European Exploration Envelope Program – E3P2

Exploration Preparation, Research and Technology (ExPeRT)

COMMENTS AND CONSIDERATION BY THE CENTER FOR NEAR SPACE

06 September 2019

1 Our Vision

1.1 Who We Are

The Center for Near Space (CNS) is the think-tank devoted to future space scenarios of the Italian Institute for the Future (IIF). This is a non-profit Non-Governmental-Organization dedicated to **anticipation** studies. As such, CNS looks for mid-to-long term scenarios identifiable by today signals.

Since its inception, the CNS focused its activity on the conviction that the era of the **Expansion of Humanity in Space** already begun and that its evolution requires the development of the private/commercial component.

1.2 Cislunar City

Geo-lunar space is the closest and most suitable environment to focus on. Scientific, industrial and recreational infrastructures located in LEO, LMO and in Lagrangian points will support life outside the Earth's atmosphere, while different types of transport will guarantee mobility and connections with the Earth. CNS believes that in the second half of this century – *symbolically 100 years after the first step of a person outside the Earth* – a permanent community of a thousand individuals distributed in various “districts” will crowd the cis-lunar space: a true **Cislunar City**, also beneficial as an intermediate step toward Mars.

Living in space requires effective integration and simultaneous evaluation of many aspects. To address this research, the CNS "OrbiTecture" working group involves scientists, technologists, architects, botanists, artists, sociologists, psychologists and so on, but also university and high school students. It works on stories and reasoning about building outside our planet, making extended use of innovative robotic additive manufacturing for both the main structure and the internal secondary structures of the space infrastructure.

1.3 OrbiTecture® – the New Paradigm

The term **OrbiTecture®** (contraction of Orbital Architecture) defines a systemic approach of architectural design with new habitability requirements for the future human space habitats in orbit and on planets ground, devoted no longer only to research but also to production activities, common living and social development. It was presented for the first time in its fundamental formulation in 2017 by the international architecture magazine *Le Carré Bleu*, but a first hint was made to it in 2015 within the activities of the Center for Near Space.

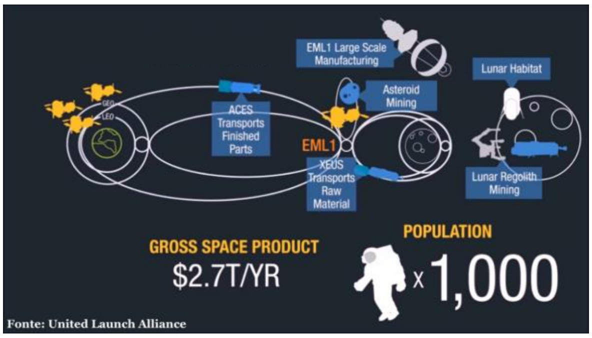
The term refers to the previous “urbatecture”, coined in the early '60s by architect Jan Lubicz-Nycz to highlight his project -not implemented- for Tel Aviv, with integrated multifunctional mega-structures designing entire part of cities. The term was later brought in again by Bruno Zevi to define an architectural paradigm aimed to go beyond the “segregationist” mindset of rationalist town planning. Accordingly, the conceivers of the concept of OrbiTecture maintain the need to go beyond the approach so far adopted in the construction of space infrastructures – in particular the one used for the International Space Station – based on the division in compartments and juxtaposition of pre-assembled components and units, in favor of a systemic approach of the design of new space habitats, on the basis of the principles of functionality, comfort, livability and direct construction in Space.

2 COMMENTS AND CONSIDERATIONS OF E3P2-EXPERT

2.1 System Studies

2.1.1 System of Systems

One major or the most important overall study needed is the one of the Cislunar City as a whole. The need is to properly balance the distribution of functions among the 10-12 districts and the supporting technologies to allow the best life of a 1000-person permanent population. The process of developing over time the Cislunar City is another paramount problem, to minimize time and costs, using also the development of a systematic and complex transportation system that can be estimated in the order of 100 thousand trips seat/cargo equivalent per year. The proper identification of functions such as interchange node, pier, refueling, maintenance, construction, lodging, work areas, socialization spaces, is important as well and the same is the acquisition and transportation of raw materials (from Earth, Moon, asteroids).



The Cislunar City

CNS has identified new criteria as:

- minimum weight per capita
- maximum space per capita
- integration of different activities inconceivable within the ISS present spaces, designed not for ordinary people

2.1.2 Habitat

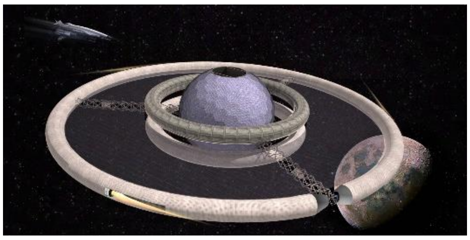
The development of the Cislunar City will need definition of in orbit and on ground habitats satisfying not only scientific research requirements but also needs of ordinary living. It would be paramount introducing since the beginning other type of requirements to sustain a more affordable day-by-day life. Communities of persons dedicated to managing the districts and their systems, to maintain them, to look at the economic/financial aspects of the life in space, to start a more general economic/commercial life up to hosting tourists or travelers, will need the adoption and satisfaction of new requirements for which extensive preliminary studies and technology development are necessary since now.

Basic assumptions may be:

- Limit transfer costs by reducing mass and implement manufacturing in reduced gravity conditions, both inside pressurized modules (including food) and in vacuum. Make extensive use of additive manufacturing in vacuum
- Production in space with the use of Moon/asteroid raw materials will have to be accompanied by in space assembly integration and testing so to establish a true *Made in Space*
- The presence of reduced gravity may offer quite a lot of advantages which must be exploited to optimize the entire process
- The Cis-lunar city will be composed of underground quarters and overground buildings. Define the configuration and connections amongst different blocks considering functionality of different areas too vs their intended utilization
- Limit dependence on the Mother Earth by maximizing sustainability principles and using farming
- Extend to space principles and concepts of the Green Economy and Circular Economy.

SpaceHub®

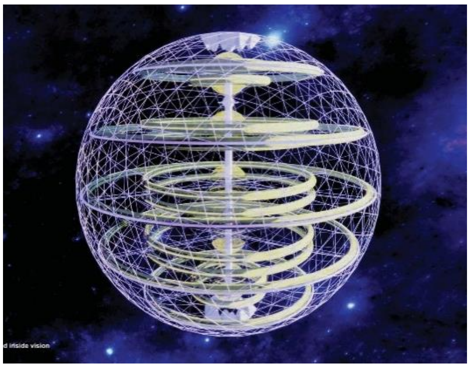
CNS has studied a 100-person multifunction space station called SpaceHub® and positioned in the Lagrangian point L1. The analysis of functional requirements, numerous evaluations and logical principles have then made the whole take on a planetomorphic conception, as specifications and manufacturing technologies have been outlined.



SpaceHub®

OrbiTech®

A subsequent occasion for reflection was to develop similar concepts in response to an international competition notice aimed at identifying proposals for a settlement in space of 2,000 inhabitants with the possibility of growth by stages up to 10,0 00. Based on similar principles to the previous ones, we came to OrbiTech®.

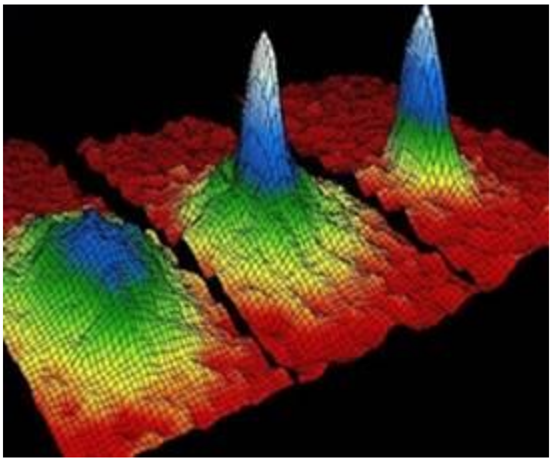


OrbiTech®

LunaPark (or LeviLab)

CNS is presently investigating a lunar settlement. From a methodological point of view, the proposal follows a similar path: but once its order of magnitude has been hypothesized, the logical principles of reference are substantially different. It is not a question of thinking about finite units capable of floating or moving in space. There is a need to interact with a relatively unknown pre-existence: the lunar soil. In these cases, it is necessary to think of settlements that are not finished and are predisposed to growth. It is unreasonable to pursue typologies like igloo that are intrinsically isolated and that may eventually be doubled and connected to each other via ducts, and so on.

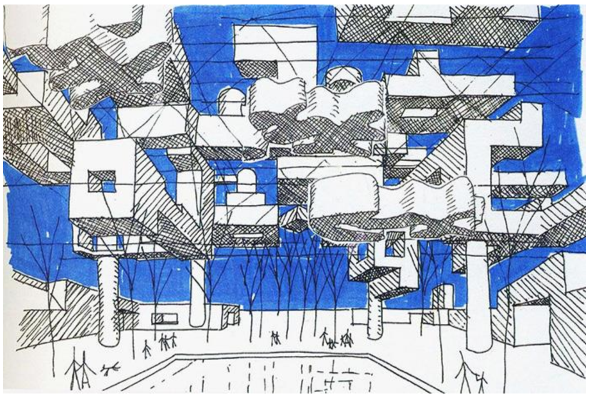
The first evaluation is "where" to place, which point to locate on our satellite: in large natural cavities (which would facilitate radiation protection), in "polar" conditions, where it seems more likely to trace water in the subsoil, or think of other points for others reasons. Whatever the choice, it is necessary to consider the different gravity compared to Earth and the articulated morphological configuration of the chosen location. It seems obvious then to set the goal not to need to first "pave" a surface, to consider that soil almost as an area of "archaeological" interest, to make use of the much lesser gravity that facilitates the creation of a habitat "suspended" from the ground. Left in its current configuration, the lunar soil remains so free for research, excavation, processing, circulation. Unlike SpaceHub or OrbiTech, LunaPark (or LeviLab) is not a closed or complete structure. It must be able to grow and change according to unforeseen needs.



LunaPark Logical-mathematical model reference

Having assumed the "archaeological" similarity, it has punctual ground support, a cover that does not need support in exactly predefined positions, similarly to a concept by Yona Friedman (1958). It has large meshes, with tree-type supports characterized by a single point at the bottom and branches upwards. The cover is a sort of a wide blanket, a three-dimensional structure articulated planimetrically and altimetrically, to provide also protection from radiation/energy production / oxygen production. Eventual undulations in the cover can help solve any structural dynamics problems. As the SpaceHub, the cover has a finish with hexahedral or different modular tanks, 10-20 cm thick containing water and/or cyanobacteria or algae, over a plate of solar cells capable of capturing the solar energy.

From a functional point of view, the first settlement will consist primarily of scientific laboratories, mining/ extraction capabilities and support spaces. For their dimensioning reference can be made to the great Antarctic bases that host up to 1200-1300 people (McMurdo, for example). Assuming extensive use of automation and robotics, CNS anticipates a settlement of about 100 people, 50% for extraction, 30% for research, 10% for management and 10% for tourism.



Yona Friedman (1958): different goals, with analogies and coincidences

There are also useful spaces for accommodating animals: both for the well-being of individuals (pets) and the food chain that must enrich crops.

2.1.3 People Mobility

As said in paragraph 2.1.1, the developed Cislunar City will have to have an integrated transportation system anticipated to be in the order of 100 thousand seat/cargo equivalent trips year. It will connect the various districts distributed in LEO around the Earth, in LLO and on the surface of the Moon, as well as in specific points such as the Lagrangian ones. As particular cases, the system will include transportation from the Earth surface to the districts, connections between the docking facility in a district and the main living/working environments (CNS introduced the concept of "lift" in its Spacehub station), mobility on the lunar ground.

Mobility on planet surface is proposed to be guaranteed by systems like Moon Camper for which studies and some technologies are already available, to be further developed with the introduction of autonomous driving, supported by dedicated satellite positioning systems and the use of artificial intelligence.

The mobility system will be used by crews, composed by researchers, maintainers, operators, labourers, tourists. It will constitute what the Center for Near Space call "*Civil Astronautics*", that is anticipated to play in the XXI century the very same role played by Civil Aviation in the XX century.

Hyplane®

A specific example of systems for mobility is given by HYPLANE®, a Mach 4.5 aerospaceplane able to take-off and land on ordinary airports and bring 6 passengers to the Karman line or a second stage to an altitude so to insert a micro-satellite in LEO. This study is anticipated to develop toward the ability to easily bring passengers from Earth to LEO and back.

2.2 Enabling Technologies

2.2.1 Robotics and Cobotics

Spiderlab robots teleoperated from Earth and from any of the Cislunar City districts. They must be characterized by robust and strong autonomy in terms of both duration of operations and capability to take decision without the intervention of humans. Raw material provision is another issue not of secondary importance and specific autonomous robotic systems can be considered.

The presence of several robots working together on infrastructures manufacturing and/or operation, as well as the simultaneous presence of robots and humans requires the development of a robust sensors, actuators, computing capability and control.

Anthropomorphic robots appear to be most appropriate to interface with astronauts without requiring ad hoc programming, but taking benefit from image and voice recognition, hands, legs and quite a lot of artificial intelligence (evolution of projects as Eurobot, Robonaut, Astrobot, etc.)

2.2.2 Small Vehicles

One of the most critical aspects to be developed is the use of ground and aerial swarms of small system. Their most important value will be the cooperative capability in the sense to work all together with different scope and tasks but toward a unique target. They must have the capability to adapt to different situations during the outdoor mission and take independent autonomous decisions. Communication among them, both ground and aerial, and with other robots or humans in different sites in the Cislunar City and when exploring the external areas will be the major technological need (Application of Artificial Intelligence and sensor technologies).

The energy production and storage on board each of those drones is paramount. The possibility to recharge them during operation by means of a larger supporting system appears fundamental.

2.2.3 ECLSS - Advanced Life Support Solutions

The continuous life in space requires the development of solutions and technologies based on the full-autonomous and mass-wise closed system concept. A lot of internal space of in orbit and on ground habitats will have to be dedicated to cultures growth as well as animals care to complete the life cycle or at least part of it. Full recycling is a clear target using as much as possible solar energy and proper selection of seeds, process cycles, etc. for the benefit of life over there. Massive generation of air gas constituents N_2, O_2, H_2 must be put in place jointly with pressurization systems and optimized for energy saving.

2.2.4 In Space Manufacturing

2.2.4.1 Additive Manufacturing

As for the technology of additive manufacturing, it is estimated that in the next 10 years there will be an increase in the manufacturing speed from 10 to 80cm^3/hour, with a growing factor of 8. Given that we are only at the beginning of these developments, on the ordinary course of a normal "S" curve, it is certainly possible to hypothesize that: (i) in the following 10 years we can have a still substantial increase of 8 times, reaching 640cm^3/hour; (ii) that in the followi ng 5 years the speed of growth is reduced to 2 times reaching 1280cm^3/hour.

CNS has conceived a specific Construction Machine with 60 additive manufacturing heads for rapid and continuous manufacturing in vacuum. Studies are necessary to push such technology forward to become mature and affordable in a relatively reduced time.

Additive Manufacturing Construction Machine

2.2.4.2 ISRU/ISFR

Production in space with the use of Moon/asteroid raw materials is a must to reduce cost and time to completion, and to set up an effective Made in Space capability for the benefit of a full space economy.

Mining, extraction and transportation of raw material to production sites in the districts of the Cislunar City must be studied and developed, looking for optimization of requirements satisfaction, material selection, processes definition, production sites location, etc.

Such production will have to be accompanied and complemented by in space assembly integration and testing by means of true in situ assembly lines and related capabilities of testing the final artefact. This will minimize or even reduce to zero the AIT on Earth with obvious advantages coming from bypassing the design constraints of launching and the earth's gravity. In few words establish the *Made in Space*

2.2.5 Radiation Protection

One of the areas of attention of CNS is the possibility to increase radiation protection by means of water with the addition of bacteria or other forms of biological material. There is no evidence yet but the hope that some bacteria can retain part of the radiation.

The large quantity of water needed to protect an infrastructure is also very useful for many other functions of an almost mass-closed system as each district of the Cislunar City must be. Having around the habitats a "glove" of water may offer many opportunities also for other use in space.

Alternative shielding devices must be conceived and implemented (e.g. electromagnetic shields). The water as well as other raw materials can be periodically distributed over the Cislunar City districts after extraction from lunar surface and subsurface, and asteroid.

Radiation Protection with water added with biological material

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