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Spaceship Earth. Space-driven technologies and systems for sustainability on ground ☆

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ABSTRACT

As awareness towards the problem is growing, eco-friendliness is today a paramount requirement for all space activities and in particular for the ground segment, fully comparable to other industrial sectors. The present work focuses on the assessment and the sustainable development enhancement of a ground-based space facility, the European Astronaut Centre (EAC), located in Germany. The project is framed within the European Space Agency development of an environmental outlook, which aims not only at the full compliance with the legislation and at assessing the impact of its activities, but also at laying the foundation for future evolution through innovation. Indeed, ESA promotes the sustainable use of space as a necessity and duty for Europe. As history teaches us, technical knowledge emerged within the space sector serves as innovation driver in other industrial branches: the goal of the project is to transform the EAC building into a spaceship integrated with the territory through the conscious management of this spontaneous process, fostering the combination between the space sector and the architecture and civil engineering fields. The work explores the potential of space technologies, processes and systems applied on ground and presents a range of space-driven innovative concepts which may improve the sustainability of the EAC building, focusing on different aspects of its resource demand – energy, water and waste management – and defining the integration with the pre-existing compound, the limitation of the impact on the surrounding landscape and the participation of the local community as additional fundamental requirements. Indeed, the project embraces the full concept of sustainability, which considers not only eco-friendliness but also its balance with economic and social aspects. Two factors – a certain urgency for action, which leaves little space for research and experimentation, and a call for ground-breaking solutions – guided the design activity: taking advantage of these conflicting requirements, a comparison between standard technologies and innovative space-related concepts was performed. When dealing with complex and uncertain scenarios, decision among the possible solutions is not straightforward and needs to be supported by appropriate

Abbreviation: AHP, Analytical Hierarchy Process; EAC, European Astronaut Center; ESA, European Space Agency; FC, Fuel cells; GHG, Greenhouse gas; ICE, Internal Combustion Engines; IPV, Innovative Photovoltaic; LCA, Life Cycle Assessment; MCFC, Molten carbonate fuel cell; MGT, Micro Gas Turbine; MRC, Microbial fuel cell; NMV, No-Mix vacuum toilet; O&M, Operations and Maintenance; PAFC, Phosphoric acid fuel cell; PEMFC, Proton exchange membrane fuel cell; PV, Photovoltaic; R&D, Research and Development; SOFC, Solid oxide fuel cell; SPV, Standard Photovoltaic; TRL, Technology Readiness Level

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methodologies: a multi-criteria and quantitative decision-making tool, able to concentrate on the main goal while considering all other relevant aspects – environmental, economic, social sustainability – was therefore developed. Furthermore, the project promotes local community participation in the decisional process, as a way to enhance knowledge, generate understanding and promote towards the EAC redesign, space activities and their potential innovative impact on sustainability.

1. Introduction

Nowadays sustainability is an essential requirement for all industrial activities, both from a social corporate responsibility and from a regulatory compliance point of view. The space sector in the past has shown a lack of commitment in this sense, both in terms of environmental footprint reduction and in impact monitoring. Up to now, the space industry is still implementing insufficient analysis on the environmental impact of its activities. This project aims at filling this gap towards the current perspective of sustainability by focusing on the space activities on ground.

This main challenge is framed within the European Space Agency (ESA) development of an environmental outlook, aimed at the full compliance with the legislation and at the assessment of the impact of its activities. ESA commits to become an exemplary space agency by promoting the sustainable use of space as a necessity and a duty for Europe. Action is necessary to turn a threat into an opportunity. Keeping in mind the peculiarities of space operations – the only anthropogenic activities which cross all layers of the atmosphere we concentrate on the definition and implementation of design procedures suitable to minimize the environmental impact of space assets on ground. Furthermore, in order to enhance its innovative potential, the project fosters a contamination between the space sector and other industrial areas as a starting point for the design activity. Even focusing on different design targets, outer space assets and on-ground activities, a common goal may exist: the development of resource efficient processes and technologies which might reduce raw material inputs, energy consumption, waste and costs.

Within this framework, our work focuses on the assessment and the sustainable development enhancement of a ground-based space facility. In particular it has been decided to use as a case study the European Astronaut Centre (EAC) in Köln, Germany. The EAC has been approached as a spaceship on Earth, requiring at the same time innovative and sustainable technologies. This definition covers both cardinal aspects of our design activity: the definition of space-driven concepts for the EAC redesign and the environmental advancement goal of the project.

1.1. Requirements definition

The EAC buildings provide training facilities to the astronauts and include offices, meeting rooms, training areas and a swimming pool as well. All these elements require a high energy and water demand and produce a large amount of waste. Their management acquires high importance from an environmental perspective, and becomes the key for sustainability improvement. EAC, unlike many ground-based space sites, is not located in a deserted area but near a city: accordingly we identified the integration with the pre-existing compound and the attenuation of the impact on landscape and local community as additional fundamental requirements.

Indeed, our design activity began with the broadening of the environmental advancement objective in order to fully embrace the concept of sustainability, considering not only eco-friendliness but also its balance with economic and social aspects.

In collaboration with ESA partners we structured our tasks as follows:

- The sustainability assessment of the EAC by the ecology point of view.
- The undertaking of a design process within a technical context, namely the exploration of the potential of space technologies applied in the architecture and civil engineering fields.
- The generation of space-driven innovative concepts which may turn the EAC into an “Environmental Advancement Centre”, namely a first attempt to enhance sustainability through space technologies, processes and systems. The extreme performances, limited resources and strong constraints that characterize the outer space environment are regarded as design opportunities, inspiration and sources of innovation for the ground segment.
- The definition of a decision-making process for the evaluation and comparison of the concepts developed. The tool requires flexibility in the criteria definition and needs to consider technological, economic and social aspects.

1.2. Exploring the opportunities

As a second step, we tried to identify the most relevant limitations and constraints of the project. This process allowed us to highlight several opportunities for innovation. Taking on this perspective, we pinpointed the most relevant ones:

- The EAC building, far from being space-specific, supports the development and testing of concepts that are potentially applicable to the standard construction industry.
- The EAC location enables the experimentation of the