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# DESIGNING BIOLOGICAL AUTONOMY FOR ORBITAL HABITATS - INFLATABLE CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEM (ICELSS)

**Abstract**

Controlled Ecological Life Support Systems (CELSS) framework has been developed at the interface of engineering and interdisciplinary fields and thus invites the emerging field of space architecture to rethink habitats beyond purely mechanical and functional architecture, but rather as connected human-plant-machine ecologies. Most of the flight hardware to date remains small-scale, rigid, and of an experimental nature, with layouts that cannot be straightforwardly extrapolated into full-scale habitats that are necessary for long-duration missions. This paper takes the approach that if biological autonomy is taken as a long-term design driver, life support architecture can be reconceived as an integrated, easily assembled CELSS environment that intertwines (1) crop yield metrics with (2) spatial configuration and (3) crew experience.

Although decades of work recorded from Salyut and Mir to the ISS, the BIOS experiments, and MELiSSA, have generated a substantial body of CELSS knowledge, the idea remains at a conceptual stage. Most LEO experiments are confined to rigid small-scale growth chambers, whereas bioregenerative autonomy, for future orbital or surface habitats, will require tens of square metres per individual and careful coupling of subsystem streams.

Following a comprehensive literature review conducted of the historical and modern plant growth systems, crop portfolios, and geometries, the paper initially identifies quantitative requirements for closed-loop systems to be fulfilled, such as cultivated area, harvest index, lighting and thermal requirements, Nutrient Delivery System (NDS) solutions, humidity regulation, gas exchange balance, and waste management. These parameters have been used to create an architectural brief for an Inflatable Controlled Ecological Life Support System (ICELSS) module, the size referring to the SpaceX Starship, exploring the feasibility of inflatable structures hosting hydroponic, aeroponic, NFT, and felt-based growth systems while maintaining individual atmospheric conditions for each cultivated plant species.

The main objectives have been to generate ICELSS layout alternatives and assess them in terms of optimal spatial arrangements for air, water, waste loops, crop area per person, envelope packing efficiency, and implications for psychological well-being.

The paper hypothesises that an ICELSS module with $<25m^2$ of cultivation area per crew member can substantially reduce Earth-based resupply, while providing a spatial and social “green core” for an orbital habitat. By combining biological performance criteria with architectural configuration, the study aims to shift CELSS research from isolated chambers toward integrated habitat modules, offering a design framework and data that can be adapted to future LEO-, and potentially lunar, or Martian, missions.

## Declaration on the use of Generative AI and AI-assisted Technologies in the writing process

Grammar correction.