Station (ISS) that have the least weight and volume possible and can be used and stored quickly and easily by astronauts, space travellers, tourists, living in an extreme and difficult to manage environment. As well as astronauts, travellers face similar situations, although not so extraordinary: weight and luggage volume restrictions, climate changes, etc. Thinking about the comfort and the transformability necessary to the clothes we wear when we travel and want to keep a light luggage has generated a system of garments that bend – following the Japanese technique of origami just like satellites and solar panels—and also change shape and function through a zip system that allows you to switch from outerwear to a dress by removing and moving the parts that compose it.

The foldable clothing system suits the tourist and the traveller who has to change the look during the day passing from a flight by plane to a business meeting and maybe even a dinner party keeping the same dress, even if with different configurations, included a sleeping bag stuffed with lightweight material, as aluminium Multy Layer Insulation Film (MLI), and thermal insulation used by the European Space Agency (ESA) for different applications in spacecraft, instrumentation, wiring, structural elements and reflective parts of satellites. Sympatex®, a high-performance technical fabric on which are printed conductive ink antennas (Fig.4.12)—inspired by an ESA patent—has been chosen to create transformable

![Fig. 4.12 Couture in Orbit ESA-POLIMI. The shooting backstage of Tourist in Space capsule collection at the Immagine Lab of Politecnico di Milano. It is possible to see the pattern of the ESA antenna printed on textile with conductive ink. Credits by the author](image-url)
clothes, which, in addition to forming a strong and recognizable graphic pattern, allow localization, the transmission and reception of signals.

The white background contrasts with the colourful printed parts with images of the Earth seen from Space thanks to satellites, while the colours of the hinges suggest how to use the garments and transform them. The inspiration from satellites brings another value to this project: the possibility to have a localization system printed on textile with conductive ink which works as an antenna. The ESA Patent of a 3D antenna, Optimized Antenna Elements Position and Dimensions, offers a method and software product with which antennas are designed. The configuration of the antenna is made of little 3D cones that looking from the flat side creates a pattern of concentric little circles similar to a flower.

In this case study, like in the project Therapic Garments 23.44° inspired by the space Cooling Technology (Fig. 4.13), the idea to translate these cones into the same configuration of the antenna, but printed in 2D with conductive ink, is a good example to demonstrate the power of beauty, transforming technological pieces—integrated together in that configuration just following functional principles—into a significant drawing (Fig. 4.14) that gives a strong identity and recognition to the garment, as explained in the paragraph A Bridge Between Human Science, Technology & Beauty in first chapter The Strategic Role of Design for Space.

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7ESA Patent PAT619, Optimized Antenna Elements Position and Dimensions.
4.3.7 Learning Outcomes

*Couture in Orbit ESA-POLIMI* allowed students to discover the potentialities of Space as a source of inspiration to reach new ideas and to imagine new scenarios on Earth in which Space Technology can be applied in different ways to increase the quality of life, combining aesthetic values with functional aspects and society’s needs. They focused on a *design vision* with an *out-of-the-box approach*—like an astronaut looking at Earth from Space—but developed a real capsule collection starting from designing concepts to the realization of the prototypes.

An important part of the project was the relations of students with ESA’s partners and companies of the private sector during the development of the design concepts that allowed them to be more conscious of space technologies and smart materials applied in the capsule collection. In addition to the project, they learnt how to create and organize a catwalk and an exhibition participating to all the phases of the event *Couture in Orbit* at the London Science Museum and going in depth into this experience with a strong enthusiasm.

*Fig. 4.14  ESA Patent of Optimized Antenna Elements Position and Dimensions*: the picture shows a circular layout of array designed accordingly to the present methodology and employing radiating elements with different apertures. Credits by ESA
4.3.8 Results Dissemination and Exploitation

The results of our capsule collection *Couture in Orbit* from the Italian side ESA-POLIMI were spread through the most important newspaper and magazines crossing the fields of science and fashion, from *Vogue* to *Il Sole 24 Ore*, and we received many invitations to present our project during international events, exhibitions, symposia and scientific TV programs among which.

Space for Inspiration, event-talk by ESA, London Science Museum, 2016; *Couture in Orbit* ESA-POLIMI, event-catwalk organized with ESA-ESRIN for the *European Researchers Night*, Rome 2016; *Fashion in Space*, lecture at the National Conference *Space4Sustainability*, organized by the Associazione delle Imprese Per le Attività Spaziali (AIPAS) Macro Museum, Rome, 2016 are some.

We received also the awards:

- *ADI Design Index 2017*, the prestigious selection of the best products of the year by *Compasso D’Oro* [7];
- *Lombardia’s Excellences Award 2017*.

4.4 Space4InspirAction. A Space Design Course with ESA

*Space4InspirAction* (S4I)—created in 2017 by Annalisa Dominoni and Benedetto Quaquaro and now at its 4th edition 2020—is a Space Design Course, Master of Science in Integrated Product Design, at the School of Design, Politecnico di Milano. It is the first and unique international Course of Space Design in the world recognized and supported by the European Space Agency (ESA) through experts and scientists who suggest and then deepen the project themes in line with the objectives of the space Agencies strategic programmes. The collaboration between the S4I Course and ESA is not a spot project, but the beginning of an ongoing agreement about an *academy—research—design* process to ensure the development of innovative ideas in which the contribution of Design discipline is fundamental and strategic to generate disruptive visions of habitability and equipment solutions to increase the wellness in Space, with particular attention to the *new human factors* and interactions between operator, tools and environment (Dominoni et al. 2018).

We have every year international students coming from all the world who contribute to create a multidisciplinary working group thanks to different background, cultures, curricula and know-how. There is a big selection and only the best students can participate, and in the maximum number allowed, not more than sixty.

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8The *new human factors* are treated in third chapter *Research and Design for Space Life*. 

When we created the Course with the support of ESA, we decided to take inspiration by the name of the international congress, Space4Inspiration, to which we have been invited, as guest speakers by ESA, to lead a lecture of Space Design in 2017 at the London Science Museum. Our idea to add Action to the word Inspiration wanted to underline the design soul in action of the discipline in Space Design. We wanted to bring out how we can both design for Space and for astronauts, but also how Space can be a great inspiration to generate terrestrial innovations through space technology transfers, but also behavioural and visual spin-offs and spin-ins.

Space Design is a new discipline that is being formed due to the strong attraction that Space has always generated on society, thanks to its narrative power, and which will have a decisive influence on people’s behaviours and performances in the near future. Design can speak different languages, combines science and beauty, becomes a mediator between technology and needs through projects that generate new scenarios and new paradigms with which to confront.

Space can be a great inspiration to create design-driven projects that can inspire companies which look with interest in innovation and research to find new products.

Moreover, the International Space Station (ISS) can be seen as the most extreme example of sustainability that the human being has managed to achieve because it can be considered a living organism capable of recycling 100% of its resources. Besides, it is the only international experiment, visible to everyone, that has managed to unite different cultures and races in a project of collaboration and scientific progress for the whole world which goes beyond the divisions between countries.

The Course S4I is a unique opportunity to develop a strong capacity of visioning looking at Space as an inspiration to innovate and design new projects of Space habitats and tools, but also new scenarios that could help people to live better in a sustainable way. Furthermore, Space allows students to develop creativity by confronting with confined and microgravity environment, that is not part of our common experience. I believe Space innovations will have a strong influence on how people behave and perform, and the role of Design is to humanize technology to meet the needs of a sustainable society. I also believe Space can really inspire students and help to understand better how they can be more conscious of the transformation technology brings.

The aim of our Course S4I is to create new professional figures which will be able to

- connect both technology and beauty languages,
- increase creativity and visioning,
- find design solutions crossing know-how and research,
- imagine new cultural and business models to increase well-being according to sustainability.

The partnership with ESA foresees the participation of experts and scientists who define together with us the themes of the projects to develop together with students,
according to the strategic programmes of the space agencies, and integrates their experience and know-how with lectures useful to set up the base of the research and the development of the projects. ESA’s support is a big value because a theme like Space allows students to develop creativity with intense visioning activities by confronting with confined and microgravity environment that is not part of our common experience. Thanks to ESA we are able to compare our design vision with real conditions and requirements and find innovative solutions designed for Space, but that can be also transferred to daily life on Earth becoming spin-offs.

The Course *S4I* has a dual purpose: on the one hand pushes students to get inspired by Space and define new visions; however, starting with real conditions and requirements, on the other to imagine new spin-offs, or terrestrial applications, that can be transferred to our daily lives to improve them. For this reason, design companies from the private sector are involved in the projects, together with space companies, with the aim to translate space inspiration and vision into spin-offs generating new concepts of products. It is our aim to enhance the high quality of the projects developed during *S4I* with the exploitation of the results through media press and exhibitions.

The frame of *Space4InspirAction* Course is composed of two parts which interact with each other:

- a theoretical and explorative part which provides lectures with ESA experts and scientists as well as engineers by space industries who integrate their experience and know-how useful to the development of the projects;
- a practical part, the real project, developed with professors and supported by ESA and space industries in which is required a disruptive capacity of visioning.

The sequence of activities is planned to introduce progressive levels of complexity and to give students the opportunity to use previous knowledge and that they are learning in parallel in the theoretical integrated part with the aim to increase their capacity to manage information with different skills.

The topics of *Space4InspirAction* Course changes every year, following the ESA’s space strategic programmes, with the aim to find connections between *living in Space* and *living on Earth* and suitable solutions for two both, looking at astronauts activities in microgravity and the alterations of body postures and movements in relation to their objects that can generate new gestures and ideas for our projects. Space knowledge, space research results, experimentations, new materials and technologies suggested by ESA are important drivers to increase the innovation value of the projects.
4.4.1 Design Methodology for Space

The unusual and extraordinary environment offers the students the possibility to think out-of-the-box, like astronauts’ experience looking at the Earth from another point of view, and the chance to increase the creativity and the ability to imagine and design new objects and tools starting from a perspective completely unknown. Microgravity and confinement are the principal keywords of Space to inspire new projects, stimulate reflections and connections between Space and Earth and find suitable solutions for both environments.

Through a new methodology that I have developed and called Usage and Gesture Design (UGD), and that is specific for Space Design, emerges as the figure of designers is not limited to creating objects, environments, architectures, but can be extended to the suggestion of new behaviours and gestures of astronauts in relation to the use of designed objects, environments and architectures.

Multidisciplinary approach is fundamental for the creation of new professionals who are able to speak different languages of the project and that is why we use to involve in the Course S4I—a part ESA experts of different areas—aerospace, mechanic and mechatronic engineering students, who work in groups with our design students, including product design and interaction design, to ensure the feasibility of new creative and disruptive ideas, and increase the skills of all students.

Of course, all the project we developed would not be possible without the support and participation of ESA and companies, both in the space sector and private, to face real contest and real problems and find disruptive ideas but based on feasible know-how and technology. This is an important part of the project that push students to be confronted with ESA’s partners and companies during the development of the projects, because they can become more conscious of space programmes, technologies and challenges crossing different knowledge. We think innovation can arise by exploring many fields, better if they are very distant, and produce disruptive ideas as the case studies reported in first chapter of this book The Strategic Role of Design for Space.

A last point, that is not properly a methodology, but a practice that we pursue with conviction is the importance of dissemination and exploitation of the results through scientific publications, newspapers and magazines with big circulation, radio and tv programmes as well as exhibitions.

Beyond these methodologies, there are others integrated in the path of Space Design which belong to the Design discipline and that are very useful in Space. Here I summarize briefly all the approaches, practices and suggestions to face the development of the projects, starting from Design and ending with Space Design’s methodologies:

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9 The methodology Usage and Gesture Design (UGD) is treated extensively in this book especially inside first and third chapter because is the base of the Space Design discipline.
the relevance of thinking out-of-the-box for visionary projects: the unusual and extraordinary environment offers students the possibility to think out-of-the-box, like astronauts experience looking at the Earth from another point of view, and the chance to increase the creativity together with the ability to imagine and design new space environments and tools, starting from a perspective completely unknown (Dominoni 2015);

Design is a problem creating discipline: I like to define the designer a problem creator, the opposite of a problem solver, which generates innovation and increases people’s well-being, and this is true both in Space and on Earth. Design is useful if it finds new problems to solve, if it creates something new that nobody has ever thought before. If an astronaut lives and works in a comfortable environment, with equipment and facilities designed properly to be used in Space, its performances increase as well as the quality of the activities, individual and collective, and can be determinant for the success of a mission;

the new human factors: the boundaries of intervention areas for Design seem to converge into a new methodology with a background halfway between design and human sciences characterized by an increasing attention towards the user, and the value relative to the use and to the emotions aroused by the product on one hand, by a strong involvement in the processes of technical scientific innovation on the other (Green and Jordan 2019);

User Center Design (UCD) + User Experience Design (UXD): the most significant characteristic that distinguishes the designer’s approach is a prominent attention to the users of the products. The designer must interpret, by means of the formal and symbolic qualities of its projects, people needs, expectations and desires, and at the same time, elevating the degree of their general well-being. Design places the human beings at the centre, with a User Center Design (UCD) approach, trying to interpret their needs in the most sustainable way. Going beyond, Design creates new experiences for people, with a User Experience
Design (UXD) methodology, imagining how it could make more pleasurable and unforgettable the human life (Fig. 4.15);

- focus on the design process: during the design process we have to consider, as usual, all the methodologies which belong to the Design discipline (Dominoni 2010) as design thinking, in the preliminary phase of the concept design, followed by design to cost and design to recycle, during the development of the process to make the project feasible, attractive, affordable and usable;

- Use and Gesture Design (UGD): the most important and most interesting difference between Design for Earth and Design for Space can be identified in the design process, which regards the capacity to forecast the design of use and gesture, visualizing possible human gestures and movements in Space, in confined environments and in microgravity conditions, which cannot be compared to human experience on Earth (Fig. 4.16). Through a new methodology that I have developed and called Usage Gesture Design (UGD) we do not limit ourselves to creating objects, environments, architectures, but also, we design new behaviours and gestures of astronauts in relation to the use of the new objects, environments and architectures. Applying a UGD approach means projecting the features of the future object on the scene of its possible uses and visualize them in action: in your hands, put on you, in the environment to zero gravity where the object will be used, and how it will be used, in which ways, etc. That means the design activity to create a new object, or an environment, must be contemporary to the forecast of the use of the new object, or environment. The designer becomes a filmmaker, able to create a potential script of the new object, together with the environment, the movements, and the gestures of the astronauts;

- crossover between Space & Earth Design (SED): Design of Space is also a process from Space to Earth and vice versa to generate spin-offs and spin-ins, technology and behaviour transfers, new applications and new products. We push students into a design process in which they experiment a practice crossing;
• different fields and knowledge, that we called *Space Earth Design (SED)* to learn how it can generate opportunities. Considering that both Space and Earth are inhabited by the human being, we can find solutions by the observation and experience gained in Space (technologies as well behaviours) that could be transferred on Earth contexts and vice versa.

If the methodologies described represent the tools to Design for Space, as designers and architects, there are some methods of *active learning* that in the academic field are very useful to have immediate feedbacks by the students. The *active learning* methods provide an important role to the students, who are called to get involved in different contexts. They range from individual practice to pairs or small group discussion on specific topics, to the exploration of topics and problem-solving, making the entire learning experience a collective research, connection and knowledge processing experience. The *active learning* methodologies are also clearly related to the *flipped classroom* approach, which is based on the idea that students explore some content before the lesson which is then given maximum value for the application of knowledge in a dynamic interaction with teachers and peers. Usually, we programme lectures, with ESA scientists and companies’ experts, at the beginning of the Course S4I to allow students to go in depth into information and tools to approach the projects. The lectures are scheduled to be maximum 45 min each followed by a 30 min session interspersed with moments for questions and for the consoling of the notions just learned through the use of *Socrative*. The professor prepares 3/5 questions on the content explained during the lecture with the aim of consolidating the knowledge and skills constituting the lecture’s fundamental concepts to be taken away. Students answer individually or in pairs. *Socrative* allows to visualize the answers to multiple choices maintaining the anonymity of the students and giving us an immediate feedback on the correct transposition of the information, and therefore of the clarity of the contents expressed. This tool is one of our favourite methods of active learning because we found it is a very useful system to have feedback and consolidate knowledge: usually, the majority of students responds correctly and besides, who has the wrong answer, more easily remember the new information. Another method that we use to check the mood of the classroom and know what the students have in mind is *AnswerGarden*, a very simple and minimalistic tool that *photograph the thoughts* of a precise moment of all the participants—that could be after a lecture, an exercise or an explanation of the project organization—takes shape and grows up according to the evolution of the day, the topics of the lectures, the feeling and the emotion of everyone involved. Thanks to *AnswerGarden* the class becomes a *living organism* that reacts to the inputs given by professors, guest speakers and students, and which creates a feedback in movement and open to a continuous transformation during the day: this is an *active learning* experience able to increase the empathy between us and our students that can be associated to the idea of a self-sustaining spaceship, which changes behaviours according to the various environmental stimuli and grows, thanks to the participation of all the actors involved.
Both Socrative and AnswerGarden are virtual tools that can be used by students in classroom, but that we discovered was very useful also during our last learning experience leading the Course Space4InspirAction (S4I) 4th edition in distance due to the Covid-19 pandemic in 2020; we developed projects with a network of students, who are living in different parts of the world, and in which, despite the distance, all the actors collaborated to enrich the experience.

To conclude this paragraph of the Design Methodology for Space I would report the data collected by us after the end of the Course S4I 1st edition concerning questionnaires in which we asked our design students to give us feedback on the experience of the new Space Design context; the involvement of ESA and companies both from Space and the private sectors in the development of the projects; the working groups with multidisciplinary teams made of design and engineering students; the impact of our methodologies; the three keywords that in their opinion the peculiarities and the best qualities of the Course Space4InspirAction and their suggestions. We raise an interesting list of comments in which they underlined the advantages of this new experience:

1. a Course of Space Design is an added value of the School of Design;
2. ESA and industries support the projects’ optimization with integration of technological know-how, and it is a great opportunity to increase knowledge and compare ideas and concepts with feasibility;
3. the multidisciplinary teams organize ideas and concepts in a coherent logic;
4. the collaboration with different professional figures will increasingly characterize future works and this experience allows to open a constructive dialogue of exchange;
5. opportunity to know each other and debunk myths as the designer is an artist and deals only with shaping things, the engineer is too rigid mentally;
6. collaboration increases inspiration and multidisciplinary communication;
7. methodologies balance visioning and practice for more inspiring projects.

The most recurring tree keywords to describe the Course S4I that the students suggested in the questionnaires were freedom, creativity, experimentation and I think they reflect very well the intent and the spirit that prompted us to create a new discipline in Space Design and to experience during these first four years many issues related to how we live today on the International Space Station (ISS), but also to those that we will soon live on the next space stations and lunar and martian bases, which will open a new era of planetary colonization.

4.4.2 Space4InspirAction 1st Edition 2017

The themes we have chosen during the 1st edition were focused on three topics and involved companies with the specific know-how to help us developing the projects together with the European Space Agency (ESA):
– *Space Food*, considering that nutrition is one of the topics that attract the attention of the space scientific community with the aim to create an autonomous life cycle integrating plants growth in the space habitats; for this project, we chose Argotec, the Italian company which realized and launched a coffee machine on the International Space Station (ISS) together with Lavazza, and which created the *bonus food* for the astronaut Samantha Cristoforetti during the *Futura Mission*.

– *EVA Suit*, that means a suit for Extra-Vehicular Activity (EVA), a very complex project that we could consider like a small space station complete with all the parts and systems useful to maintain the living conditions inside, protecting the human being to the vacuum of Space outside; we have chosen the Italian company Dainese to support us, leader for motorcycle garments and accessories including protective helmets, gloves and boots. In addition to dealing with protective sports clothing, they have a strong know-how in designing space suits for the ISS Intra-Vehicular Activity (IVA) and the Moon working EVA for NASA.
Interplanetary Missions, including both the spaceships for the travel to another planets and lunar and martian bases; we had the chance to count for this third project of the support of Thales Alenia Space (TAS), the world’s leading player in the construction of space habitats, to explore how to build a space habitation module, an orbital station with microgravity, a Moon or Mars base in reduced gravity.

The results of the 1st edition 2016–2017 of Space4InspirAction (S4I) have been presented during a public event at the Planetarium Ulrico Hoepli in Milan (Fig. 4.17), an exhibition for the Long Night of the Stars, an ESA event celebrating the 50th anniversary of ESOC, the European Space Operations Centre, in Darmstadt, Germany, and during the European Researchers Night in 2017 at the ESA Italian headquarters in Frascati, Rome.

In the next pages a short excursus of the projects to give an idea of the big variety of the ideas, all of them driven by the desire to make closer Space and Earth and increase the well-being of the astronauts producing spin-offs and spin-ins.
4.4.2.1 Space Food

Considering food has a big importance for the health and the well-being of the people in general, and in particular for the astronauts who live in a confined environment without natural stimuli, the major part of the projects is about creating a new immersive food experience in Space, including also space tourism.

In Virgilio (Fig. 4.18), people go on these trips to experience what an astronaut experiences, microgravity, feeling weightless, eating in Space, where food is easily grown and processed on board of spaceships. By using an advanced form of cellular culture, we are able to bring just a few stem cells of different typologies of food, which we can, through a computer-controlled environment, grow when required, and through a laser system transform them into a printed food with shape, dimension and layers determined by planets, comets, asteroids or stars compositions, that are translated into ingredients. For example, asteroids have a frozen core but solid crust, so it could be translated into a solid cookie core with a chocolate crust flying through the module. In this way, you can learn about these space objects while eating them. The production chain explained earlier gives us the possibility to produce anything we want, when we want. An important factor to consider is the experience of eating this special food. That is why we also devoted some time to the module in which the space tourists will consume it. The module
consists of a sphere (which recalls the food the travellers will eat), which allows people to experience microgravity to the fullest (as opposed to current volumes within the ISS). To help them move around, we designed two paths on the inside surfaces of the module, on which a nanotechnology adhesive helps them walk around the sphere and look around. Two larger windows fuse outer space with the confined volume of the module, to enhance the experience of floating outside the Earth’s atmosphere. This three-dimensional walk is something that cannot be done on Earth and will add to the amazing experience. The food that has been produced is floating around inside this module, and the space tourists will have to grab it in order to eat it. Fortunately, they are not alone. A guide, Virgilio, is there to help them through this voyage, taking them through the space menu as an exploration of the universe, explaining them what they are eating and where they are located. In its entirety, this explorative concept looks at a new way to produce food, but more importantly, the way this food can carry a message and the valuable experience it creates for space tourists.

Coming back to astronauts, Bloom creates a poetic and seasonal experience taking advantage of the microgravity: inspired by the lotus in the pond and lanterns floating on the river, food is stored in flower-shaped packaging, which once heated, rise upwards opening the petals slowly until they form dishes that astronauts take and consume without the need for other tools. Shake It suggests astronauts use

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**Fig. 4.20** Thanks to *Leaf* system astronauts can cultivate, grow plants, carry out research and experiments, feed in a healthy way and maintain an emotional relationship with the Earth. Credits by *Space4InspirAction*, Politecnico di Milano
different gestures to shake this heater (Fig. 4.19) in order to have a real experience of making food like on Earth, using the pot to heat and mix food.

Moving from space food tools to systems to grow plants transforming the spaceship or a habitat into a self-sufficient organism, in terms of energy and renewable resources, the self-sustaining Leaf module is a concept designed to support space explorers during long trips, thanks to the growth cycle of plants on space stations or planetary surfaces that allows for the feeding of the crew and for scientific research. Starting from MELISSA, Micro Ecological Life Support System Alternative—a ESA project for a closed life support system aimed to produce food, water and oxygen for manned space missions increasing regenerative behaviours—Leaf module promotes in a whole process of farming, researching, eating and recycling, a strong interaction between the crew and the plants, creating an emotional connection with Earth and maintaining an environment surrounded by plants that provide explorers with air and a familiar habitat as well as a better nutrition (Fig. 4.20).

On board the International Space Station (ISS) astronauts always need to have their hands free to grab any tool in an emergency. The lunchtime is always fast and often takes place in a matter of minutes between a commitment to another. On the opposite side, in view of these new types of tourist travel, there is a need to rethink the food system, as for a tourist feeding time must be quality and at the same time a new experience. Gulp is composed of two main elements: a small cuff, always worn by the astronaut in the upper part of the forearm and an elastic band, which is inserted into the forearm only at the time of the meal. When the envelopes are inserted into the rails of the bracelet, thanks to sensors placed on the bracelet, the foods are recorded so you can track your meal to meal the very delicate astronaut.
diet. Thanks to its high practicality, it can also be used in sports and work extreme situations wearing the bracelet during cycling or climbing. A good example of spin-off of both technology and behaviours from Space to Earth.

4.4.2.2 Extra-Vehicular Activity (EVA) Suit

The EVA suit opens to many new interpretations considering that in the near future astronauts will pass in the same day through different kind of environments and gravity, orbiting around the Moon in microgravity, exploring its surface with 1/6 g and living the transition from inside the pressurized habitats to outside, floating in the vacuum or walking on the ground. At this purpose Mexe is a concept designed to facilitate the exploration and construction of settlements on the Moon; the system consists of an EVA suit that increases the physical capabilities of the astronaut supported by a multifunctional vehicle (Fig. 4.21). The suit has an additional feature, an internal exoskeleton that increases the astronaut’s physical capabilities and reduces fatigue and stress from EVA. The exoskeleton system adapts to the astronaut’s anatomy, identifying points of articulation that require support and maintain an individual profile of each user, learning and adapting to the requirements of the astronaut. To facilitate the development of all activities that are required, the EVA suit has been developed which keeps the astronauts in a controlled environment and provides the necessary resources for their survival, it also protects them from external threats such as radiation, meteorites, or debris.

A disruptive idea to eliminate the removed lunar dust from the EVA suit is to imagine the suit breath and through this movement reject debris. In addition, the outer layer of the breath clothes uses a special material that produces positive
charges in the Sun’s radiation like *Sun shower*, thus repelling the same positively charged lunar dust. But it still cannot exclude the possibilities that some large particles dust cannot be repelled and still stick to the clothes. By realizing the movement of breathing to remove large particles dust, we use a particular material under the outer layer that has the characteristic like the sponge that can capture gas, store gas and release gas, when cleaning the EVA suit, and this layer will be filled with the gas and it has the trend to go out affected by pressure difference due to the vacuum environment of the Moon, thereby causing the clothes to expand while removing the gas. In the shape, we hope to strengthen the visual effect of *Breathing Suit* so that astronauts can clearly feel inhaling and exhaling of the clothes, so we use three-dimensional geometric appearance, where the clothes maintain some small folds in the normal state and expand instantly when removing dust. We suppose the using environment is that astronauts enter a preparatory cabin to make their EVA suits remove lunar dust, waiting for the cabin to finish collecting dust, then leave their EVA suits and go into the master cabin, where the cleaned clothes can be used again.

Another concept design, *Robot Pet*, is inspired by clean fish in the sea that helps to clean bacteria and other microbes parasitizing on the body of big fish. The main function of this concept design is cleaning the lunar dust on the clothes; meanwhile, it can be like a pet to accompany and help astronauts when they engage in the lunar exploration (Fig. 4.22). The principle of removing dust is also to use the electric field. *Robot Pet* can move on the astronauts with four wheels covered with the material nano-level bristle structure like gecko. It has an internal cavity with electric field to absorb dust and collect them in storage bags and each part of the object can be disassembled and cleaned for recycling use. In addition to the dust removal
function, we imagine it can also be effective as a *pet interaction* with the astronaut, which is realized primarily by voice and pet head effects. The head of the robot pet can shake as the music playing, it can change the colour, according to the astronauts in different states, and display astronauts’ health status data and give warnings. It can also increase the experience of communication between astronauts looking at each other’s pet activities to engage in dialogue.

Considering the complexity of the EVA suits and the low visibility, it is important to support astronauts with smart tools able to become additional prostheses to be used as extensions of the human body, like in this example. All the projects are based on real technology projecting new applications and disruptive ideas to increase astronauts’ performances and well-being.

### 4.4.2.3 Interplanetary Missions

A long-duration spaceflight, a challenging environment in confined spaces, together with other people, travelling towards a new home. This is the chain of thought to start defining new concepts to go to Mars, for example, with the *Mars Transfer Vehicle*, designed to travel between Earth and Mars bringing people and research equipment (Fig. 4.23). Because long-time exposure to microgravity has severe physical consequences, we designed the spacecraft to have *artificial gravity*. The ring at the front of the craft, to which the habitation modules are also connected, rotates creating a centripetal force that equals that of the Earth gravitational field, helping to counteract those negative effects, and it also has a positive psychological effect to the occupants, being able to move like on Earth.

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*Fig. 4.24* This *Mush Rooms* habitat system grows up thanks to a mycelium inside an inflatable structure that breaks when it has completed its growth and dying has crystallized. Credits by *Space4InspirAction*, Politecnico di Milano
The centre of the spacecraft (cupola) does not rotate, so occupants can still occasionally experience microgravity. An interesting aspect of this project is that of the artificial gravity. After the modules have been connected to the spacecraft around the Earth in orbit, the ring will start rotating so to recreate the Earth gravitational field of 1 g. However, the gravitational field of Mars equals 1/3 g. So, as the journey through space proceeds, the rotational speed of the rings decreases (centripetal force is directly proportional to rotational speed, with fixed diameter) as to slowly go matching the gravitational field of Mars, 1/3 g. In this way, the transition is smooth for the settlers, and they can start training and getting used to the new gravity field. The journey can last from 5 months to as long as 1 year, so we developed the spacecraft to take advantage of all this time. On Earth, the settlers will receive basic training regarding space travel, spacecraft operations, social training and others. When they have finally arrived on the spacecraft, they will receive specific training for their activities on Mars supported by doctors, engineers, nutritionists, personal trainers, psychologists, scientists, etc. Within the ring, they can find various training areas to use. Laboratories, physical exercise, an area where the surface of Mars is recreated for movement exercises. The ring also contains the shared eating facilities as well as sleeping quarters for the crew.

Once arrived on Mars, we should have a colony ready to welcome us, like *Mush Rooms*, an independent construction system of modular cells for the interplanetary colonization (Fig. 4.24). We got inspired by the progressive building of a society in
a specific context. For this reason, we recreated this gradualness with the use of a material that has its own growing steps. Moreover, the idea of mushrooms was conceived not to bring a material from the Earth but generate it on the planet itself.

### 4.4.3 Space4InspirAction 2nd Edition 2018

The 2nd edition confirmed the presence of Thales Alenia Space—a joint venture between Thales 67% and Leonardo 33%—the world’s leading player in the construction of housing modules for the ISS—who chose the collaboration with our *Space4InspirAction* Course to design the Gateway, the new cis-lunar station, on which all the space agencies are concentrated at this time.

The results have been presented at the Altec Thales Alenia Space headquarter in Turin during an event with an exhibition in which all the engineers working on space habitat topics took part and we gained a lot of satisfaction confronting with them on our project solutions. The main objective of the twelve projects presented was to improve the living and working conditions of the astronauts, focusing on the well-being and psychological and emotional aspects that, together with biomedical ones, are essential for the success of a mission: integrate augmented and immersive VR to allow a wider and varied perception of space; use water as a shield against
cosmic radiation; introduce illumination systems that match the circadian rhythms; integrate sensory environments to be able to stimulate all the senses and innovative technologies that reduce noise on board. The work activities are facilitated by new equipment that transforms microgravity into an advantage, favouring fluctuations that are possible without weight, and much importance is given to entertainment, both personal and collective, promoting privacy as well as conviviality to strengthen the membership of a group.

Among the projects, there are proposals for space habitats that exceed the internal square section of the current spatial modules proposing hexagonal and octagonal sections useful for obtaining more space to be dedicated to areas of containment and passage of cables and systems, as well as being aesthetically more interesting because of the new dynamic visual perspective (Fig. 4.25). For the management of the storage, a new internal structure has been developed, using aluminium and fabric to make it lighter and customizable: the easy movements of the flexible structure make it easier to customize the containment. The panels have a pattern created to generate interactive experiences using a soft and technological material that contains lights for the lighting of the module in accordance with the rhythms of the Sun on Earth that mark the time of the astronauts on board.

In some projects, the internal volumes are completely redesigned and alternate large areas with foldable areas that are transformed according to the various needs of space; mobile and light structures, can be fixed at any point of the station to work or rest; interactive screens cover the instrumentation in order to achieve an overall visual order and a clearer perception of the whole environment (Fig. 4.26). C-Touch is a system based on the combination of fabric and projection that wants to

Fig. 4.27 The perception of the internal spaces of the Gateway are transformed by VR to divide rooms and recreate others artificially both collective for gathering then personal to gain more privacy. Credits by Space4InspirAction, Politecnico di Milano
give the space inside the Gateway module a good level of visual comfort to improve the psychological needs of the astronaut. The aim of the project is to create a visually clear and orderly environment that interacts with the astronaut and modifies the space according to the different times of the day. The mobile textile system covers the two longitudinal parts of the module, one dedicated to rest and the other to work. In the working part, the curtain can be raised and lowered by hand, during working hours the fabric can be closed to use the entire working space or it can be partially opened and become an extension of the interfaces for the astronaut.

The spaces are transformed also according to the activities that are carried out, and in these operations light and augmented VR help to divide the spaces and to recreate others artificially, creating environments clean and comfortable (Fig. 4.27). Many schemes of Virtual Escape are foreseen to change the perception of the spaces, both collective then individual, for example, the perception of privacy is also linked to the possibility of isolating oneself and immersing oneself in the home environment wearing a special helmet.

The examples are intended to give a general idea of all the projects developed, without going into details, because they could not be treated individually as case studies for lack of space. What is important here, is to give an idea of the diversity of the proposals that explore new configurations and space partitions to make the Gateway more comfortable, efficient, safe, and attractive for the crew.

The project Core revolves around the idea of protection: first of the crew members from the effects of radiation, and secondly, of their privacy in space. A modular network of shielding made with water inside integrates with the current water system in Space (Fig. 4.28). Core monitors and ensures water efficiency in

**Fig. 4.28** Core shelter protects the Gateway by cosmic radiations thanks to water bags which can expand or compress according to protection and space needs. Credits by Space4InspirAction, Politecnico di Milano
Space and exploits the possibility of predicting solar storms to generate localized and targeted protections against galactic rays and cosmic radiations. The modular water bags, inspired by a bellows, are designed to expand and compress in order to provide astronauts with sufficient protection depending on the intensity of the storm. By providing localized protection, this shielding system will maximize the scarce amount of water on board the cis-lunar Gateway station through integration with the unused water, recycled or drinking water system. The amount of water needed to run the system is, therefore, what is currently provided in the module of the cis-lunar station Gateway, without the need for an increase. The modular and swivel interior has the aim of maximizing the perception of a private space within the common space: this new habitat, obtained through the rotation of a slice, creates a kind of personal refuge that offers comfort, relaxation and, above all, feeling of private space.

Considering that the Gateway will be smaller than the International Space Station (ISS), the need of privacy, already present on board the ISS, will increase. For this reason, alternative design solutions which could offer light ways to recreate private spaces, even if using VR, are desirable.

4.4.4 Space4InspirAction 3rd Edition 2019

The 3rd edition of the Course activated a collaboration with the Fashion Institute of Technology (FIT), New York, which design the packaging to enrich our products: we focused the topic on Space Objects inspired by Space scenarios and designed for
astronauts with extensions to our daily life on Earth, like spin-offs of objects to be
sold as merchandizing for space enthusiasts through the ESA online shops.

We presented the results to the specialized press projects with a detailed
description of the idea behind the object, a professional quality video that showed
those objects in an attractive way, and the possibility of touching the prototypes of
the objects themselves, made with 3D printers and also equipped with a customized
packaging. The twelve proposals considered the physiological alterations of the
human body due to the microgravity conditions which lead to an overall reduction
in sensory perceptions, such as, for example, the desensitization of the taste buds
that leads to lack of appetite and, consequently, to incorrect eating habits, then also
reflecting on the mental health of the astronauts. The projects aim was to increase
the well-being by activating the sensorial perceptions, for example, with a set of
tools that, recalling textures, shapes and colours of familiar foods, act on the taste
buds of the astronauts, allowing them to stimulate and fully enjoy every type of
food (Fig. 4.29). Moreover, once stimulated, the Taste Buds remain more sensitive
for a certain period of time, before returning to their desensitization condition,
allowing users to better enjoy all the solid foods they have. Finally, each tool goes
to occupy half of the straw, the part in contact with the tongue, so it is also possible
to combine two different ones and mix different sensations and shapes. This choice
was made taking into consideration the subjectivity of the theme; each of us, in fact,
reacts differently to flavours, based on the sensitivity of his taste buds, and in this
way, he is free to try and combine the tools that allow him to amplify his favourite
flavours. Although designed specifically for astronauts, this project could also be
widely used in everyday life, starting from temporary conditions, for example, bad
flu that can make the taste of food unpleasant, up to permanent physical problems, perhaps due to injuries or pre-existing conditions.

The sustainability principles which push us to imagine to re-use everything, including waste, overall on the International Space Station (ISS), inspired a system that allows sprouts to grow from the seeds in conditions of microgravity reusing the moisture collected in the towels after physical activities and showers. From the other side, we need emotional projects to help astronauts filling the gap with home, so why do not imagine using new tools to convey the sensation of touch millions of kilometres from Earth and give an astronaut, through a series of impulses, the warmth of an embrace? SendSense is a device that helps connecting people together by sending their sensation of touch to a loved one, who is far away (Fig. 4.30). Conceived for astronauts on the ISS to interact with their family on a deeper level than just voice chat, it is made of two parts: a core, in hard material, and a softer part grasping around the core. While the former is static, and mostly used as a charging and transmitting base, the latter is made to be wearable, leading to two different scenarios. The product has a twin placed on Earth and owned by the astronaut’s family: the two work mutually both sending and receiving touch messages in the same way.

All projects are focused on emphasizing the importance of gestures, to design new ways of using objects and tools that could make the experiences more meaningful and profound. Pare brings the gestures of paring and enjoying fruits thanks to an edible packaging made of algae which contains a fruit powder that swells with water rehydrating in a star fruit like a lemon. Pare saves...
space and weight while being transported, and more importantly, there is no residual waste to be stored and discarded afterward.

Also, body care and personal hygiene are linked to the senses as they are needed to increase well-being. Very simple and trivial actions on Earth, such as cutting your nails or washing your hair, are very difficult in microgravity and in a confined environment: and some solutions propose simple and functional alternative systems—all based on the idea of collecting and containing waste and water to avoid that floating will clog air filters and on board instrumentation—which can also turn into terrestrial spin-offs. The common intent of projects dedicated to personal hygiene is to transform these activities that in orbit are very complex in pleasant moments avoiding the stress of performance in microgravity.

Another occasion of stress on board the International Space Station (ISS) is also given by the continuous background noise. In long-term space missions, astronauts can feel stress and discomfort not just because of the pressing daily work schedule, but also because of the environment of the ISS. The ventilation system is composed of several numbers of fans, which end up with a continuous, loud background noise. Aim of Onanze is to solve this issue by reducing the fans’ noise in a passive way: the mechanical soundwaves are forced to bounce in wavy canals, so the specific frequency of the disturbing noise is erased.

The soft part of the product is in contact with the skin and is tailor-made according to one’s specific ears shape (Fig. 4.32). Along with its outer profile, there are three little balls placed in an exact position following reflexology principles. In addition, this object has a microphone connected to the ground control in order to monitoring astronauts acoustic stress level. As a spin-off on Earth Onanze may be used in noisy working environments, its uniqueness lays in the perfect adherence to

Fig. 4.32 Onanze reduce the noise on board the ISS erasing the frequencies and allowing the astronauts to choose their own background sound and maintain a good balance increasing the well-being. Credits by Space4InspirAction, Politecnico di Milano
the ears, which does not require any wires, nor headbands. It has not been designed to isolate, likewise usual headphones, but to enjoy your own sound environment.

There is not enough space to describe all twelve projects, each with its own specificities, what is important here, is to give an idea of the diversity of the approaches that look at life in Space and the habits of astronauts as an opportunity to improve some performances, that in the absence of gravity become more difficult.

Focusing on human factors as well as physiological and psychological behaviours in relation to objects and the environment, we can increase the comfort and efficiency of performances of astronauts on board the ISS, making their activities easier and more pleasant, developing the ability to observe and predict new uses and gestures: the Use and Gesture Design (UGD) methodology is particularly useful when we confront with small and handled objects which can solve even small problems but useful to increase the general well-being.

Fig. 4.33  *Fitness in Microgravity*, from the lens of Design, means also to perform other sports, as ski, in an immersive virtual panorama that recall our wonderful mountains on Earth. Screenshot taken by the author during *Space4InspirAction* 4th edition, Politecnico di Milano
The 4th edition of the Course *Space4InspirAction*, that is going to the end while I’m writing this book, was characterized by experience of distance learning due to the Covid-19 pandemic which forced all of us to stay confined at home increasing the need of privacy like it happens on board the ISS (Clearwater 1990). This new condition allowed us to choose two themes for the projects that could be lived in the personal experience of the students in a confined environment: being in isolation as astronauts they could better understand their needs and behaviours and find innovative solutions to increase the comfort and the well-being in Space (Dominoni and Quaquaro 2020).

We foresaw two projects, one oriented to designing in-depth *technical machines and tools* following strict requirements for confined and microgravity environments, one focussed on creativity and the power of Space to inspire the common imagination, looking at science fiction and *Space Age* as examples to define new *emotional scenarios*.

The first brief (Space Action), developed during the month of April 2020, was dedicated to *Design for Space*, with the topic *Fitness in Microgravity* focused on the sensorial and practical aspects of fitness activities in Space, in absence or reduced gravity and in confined environment. The aim was to re-think new machines and tools for the physical activity and other terrestrial sports to practice, as skiing (Fig. 4.33) or swimming, on board the International Space Station (ISS),

![Lighting in Space](image-url)
but also imagine how astronauts could make the same activity inside the future cis-lunar orbital station called Gateway and/or on the lunar surface, thinking about the life inside the new human bases on the Moon. We wanted to increase the comfort and the performance of astronauts, reduce weight and volume, but also, transform boring physical exercises in entertainment and increase the quality of crew relationships through the *gamification* of fitness activities. As usual, we believe that in a Course/Laboratory of Design it is very important to involve a real company with a specific know-how on our topic: so, for this first project we asked to TechnoGym, a leader in the world in designing fitness machines for *wellness oriented* customers.

The second brief (Space Inspiration), developed during the month of May 2020, was dedicated to explore the most emotional aspects of Design, analyzing the suggestions that Space has exerted and exerts on the terrestrial life of every day, to get to define terrestrial *Space inspired* products. The aim was to focus on the power of Space scenario to inspire the common imagination through science fiction, literature, movies, music, but also environments, architecture, fashion, art and design. Students were asked to choose a sci-fi movie and imagine *Lighting in Space* defined by style, shapes and colours, in which the role of the light has the great value to change the perception of the environments (Fig. 4.34). For this project, we involved
the company Foscarini, an Italian excellence in the field of lighting design, overall regarding decorative lamps, very known worldwide.

Choosing this two projects we wanted to face students with the human factors aspects, putting the user at the centre: we asked them to deepen into the technical details of the fitness machines currently used on the ISS, considering at the same time the physiological alteration suffered by the human body in microgravity, and underlining the essential impact of the Usage and Gesture Design (UGD) methodology, which we have created to support Design for Space. From the other hand, we intended to stimulate the imaginary of the students pushing them to go beyond the boundaries of the project, to let the fantasy free, to make different associations, no strongly related with the reality, and explore the Space scenarios and the sci-fi movies inventions to generate powerful objects, overall from the visual point of view, like it happened during the Space Age. The results we gained were very interesting and surprising for both the themes.

In the 1st project of Fitness in Microgravity students went in depth into technical details in order to increase the performances of the astronauts during fitness activities introducing new topics connected with entertainment—as the possibility to perform other sports, like swimming, skiing, or climbing, according with the microgravity conditions—and with the need to relax and meditate—imagining immersive bubbles to perform pilates and yoga—including also the possibility to strengthen the team spirit with exercises to do in pairs and groups. In this example,
acrobats inspired the project and the trick was to translate choreography and movements in a version for Space, where microgravity makes possible exercises unthinkable on Earth, but at the same time, complicates the ability of astronauts to balance and maintain position, overall if exercises are thought to be performed as well as individually, in couple and in groups (Fig. 4.35).

In the 2nd project of Lighting in Space, they explored the various possibilities of the light to change the perception of the environment, making spaces larger or bigger according to the different needs of the astronauts, using the power of shadows to project natural effects like the poetic komorebi (Fig. 4.36), the light that filters through the leaves of the trees, enhancing the comfort zone of the private spaces giving the feeling of a warm and cozy environment with soft light, or again, increasing the well-being of the crew working on the power of light to re-create natural circadian rhythms. In particular, light projections are used to depict the reflections by hypothetical windows, giving the illusion of being in a room with openings. The lighting system is thought to be easily integrated into the current lighting system present on board. An OLED screen is placed inside a cylindrical mask with cut-outs. The mask can rotate and it comes with the silhouettes of two windows, being customizable. The OLEDs mimic the temperature and the intensity of natural light in two different modes, automatic and weather, which can be set using a small switch recreating a sunny, cloudy and rainy day atmosphere depending on your choice.

4.5 Fashion in Orbit Versus Space Fashion Design

The extraordinary results of the project Couture in Orbit presented in London have since generated over twenty million media feedback responses and this inspired us, along with the European Space Agency (ESA), to create a specific Higher Education Course called Fashion in Orbit at POLI.design (the consortium of Politecnico di Milano) in February 2017 and based on the same idea of a capsule collection of garments to be worn on Earth that integrates space technologies and innovative materials. Fashion in Orbit was not a curricular Course but was open to young professionals who want to develop innovative products in fashion inspired by Space and technology research in order to find new applications and spin-offs for materials and textiles. The 2nd edition 2018 we transformed the Higher Education Course Fashion in Orbit in an academy contest called Space Fashion Design that expands the project field including fashion as well as product design and accessories, always driven by space technology—to follow the fast changes of these two worlds that increasingly overlap and lose their original boundaries by embracing

10Fashion in Orbit and Space Fashion Design are two projects of Higher Education Courses created and directed by Annalisa Dominoni and Benedetto Quaquaro at POLI.design (the consortium of Politecnico di Milano) with the support of the European Space Agency (ESA).
more fluid dimensions of project and technology—and transforms the format into a competition on invitation to young professionals, with expertise in Space Design, tailored to the needs of the reference company with which previously we built the brief together with ESA. The aim is always the same of the 1st edition 2017: to develop ideas of innovative products in the fields of fashion and design and find new applications and spin-off for materials and fabrics, inspired by space technological research.

4.5 Fashion in Orbit

The Fashion in Orbit Higher Education Course involved ESA and specific companies of technology focussed on sensors system and data collection together with many other companies coming from smart textile and luxury. It has been led from 30th January to 17 February 2017 for three weeks, eight hours per day.

Colmar, an Italian brand of sportswear, was the main sponsor, while the other companies—Alcantara, Caimi Brevetti, Coats, Limonta, Luxury Jersey, Omniapega, Sitip, Soliani, Thermore—supplied materials, fabrics, accessories and fabric processing systems to realize the capsule collection. The aim of the Course was to create a capsule collection, using Space as a strong propulsive rocket to enhance imagination, and space technologies a starting point. We had the great luck to manage a very high level and composite resources to work with, having on the table fantastic fabrics, accessories and technologies to manage. They were so different from each other, as the composition of the international group made by students and tutors with different nationalities and background, and this variety has been a richness. Our first consideration is that the capsule collection of Fashion in Orbit is strongly influenced by this condition of multiplicity as our universe is made by many galaxies. Different flavours and different situation are floating and relating the one which the other with a result of a cosmic equilibrium. Second consideration is about the specificity and the use of technologies. We declared in our manifesto to use Space and Space technologies as inspiration. It has been clearly understood by students: they tried to get a strong suggestion by using different materials looking at them a fantasy enhancer. A fabric which could make a fantastic job for a specific use, may suggest an emotion or a poetic thought. Being Fashion in Orbit a conceptual work, we decide to declare the results of using sensor technologies by showing luminescent light signal, thinking of an implementation which will come. Third, consideration is about Space, Earth and visual topic. Fashion in the age of technology makes us understand better how we can be more conscious of what the transformation technology brings. Space innovations will have a strong influence on how people behave and perform on Earth. The Fashion in Orbit collection takes inspiration by Space and it has been developed to have a strong influence of terrestrial look. The visual aspect has a dominant part in the developing process,
with the goal to reach high impact images, typical of the fashion system. Fashion in Orbit’s pillars included fashion, technology and Space inspiration. We presented the capsule collection realized, thanks to the support of the European Space Agency (ESA) and the technical materials and fabrics given by the companies involved, during an event at the School of Design, Politecnico di Milano, which included the exhibition of all the space capsule collection prototypes. For the occasion, we realized a portfolio which collected all the works to offer to the companies. During three intense weeks, we led a group of international students working hardly approaching Space to Earth. The aim of Fashion in Orbit was to explore new visions of fashion in the age of technology taking inspiration by Space: upside down, floating, emotional state, connection, transition, personal space were some of the keywords we chose together with the group of students to link all projects in one capsule collection, imagining life in Space and the extraordinary experiences as weightless looking at the Earth from another point of view. All the conceptual works represented different identities and backgrounds and shared an intimate relationship with the cosmos, which is expressed through clothing with new languages full of emotion, feeling and poetry mixing fabrics and materials in unusual ways. The interactions between the human being, the body and the environment were explored and reinvented suggesting new needs and scenarios in which all the senses participate in the dialogue with the garment by activating bio-sensors, luminescent signals and mechanical movement to make explicit our intentions (Fig. 4.37). We think these great achievements in such a short time could be an inspiration for all the companies which participated in Fashion in Orbit. Our wish is that some of the many ideas emerged during the development of the Course could

Fig. 4.37 The experimentation of different ways to use 3D fabrics together with the integration of bio-sensors and light signals produced a capsule collection characterized by a strong visual impact. Credits by Fashion in Orbit, POLI.design, Politecnico di Milano

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generate innovation and become new products in the real market thanks to the involvement of one or more companies that participated interested to the outputs.

4.5.1.1 Learning Goals

The Course was tailor-made for those who wanted to explore fashion in the age of technology and better understand how to become a more aware protagonist of this transformation process, knowing that Space innovations will have more and more influence in the near future on behaviours and people’s performance. It offered a unique opportunity to build transversal relationships with multidisciplinary teams of experts from the most technologically advanced sector in the world, as Space is, and to explore how research conducted in Space can inspire fashion and create new opportunities for social and business growth. Participants had the opportunity to create a capsule collection characterized by a high level of innovation, thanks to the collaboration with leading industrial partners in the fields of smart textiles, technologies and wearable, and to present it through a professional portfolio with a strong and recognizable image.

4.5.1.2 Syllabus

The Course *Fashion in Orbit* consisted of two main modules, the first made of theoretical content, the second about Design and visioning to support the development of the capsule collection and the realization of clothing and accessories. The
first module was addressed to professionals and companies operating in the fashion field and who intend to get in touch with ESA and the most qualified realities that make innovation and provide the results of their research to inspire new products. Lectures were led by scientists and researchers from ESA who presented space technologies, including specific case studies in fashion, and indicated the most innovative applications to explore possibilities to create a capsule collection according to the brief given by the main sponsor, in agreement with the other companies involved. The second module concerned the development of the capsule collection thanks to a highly qualified tailor’s workshop supervised by us together with ESA and the other companies. We started with the transposition of the concepts in paper, then in canvas, then the realization of the garments using fabrics, technologies and materials provided by the technical sponsors going in depth into detail to design the executives drawings of the various projects (Fig. 4.38). Once the collection was complete, participants were involved into a co-design experience of the fashion photo shooting at Immagine Lab of Politecnico di Milano which integrated the project of mood, lights and the overall image, useful for the creation of the digital portfolio of the whole collection, tackling the various aspects of communication design with the support of external professionals.

4.5.1.3 Design Methodology and Learning Outcomes

The capsule collection was developed on the basis of a precise brief that took inspiration from space technologies among those presented in the first part of the course. Participants worked both in classroom, for the presentations of the companies’ products and technologies, and in the Fashion Lab of Politecnico di Milano, with innovative textile materials reproducing the real dynamics of a fashion brand, from the presentation of the product to the communication system.

Crossing different knowledge we can achieve innovative ideas: taking inspiration by Henri Poincaré definition of creativity (Dominoni 2008), which is the ability to combine existing elements in new combinations, we believe involving in the same project many companies with different background, technologies and products was a good methodology to generate innovation. In this Course, it happened to be a surprise by the ideas emerged during the gathering with all the companies together with ESA, thanks to the crossover of know-how and experiences.

Participants acquired design and vision skills useful to collaborate with design companies and studios specialized in fashion design and innovation-oriented products. They practiced all the phases of the concept development for a new product of fashion, from the first ideas to the realization of the prototype, experimenting new material behaviours and technology applications. Also, they learnt how to create an innovative portfolio to present their work and how to valorize products through digital photo using light as a value to underline the principal aspect of the project.
4.5.2 Space Fashion Design

The 2nd edition 2018, compared to the previous Fashion in Orbit, extended the field of application to product design, in addition to fashion design, to follow the fast changes of these two worlds that increasingly overlap and lose their original boundaries by embracing more fluid dimensions of project and technology. It has been led from 5 to 16 February 2018 for two weeks, eight hours per day.

The nature of the Higher Education Course was changed in a more dynamic formula to allow us more freedom from an education programme, which presuppose a part of lectures and researches to introduce the topic of the project, to a contest on invitation for young professionals, with some expertise in Design for Space. Promoting this change of structure, we were able to open to a main sponsor and responding more efficiently to the brief we built together. Because of the appreciation of the results of Fashion in Orbit demonstrated by the companies we involved, it happened that the main sponsor of the first edition, the Italian sportswear company Colmar, decided to sponsor the Space Fashion Design contest.

The European Space Agency (ESA) supported Space Fashion Design Competition Workshop for the integration of technology through the programmes Technology Transfer Program (TTP) and Space Solutions—responsible for Italy Rina Consulting—and companies that already collaborate in Space projects, like Bercella Compositi, and Ribes Tech, a start-up supported by the Istituto Italiano di Tecnologia (IIT) and Politecnico di Milano in collaboration with Omet developing printed technologies, as photovoltaic cells and circuits. We defined a precise brief tailored on needs and interests of the company in connection with ESA Technology Transfer Network—Rina Consulting. The focus was on new concepts of ski garments taking inspiration by space technology with the aim to find new applications to increase the clothing performances. The project involves the development of wearable and integrable product ideas in sportswear—especially for skiing, but also extendable to other sports and sportswear in general—which were able to generate energy thanks to the developments of flexible photovoltaic technology by Enecom. RINA Consulting is also committed to carrying out a pre-feasibility study with the participants for the integration and operation of space technology that allowed to have the useful elements to make a strategic choice among the proposals presented. Parallel to the innovative technological solutions will be given equal attention to the style of garments and accessories that will have to align with the DNA of Colmar to be recognizable. Keywords: simplicity, linearity, elegance, with a strong attention to detail.
4.5.2.1 Learning Goals

Participants had the opportunity to work together with ESA experts and big companies of fashion design like Colmar learning how to develop a whole project, from the first ideas to a detailed 3D concept, in which technologies and materials are defined together with fabrics and colour palette. Space Fashion Design offered a unique opportunity to build transversal relationships with experts and to explore how research conducted in Space can inspire fashion and create new business models created on innovative applications.

4.5.2.2 Syllabus

The 2nd edition was built on a competition workshop of two weeks full time (eight hours a day) structured as a design studio, with a group of young professionals and researchers led by us, with the partnership of ESA for the space technology inspiration, and with the support of Colmar to allow us to deepen the know-how of the company in terms of vision, strategy and products and understand better the brief’s inputs. The concept was focused on the design of clothing, accessories and innovative products for ski field according to the needs of the company. Within the competition workshop, a session was devoted to the development of practical and strategic skills for the final presentation of the projects.

The outputs were divided into four distinct parts:

1. Preliminary Research, aimed at identifying product innovations under development and those on the market, and SWOT analysis, to assess Strengths, Weaknesses, Opportunities and Threats;
2. **Moodboard**, with indications of context, use, colours and materials;
3. **Concept Design**, descriptive of the general idea, visualized through sketches and renders (Fig. 4.39);
4. **Pre-Feasibility Study** of ideas, by Rina Consulting, which allowed us to gather useful elements to facilitate a strategic choice among the proposals submitted for possible future developments.

### 4.5.2.3 Design Methodology and Learning Outcomes

In this competition workshop, we applied the five principal methodologies that are the pillars of our design research and practice, plus other two specificities for Space Design discipline:

1. Design Thinking
2. User-Centered Design (UCD)
3. User Experience Design (UXD)
4. Design to Recicle + Design to Cost
5. Usage & Gesture Design (UGD)
6. Space Earth Design (SED).

The first four methodologies belong to Design discipline and focuss on the user needs with the aim to design a complete experience made of smart products, able to integrate technology and increase the performance while taking into account a sustainable design process. The last two are *dedicated* Space Design’s...
methodologies, considered fundamental to design a new product imagining since the beginning of the development of the idea gestures and movements (UGD) how the astronauts could be in microgravity with it (how to use it, in which way, with which gestures, etc.). Making this effort of imagination we have an expansion of the context with more elements to integrate into the project and it is easier to create connection between living in Space and on Earth (SED).

One of the best skill participants learn is to make research activity for industry comparing information collected with the goal to achieve, moving in between intuition and feasibility, imagining new possibilities to use innovative technologies according to people’s needs, for example, integrating ESA Cooling Technology for thermoregulation, or Electro Osmosis Process to extract sweat while skiing (Fig. 4.40). Space technologies by ESA are a strong motivational input that push designers and companies to find alternative and creative solutions for terrestrial projects starting from a perspective completely unknown. Participants experiment the importance to present their ideas with concept, images and words that are able to catch the attention of the companies’ leaders, and they practice the power of story-telling to increase the value of the projects.

4.5.2.4 Projects Visions

The various proposals which emerged by the competition workshop provided to enhance the research prospective of Colmar with different innovation technology suggestions with the possibility to use more than one technology solutions, combining them. In order to help thermoregulation of the ski jacket one proposal designed a system of cracks in the padding, able to be closed and opened manually by the user, to second of the overhead-heating inside it. Lining of the jacket with cracks be closed and opened depending on the overheating inside, encouraging perspiration. The implementation is mechanical and manual. The first mode provides a layer of cotton wool lined, cut and sewn to ribbons. Pulling the strips, the flaps connected to the latter fold on themselves leaving free the holes of perspiration. The second modality previews the coupling of two complementary layers of perforated padding and overlap in two different positions. One of the holes match allowing the passage of air, the other two surfaces are completed by closing the openings. The position of the two layers is held by tapes.

Another suggestion introduces the use of the present space technology in the astronaut’ suits: a system of pipes and air intakes manages to maintain the internal temperature of the stable ski jacket. Inspired by the thermoregulation technology applied to NASA’s LCGV Suit, we thought to insert six tubes inside the Colmar ski jacket, which through openings on the arm, exploit the passage of air to cool the back, then expell the overheated air through an opening on the back, where it creates even an air depression. Also, exploiting the intelligent interweaving of auxetic fabrics to make the clothing more breathable and reduce sweating during
stress. This concept is based on auxetic properties that can be obtained by applying certain cuts to the elastic tissues. These openings allow you to ventilate the interior of the garment ensuring a situation of well-being. The opening of the cracks is operated by some cables in Kevlar inserted inside the jacket to ensure breathability and waterproofness of the garment, thanks to an innovative fabric based on reverse osmosis. Heating the user using a hi-tech fabric will be able to transform electricity in heat even in extreme environments based on a technology developed by HydroBot, and this type of fabric allows to extract moisture through osmosis using electric current.

4.5.3 Results Dissemination and Exploitation

The results of Fashion in Orbit and Space Fashion Design were spread through the most important newspaper and magazines crossing the fields of science and fashion and we received many invitations to present our project during international events, exhibitions, symposia and scientific TV programmes among which

- Fashion in Orbit, special guest at the exhibition organized by ESA and DRL called Living in Space, Techtextil, Frankfurt 2017;
- Fashion in Orbit, event-talk at Il Bello dell’Italia, organized by the newspaper Corriere della Sera, Mantova 2017;
- Space Fashion & Science, TV program Passi di Scienza, Milano Design, RAI Scuola 2017.

4.6 Moony. A Lunar Base in Lava-Tubes for Igluna

ESA_Lab@

We are witnessing an acceleration in the resumption of space exploration supported by cutting-edge technological research that will make possible new human missions to the Moon. Space agencies and industries predict the first permanent settlements on our satellite in early 2030.

The main aims of the researchers will be oriented to the deepening of the planetary sciences, like the origin of the solar system, but also the exploration and the finding of resources useful for the future expeditions towards Mars. Human permanence on the Moon will also give the opportunity to test the physiological and psychological effects that may emerge over a prolonged period of time in confined environments, subject to very powerful solar radiation, and in reduced gravity.

The private sector is also moving to make it possible in the near future to travel interplanetary with crews who will no longer be trained only by astronauts and scientists, but by tourists and travellers who want to have all the comforts possible
to live in a pleasant environment. That’s why Design for Space is crucial. As you can imagine the living conditions above and below the lunar surface are extreme for humans and require habitats designed to ensure their survival. In addition to confinement, due to forced cohabitation in indoor environments and without natural environmental stimuli, it is the distance from the Earth to emphasize the sense of isolation. Gravity reduced to 1/6, strong solar radiation, exposure to frequent impacts of meteorites and the extreme temperature range are some of the obstacles that man will have to overcome to ensure a continuous stay on the Moon.

A year ago, the astronaut Samantha Cristoforetti suggested my name to the Swiss Space Center as an expert in Space Architecture and Design because it was being born a collaborative project gathering university student teams from all the Europe around the theme of space exploration. Igluna, the pilot project of Esa_Lab@ coordinated by the Swiss Space Center and supported by the European Space Agency (ESA), was presented as an inter-disciplinary platform to create a space habitat to demonstrate how to sustain life in an extreme environment using space technologies for disruptive innovation and cross-fertilization. Three values support this project. First, to improve cooperation across Europe by building an international platform and collaboration between different disciplinary perspectives; second, to create an educational environment that is also able to inspire a potential future generation of space experts; third, to analyze the future development of space technologies being tested to discover possible new perspectives for space exploration. Teams of students from all over Europe, supervised and supported by their academic institutions, were called upon to develop a series of modular demonstrators inspired by the context of a lunar habitat. Together with students, institutions and professors, the aim of the Swiss Space Center was to try to involve another important actor: the local industry related to the territory of each university in Europe, to make all the projects feasible.

Creating a permanent habitat on the Moon, precisely under its surface, in the lava tubes, is a challenging project at this moment. I was invited, together with Benedetto Quaquaro, to participate in the first explorative meeting at the Swiss Space Center headquarter in Zurich. In that occasion, we presented our Course of Space Design Space4inspirAction and our expertise as space architects and designers to give shape to the future habitats looking at the needs of people and their behaviours, with the aim to increase the well-being of life in Space. As usual, it was not easy for us to be understood by the majority of engineers who sit at the table and explain them the role of Design for Space, but fortunately showing them examples of our works, the topics we promote became clearer.

Above all, it was clear that the Design discipline, taking care of the entire environment, becomes the coordinator of all the projects of components and tools developed by other universities; we had the task of integrating their projects in the best possible way so that the final result was coherent, functional and organic. We should have built the lunar base in which the other projects would have found their place, and we would also be charged with the exhibition of the final results. So, we decided to accept the assignment of supervisors and involve two of our best students to participate in the 1st edition of the Igluna project.
We were conscious that Design for Space can be of great help to suggest an approach more adherent to the needs of the human being in Space through the application of techniques and methodologies aimed at identifying security requirements, functionality, usability and pleasantness. Using Design, we have the advantage to increase the quality of life, not only acting with psycho-physiological factors, but above all with emotional ones: the greatest challenge is to create a space habitable system that is able to behave like a *living organism*, in perfect autonomy with respect to the earthly supply, especially in terms of non-renewable resources and logistical support. We realized also that our participation to *Igluna* project could be a good occasion to demonstrate to space scientific community the importance of Design approach and thought in all the phases of the development of space programmes and projects, from the beginning of the first ideas to the realization of the demonstrators.

### 4.6.1 The Roadmap of Igluna 1st Edition 2019

The *Igluna* roadmap started in September 2018 and continued until June 2019, when the project culminated in the *Field Campaign*, an exhibition of two weeks, which took place at the Matterhorn Glacier in Zermatt, Switzerland.

Such an extreme environment was the site for the demonstrator to be built, in order to test the challenge of designing with high constraints. Given the nature of ESA_Lab@, the unusual situation arises that the top-level design, e.g. the architectural structure was developed simultaneously to the subsystems. This required an even more pro-active and intensive exchange of information and tracking of interfaces. Besides, the cavity imposed some constraints: water (100.- CHF/m$^3$, only canisters), power and space are limited and the elevator to the cavity reduces the maximal size and weight of an indivisibly transportable piece (similar to the payload limitations of a launch vehicle). The habitat, which was built inside the glacier cave in Zermatt, was also accessible by tourists and media.

The event was split into two areas, one in the glacier, with the actual demonstrator and a cinema lounge, available for the projection of videos, and the second one in the town, at *Vernissage Art Gallery*, with an exhibition collecting visuals and explanations from some of the projects, not involved in any experimentation.

### 4.6.2 Multidisciplinary Teams: Activities and Methodologies

The 1st edition of *Igluna* 2019, brought together 19 teams from 13 universities in 9 different European countries. The multidisciplinary nature of *Igluna* project covers a full range of topics, going from the habitat conception and construction to life support systems, communication, and navigation, power management, as well as science and human well-being, and the last one, my favourite: if you want to build a
livable environment—especially one far from the Earth—you must take into account all aspects of human life, which includes food production, energy and oxygen, the construction of shelters, the provision of instruments and the enabling of communications. Teams from different universities were developing oxygen and electricity production processes, a mechanism to cultivate algae, a system to use urine to fertilize plants, sports facilities, a laboratory, a system of communication and control, a robot for digging paths in the ice and more.

Teams were either mono-disciplinary or cross-disciplinary but they worked in the context of a multidisciplinary project where different contributions were required to be integrated. Expertise involved ranged from a different kind of engineering, aerospace, biologic, electronic, robotics to computer science, geology, design and architecture. Success in such a multidisciplinary, inter-university and inter-cultural project can only be achieved when each team takes ownership of the overall outcome and takes maximum responsibility for its module, the interfaces of its module and coordination with all teams.

As such, the organizational structure was kept flat and direct communication between teams was preferred over a strict hierarchical organization. With such purpose, regular meetings, and status updates are arranged, as well as a networking communication system based on the app Slack. Another useful tool was the group discussion, consisting of a virtual meeting on Webex involving all the teams. It proved to be pivotal in order to have an overview of the projects, which focused on specific topics, like the exhibition hall setting, or more generic on the whole development, without the need for all moving to a commonplace. Events were usually meant to gather together all the teams and facilitate the information exchange and coordination of different projects.

Our students participated in three events within the network, plus a series of digital contacts with coaches and external experts provided by the Igluna network itself. The first meeting took place at ETH Zurich on 12–14 September 2018, and represented the kick-off of the project. The second, on 16–18 January 2019, in CERN, Geneva, aimed instead to assure a conversation among the teams in correspondence of the freezing of all the designs before the start of the manufacturing phase. Furthermore, it was compelled to the delivery of the Critical Design Review’s report, which allowed us to obtain useful feedback for the next stages. The third event was the Field Campaign at Matterhorn Glacier in Zermatt, from 17 June to 3 July 2019 to test parts of analogues\footnote{Designing for Space the term analogue is used as a synonym for demonstrator of Space environments reproduced on Earth in territories with similar characteristics, like the desert to experiment the Mars surface, and the glacier to test the Moon conditions.} and all the prototypes that belong to various experiments.
4.6.3 **Igluna Project’s Approach and Value**

Academy’s students gain access to three main benefits. First of all, it is an important opportunity within a professional perspective: the possibility to experience and report on a curriculum, the participation in a project for Space is intended to boost the future career in this field. Although, even outside the space exploration pathway, *Igluna* project represents an important training in terms of project management, being compelled to the accommodation in a network of many different teams and contrasting aims.

Moreover, the network itself is an extremely valuable asset, which gathers together not only students and professors from important foreign universities, but also experts of different kinds and institutions like the Swiss Space Center and the European Space Agency (ESA) itself. In this context, they need to behave professionally, learning how to work in a complex system, even exiting their comfort zone at need, but respecting each other skillset.

From a more technical point of view, the approach required is generally a pragmatic mindset, aiming first of all to successfully implement the technology developed in the context of the Matterhorn Glacier.

On the other side, the projects exhibited in *Vernissage Art Gallery* were inherently more conceptual and focused on the actual lunar environment. Although, they had to keep a scientific approach characterizing the overall network. Particularly, our project, being a link between the actually built habitat and its vision on the Moon, tried to picture a lunar habitat and mission development that could appeal imagination, but restraining creativity to plausible technologies and operations, based on solid case studies.

4.6.4 **Moony. A Lunar Base in Lava-Tubes**

It was in this context described above that the project *Moony*\(^{12}\) was developed: a collaboration between the most prestigious European universities, coordinated by the Swiss Space Center Esa_Lab@, which has as its objective the creation of a lunar habitat demonstrator, complete in all its parts.

The *Moony* project (Dominoni 2019), within the programme *Igluna*, sets itself as a target last one to report the prototypes of all the other European teams involved in the project, in a lunar context. These projects in fact were prototyped first to demonstrate its effectiveness in an environment extreme, such as the Matterhorn Glacier in Zermatt, which has conditions like climate and environmental, which

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\(^{12}\)Moony—a whole modular lunar base located under the lunar surface, in the natural tunnels of volcanic origin called *lava tubes*—was designed by Irene Zaccara and Emilia Rosselli Del Turco under the supervision of professors Annalisa Dominoni and Benedetto Quaquaro, experts in Architecture and Design for Space, at the Design School of the Politecnico di Milano.
impact the feasibility, similar to those of a lunar volcanic cave. The aim was, therefore, to create a habitat which serves as a container for projects of other teams. It was, therefore, a question of creating which flexibility can allow incorporation of several projects, still in the phase of development, which will end in June 2019 with the Field Campaign.

There are several issues addressed, such as how to build and place a housing module safely in an extreme context responding to requirements that can encourage the adaptation and comfortable stay of human beings.

Our work started with a broad research about the Moon contest, the existing case studies of habitat in extreme conditions, and the related technologies. This led us to the construction of a database of potential technologies and operations that could be used. Then, we applied a decision-making process to make all the bricks fit within a scenario, starting from the logistics of bringing the components on the Moon, passing through the construction of the habitat, its protection in emergency situation and finally the actual life inside.

In the first phase, our trade-off verged on the need to reduce volume and weight, while enhancing habitability and protection. The lunar habitat module is designed to connect to other similar space modules in order to create a lunar village and consists of a semi-spherical inflatable chamber covered by a light structure that protects it from any collapses that might occur, being the lunar base built in a tunnel underground called lava-tube.

This structure it is foreseen to be built In Situ Resource Utilization (ISRU) with 3D printing, using native material, i.e. lunar dust—based on a technology developed by the Italian company D-Shape, which had already collaborated with ESA for the 3D Printing Building Blocks for Lunar Habitation designed by the architect and designer Norman Foster—to minimize the material launched from the Earth.
The use of an *organic design* assures structural performance within lightness and speed of installation (Fig. 4.41).

Moreover, the parametric design can be adjusted based on the currently unknown requirements.

Secondly, we focused on the need for *automation of the construction* and how to simplify at best the process to avoid unexpected behaviours during the assembly. We designed the process step by step and added expedients to overcome potential risks, for example, a track to guide the inflatable process.

Finally, we studied the psychology related to isolation, confinement, and cohabitation in order to be able to suggest solutions that will able to ease the astronauts’ pressure about them. This involves a core role of vegetation in the lunar habitat, and a reconfigurable structure, which lets the astronauts be in control of the wide space division without constraining the individual to continuous interactions with the rest of the crew.

Inside the *Moony* habitat, the working, personal and social activities of the astronauts integrate with each other thanks to a *flexible configuration* being able to adapt to its inhabitants according to the various needs. The walls, which are also inflatable, can be opened and closed to transform the environments—by enlarging or reducing them according to the functions to be accommodated—reducing the perception of constraint and confinement in the absence of natural stimuli.

*Just to ensure a relationship of well-being between man and nature has been inserted an evolved greenhouse at the centre of the housing module.*

Personal spaces for the crew are assured in the so-called *crew quarters*, where each member of the team can enjoy their own environment, although very small in size. The common area, which integrates with the greenhouse, provides small
individual corners, where you can live your free time with greater freedom, while maintaining a kind of privacy necessary to escape from the condition of continuous coexistence. During social moments, the same common area becomes an informal place to meet and organize activities of relaxation and entertainment.

4.6.4.1 Lava-Tube: The Ideal Environment

Starting from the assumptions given by Igluna project, it was established that the first lunar module was placed inside a tunnel just below the lunar surface. Since sunlight never reaches caves of volcanic caves, if not exactly under the skylight, the temperature remains constant at $-20 \, ^\circ\text{C}$ throughout the year and the environment remains permanently dark. The area remains protected from cosmic radiation solar, thanks to a thick layer of about 10 m which separates the tunnel from the outer surface. Naturally placing the habitat underground immediately resolves the problem of free fall of meteorites on the ground, which otherwise would continually endanger the strength of the structure.

Despite all these obvious advantages, the positioning of the lunar module inside the tunnels also carries a particular risk that should be carefully considered: the possible collapse of the ceiling. The discovery of volcanic caves in fact took place with the detection of strange depressions linear that marked the ground for miles and kilometres. These are the tracks left by ancient tunnels all collapsed. Having evaluated this list of strengths and elements of criticality, they are deduced indications well-defined with respect to design of the external structure of the lunar module. First of all, this structure must of course be pressurized due to the lack of atmosphere outside. It must be able to thermally insulate the interior environment, in so that a temperature can be maintained internally stable around $18 \, ^\circ\text{C}$. The insulation, in this way, will need less protection compared to what is necessary for a lunar habitat located on the external surface that should instead withstand temperature changes of about $250 \, ^\circ\text{C}$. In addition, the external structure will no longer have the task of protecting the internal environment from radiation, since already the rock layer of the roof, 10 m thick, will perform excellently this task.

4.6.4.2 The Habitation Module

During the design of the habitation module, many factors must be taken into account, as dimensions, thermal insulation and above all the means of transport. An accurate amount of living space per person, the minimum spaces, is fundamental for the success of the mission. In the early space missions, NASA had designed environments with only $0.57 \, \text{m}^3$ per person, but over the years have been carried out many psychological studies on the negative effects that result from prolonged stay in confined spaces so small. As a result of new research on living spaces for long periods and in confined environments, the minimum volume is of $120 \, \text{m}^3$ per person (exactly the same volume considered for the International Space Station).
So, the total volume should be around 360 m³, calculating the continuous presence of three members of the crew inside the habitation module.

How to carry a module of such size, without greatly affecting the travel costs? Please note that at each pound (0.45 kg) launched on the Moon, corresponds $10,000 worth of fuel. As regarding all the study cases considered, the possible types of module viable housing are

- a rigid module;
- a module built with materials available in situ;
- an inflatable module.

The Moony concept emerged from a decision-making process based on the identification of alternatives more plausible or, at least, more convincing. Since we could place the habitat in a lava-tube, we could minimize the need for a protective shell. We adopted the solution of inflatable structures and we tried to extend its use as much as possible to all the interior environments, thanks to its practicality in logistics. We looked for a technology for the exploitation of in-situ resources for regarding the coverage. We have decided to maintain a single volume to have all the services necessary from the first mission, and to reduce the complexity and risk of failure of a connection between the parts. However, we have included a scalability system. Regarding the interiors, we have assumed to have structures in our habitat supporting all the crew activities living and working inside the lunar base, as crew areas for entertainment, resting and personal hygiene, food preparation and consumption in convivial mood, or physical exercise and recreation. In addition, we have assigned a fundamental importance at the greenhouse, which becomes the central core of the habitat and characterizes the common life, and we have maintained a large and open space for sociality, also thanks to the use of structures deployable. It is important to point out that given the complexity of the project our contribution has focused on the design of the lunar base and mainly on the structure, leaving room for subsequent projects regarding the whole design of the interior and furniture.

4.6.4.3 External Structure’s Installation Path

**Landing**

The lander slowly descends to the ground activating retro rockets. Download the two rovers, the habitation module closed, formed by the two airlocks and the tunnel deployable evacuation.

**Descent into the Lava-Tube**

Construction robot fixes deployable ladder on a safe crater area and lowers inside of the lava-tube (Fig. 4.42). A mobile system allows to explore the uneven floor until finding a site suitable for habitat, based on a list of requirements, such as a relatively flat, some distance from the skylight, proximity to strategic resources, etc.
Situ Setting
Construction robot analyses 3D morphology to calculate the necessary adjustment for the print and create a negative form CAD to fill the irregularity. Reaches the surface to load enough regolith and start the print. The ultimate goal is to create a flat surface for the habitation module, which leads automatic inflation, an exit area for the placement of the lift and a path free of obstacles linking the two elements.

Descent of the Module
Once construction robots have analyzed the uneven soil and printed 3D a smooth pavement for access and a base, the housing module is lowered into the whole cave, transported and positioned at the centre of the base by the two robots.

Inflation of the Module
Thanks to 3D printed tracks during the preparation, the robot is able to precisely position the habitation module in the area. Following the guides, the inflation takes place in a controlled way. The habitation module assumes naturally a precise and stable location on the site.

Cover and Way Out
After storage of the necessary quantity of ice and lunar regolith, the protection structure is printed with both the autochthonous materials. The habitat always maintains two exits, in order to always ensure a rapid escape from each point. Even when they are connected to multiple modules, two shall be the secured outputs, which will have to increase in number when modules will increase. A LED chain connected to a generator autonomous highlights the exits and the route. The presence of a rigid structure ensures protection until complete evacuation from the habitat. However, a monitoring system constantly measures any seismic signs of potential collapse.

Elevator
The elevator is initially hanging from the crater and extended to the ground below. Next is built with a 3D printed structure only in regolith, so that contact with the crater comes removed and the elevator is independent, not affected by any collapse or collapse of the ceiling of the tunnel. A flexible cylinder, consisting of a sequence of rigid sections connected through a fabric, is prepared to follow the exit path. A 3D printed coverage is created using the cylindrical structure as support.

Walls
Then all the walls will swell partitions, which are integrated into the inflatable but have separate air chambers. The hermetic doors will be brought from Earth and mounted subsequently. The walls are designed with special recesses designed to contain all materials technicians, boxes and personal items of each gender. This will not be necessary to add shelves or furniture.
Furniture

At the arrival of the astronauts are positioned the latest equipment and furniture. Based on principles of collapsibility, lightness and multifunctionality, the entire habitat is completed with objects supporting the daily life created to maintaining an emotional connection with the Earth environment and personal memories.

The furniture is designed to be mounted in the simplest way possible directly when the astronauts arrive in the module. The concept consists of transporting of the Moon light aluminium frames, preformed linings of all furniture and polymer resins expanding. These resins once mixed together, they expand and reach up to 6 times the initial volume. They allow for soft cushions, but according to needs or preferences of the astronaut, you can add small amount of lunar sand to increase stiffness of the object.

4.6.4.4 The Securing the Lunar Base

In addition to the inflatable module, it is, therefore, necessary to address the problem of protection against rock collapses from the lava-tube tunnel vault. The hyperbaric structure is very resistant, but it still needs another shielding. To tackle this problem, we have been inspired by many case studies—among which the Norman Foster Lunar Habitation Study Programme for the European Space Agency (ESA) 3D Printing Building Blocks for Lunar Habitation (2012), followed by the NASA Mars 3D Printed Habitat. In these projects, the habitation modules are often enclosed in envelopes more than one metre, so as to protect the whole module from the extreme environmental conditions that we are forced to face on the Moon surface. Having placed our habitation module in the volcanic caves do not need to be built such shielding, but a structure is sufficient resistant and light. Transport from the Earth a rigid structure that can cover the whole habitation module is an extremely expensive option (0.45 kg = $10,000 in fuel). The best method is to build this cover exploiting the resources that can be found above and below the lunar surface.

The structure does not completely cover the dome, but wraps it in a branched way, in order to speed up the production process. The proposed design is 3D printed, with the sintering system. To process the project the comparison with the company D-Shape was crucial.

4.6.5 The Field Campaign and the Next Edition Igluna 2020

I would like to conclude this case study by including two images that we took during the Field Campaign organized with events and exhibitions inside the Matterhorn Glacier in Zermatt, Switzerland.
The events were split into two areas, one in the glacier, with the actual demonstrator (Fig. 4.43) and a cinema lounge, available for the projection of videos, and the second one in the town, at Vernissage Art Gallery, with an exhibition collecting visuals and explanations from some of the projects (Fig. 4.44), not involved in any experimentation.

It was a great joy for us to be able to participate and support our students through a project that allowed them to open up to the outside world, to present the Moony project to the Space scientific community, including astronauts and exponents of the European Space Agency (ESA), which have enriched with their presence an event already full of potential and unprecedented experiences.

This year we participated in the second edition of Igluna 2020 that has just ended, unfortunately for students in virtual mode, continuing to deepen the issues related to habitability on the Moon: after making the mock-up Moony for the second edition we focused on the preparation, consumption and storage of food in the lunar base, as an essential element for the survival of the crew, but without neglecting aspects of conviviality and tradition to keep strong the connection with the Earth and our memory using researches conducted for the autonomous growth of plants and vegetables in reduced gravity.

We are already considering for the third edition of Igluna 2021 to explore the theme of light, given the promising results of Space4InspirAction (S4I) this year. The quality of light is very important for the health and well-being of astronauts, who live deprived of natural sensory stimuli with the consequent alteration of circadian rhythms, fundamental for the psycho-physiological balance. Going further would be interesting to also recreate the atmosphere of natural light in a lunar base with reflections and shadows to enrich the experience and remember home.
The conquest of Space is now a reality that is taking shape in an increasingly concrete and fascinating for the younger generations, and projects such as *Fashion in Orbit*, *Space Fashion Design*, *Space4InspirAction* and *Igluna* help to direct young people and the whole society towards a shared and livable interplanetary future and in which the Design will always have a fundamental role, if not indispensable.

**References**

Clearwater Y (1990) Privacy. In: Space habitability. Avignon working days report. Exploratory Studies Program for the Future European Manned Space Infrastructure (EMSI). Proceedings of American Institute of Aeronautics and Astronautics (AIAA)

De Monchaux N (2011) Spacesuit: fashioning Apollo. MIT Press, Cambridge, Massachusetts, USA

Dominoni A (1998). IVA clothing support system. In: Proceedings of space exploration and resources exploitation, pp 0015.1–0015.4, ESA ExploSpace workshop, 20–22 October 1998, Cagliari, Sardinia, European Space Agency (ESA), Noordwijk, WPP-151

Dominoni A (2001a) Vest. Development of an integrated clothing system for the International Space Station (ISS). In: Proceedings of La Scienza e la Tecnologia sulla Stazione Spaziale Internazionale (ISS), 16–18 May 2001. Centro Congressi Lingotto, Turin, ASI Italian Space Agency, Rome

Dominoni A (2001b) VEST. Development of an integrated clothing system for the ISS. In: Monti R, Bonifazi C, (ed) MSSU, Microgravity and space station utilization, vol 2, no 2-3-4. ASI Italian Space Agency. Liguori Editore, Napoli

Dominoni A (2002) Industrial design for space. Silvana Editoriale, Milan
Dominoni A (2003a) Conditions of microgravity and the body’s second skin. In: Fortunati L, Katz JE, Riccini R (ed) Mediating the human body. Technology, communication, and fashion. L. Lawrence Erlbaum Associates, Mahwah, New Jersey, USA, pp 201–208
Dominoni A (2003b) Aesthetics in microgravity. In: Katz JE (ed) Machines that become us. The social context of personal communication technology. Transaction Publishers, New Brunswick, New Jersey, USA, pp 277–284
Dominoni A (2005) VEST. Clothing support system on-orbit validation. In: SAE technical paper series, ISSN 0184-7191. Proceedings of ICES 35th international conference on environmental systems, Rome, 11–14 July 2005, SAE Society of Automotive Engineers, Warrendale, Pennsylvania, USA
Dominoni A (2009) Creative network systems for innovation. In: Proceedings of INTED 2009, international technology, education and development conference, Valencia, 09–11 March 2009, Association of Technology, Education and Development (IATED), pp 002572–002580
Dominoni A (2008) Creative design practices. The creative process in product design and environment for educational. Esercizi creativi di design / Il processo creativo del design del prodotto ambientale per la didattica. Maggioli Editore, Politecnica Editorial Series, Milan
Dominoni A (2010) Cosmic space as a key for creative design. How industrial design in cosmos space is useful to exemplify an innovative methodology for design process in education. In: Proceedings of INTED 2011, international technology, education and development conference, Valencia, 08–10 March 2010, Association of Technology, Education and Development (IATED), pp 002989–002994
Dominoni A (2015) For designers with their head beyond the clouds. Politecnica, Architettura, Ingegneria, Scienze, Maggioli Editore, Milan
Dominoni A (2019) Nuovi Scenari Abitativi per la Stazione Cis-Lunare Gateway e per le Coloni Lunari. In: Kalin S, Raimondo C, Massicci M (ed) L’Avventura dell’Uomo nello Spazio. Dalla Luna a Marte. 2. 2024. Ritorno sulla Luna, vol 2, “Le Scienze”, GEDI Gruppo Editoriale, Puntoweb, Roma, pp 088–097
Dominoni A, Quaquaro B (2017a) Future fashion. Space research inspires innovation in fashion. ROOM. Space J 10, Winter 2017:102–107. The Aerospace International Research Center (AIRC). Publishers Press, Vienna
Dominoni A, Quaquaro B (2017b) Dressing up for space. ROOM. Space J 13, Fall 2017: 106–109. The Aerospace International Research Center (AIRC). Publishers Press, Vienna
Dominoni A, Quaquaro B (2020) Distance learning during a Pandemia. How to maintain as active learning approach: the case study of Space4InspirAction course. In: Proceedings of Edulearn20. Connecting technology with education. 12th annual international conference on education and new learning technologies (INTED), 6–7 July 2020 Palma, Spain. Organizator an Publisher: IATED
Dominoni A, Quaquaro B, Pappalardo R (2018) Space design learning. An innovative approach of space education through design. In: Proceedings of IAC 69th international astronautical congress, Bremen, 01–05 October 2018
Jenkins DR (2012) Dressing for altitude. U.S. aviation pressure suits-wiley post to space shuttle. National Aeronautics and Space Administration (NASA), Washington, D.C.
Gazenko OG, Shumakov VI, Kakurin LI, Katcov VE, Chestukhin VV, Nikolayenko EM, Gvozdev SV, Rumyantsev VV, Vasilyev VK (1982). Effects of various countermeasures against the adverse effects of weightlessness on central circulation in the healthy man. Aviat Space Environ Med 53(6):523–530
Green W, Jordan PW (2019) Human factors in product design: current practice and future trends. Taylor & Francis Ltd

Griffin BN (1978) Design guide: the influence of Zero-G and acceleration on the human factors of spacecraft design. NASA-STD-3000, vol 1/rev B

Moore D, Bie P, Oser H (1996) Biological and medical research in space. An overview of life sciences research in microgravity. Springer, Berlin, Heidelberg

Topham S (2003) Where’s my space age? The rise and fall of futuristic design. Prestel Publishing, New York

Trabona C (2009) Dal piede di Armstrong l’idea per i miei Moon Boot. In: Corriere del Veneto, 20 July 2009

Wichman HA, Donaldson SI (1996) Remote ergonomic research in space: spacelab findings and a proposal. Aviat Space Environ Med 67(2). Alexandria, VA