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Space architecture education as a part of aerospace engineering curriculum ☆

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A R T I C L E   I N F O

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A B S T R A C T

Education is particularly important for new fields. In the case of space architecture, there are two core needs:

1. educating the aerospace community about the architect's function and activity and design process within the enterprise;
2. educating space architects and associated specialists about constraints, conditions, and priorities unique to human space systems.

These needs can be addressed, respectively, by two key educational tools for the 21st century:

1. introducing the space architecture discipline into the space system engineering curricula;
2. developing space architecture as a distinct, complete training curriculum.

New generations of professionals with a space architecture background can help shift professional focus from just engineering-driven transportation systems and "sortie" missions to permanent offworld human presence by offering their inherently integrative design approach to all types of space structures and facilities. Although architectural and engineering approaches share some similarities in solving problems, they also have significant differences. Architectural training teaches young professionals to operate at all scales from the "overall picture" down to the smallest details to provide directive intention – not just analysis – to design opportunities, to address the relationship between human behavior and the built environment, and to interact with many diverse fields and disciplines throughout the project lifecycle.

1. Field of space architecture

The Field of space architecture as a discipline is defined on the space architecture website as "a system of enclosed and modified space that is used for enhancing and sustaining specified human activities" [1]. Although there are still debates going on about what should be included into the definition, that description is very close to the subject. In general, if humankind is going to continue space exploration we have to stop treating space as a one-time lab experiment and start dealing with it as with any another habitation environment where living conditions differ from what humans are used to. Introduction to space architecture as a discipline and philosophy of life to aerospace and other engineering students

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may be an important step towards building such attitudes.

Donna Duerk [2] wrote her "Curriculum for Aerospace Architecture" specifically oriented for architectural students to better understand NASA's vision and mission. It is a comprehensive and detailed curriculum that specifically explains the aerospace profession to architectural students. Space architecture by its nature lies in between engineering and architecture, human factors, and art. This understanding is important for all the professionals involved in design of space facilities throughout all stages of the design process. Space architecture by nature is symbiosis of many disciplines; it is a way of thinking and design problem solving that provides a common language for communicating between disciplines.

1.1. Role of architecture

The role of architecture has always been to create spaces that satisfy the clients' requirements and serve the best functions as defined by those clients and their objectives for the building/structure. Every building/structure that has been built has once satisfied its function or purpose on different levels, or sometimes not at all. Imperfectly functional structures on Earth may be built and may survive but there is no such luxury in space or extreme environments.

1.2. Role of architect

Defining an architect's role during the design and construction process on Earth is pretty easy. The role of a space architect is much more complicated in the aerospace field. This field is traditionally engineering based and machinery-oriented with people considered to be machine operators and even mechanics sometimes. Integrating architectural curriculum with engineering education is a natural way to evolve aerospace education into a new form that will offer students broader visions on problem solving and expand their horizons and perspectives in applying themselves in their professional worlds after graduation.

1.3. Levels of involvement

Traditionally, the level of involvement of architects and engineers in the design process varies depending on the design stage. In space architecture, design solutions have to correspond with and be based on proven technology much more heavily than in terrestrial projects. Sometimes that limits selection of design options and takes potentially good design alternatives out of consideration. For example, the International Space Station (ISS) rack system has been used for years even though they are heavy and require significant launch mass capacity they are still the preferred design approach for conventional modules. Materials, equipment, and technologies have improved dramatically over the last decades and there is probably no need to continue using heavy and stationery positioned racks any more, but these racks most likely will be around for quite some time as it takes decades to implement new design solutions into practice.

All involved disciplines need to help each other throughout and across the design process and be involved at different levels at all design stages.

1.4. Space architecture issues and concerns

- Introduce and accommodate all human factors components into design solutions by teaching to comprehend all issues from the earliest stages of the design;
- Present the theory, requirements, and design concepts for structures and systems in extreme environments and outer space;
- Topics of focus include human factors, ergonomic influences, extreme environments constraints/influences, and psycho–social factors;
- Find a reasonable compromise between "necessary" and "desirable";
- Come to the comprehension of esthetics "inside out" at first stages of the design development.

2. Design areas

A successful design is a collaborative work of professionals from diverse backgrounds. Definition of those areas and relationships between them is an important part of working on a project process. It is also a common way of architectural practice because by nature, the architect has to find a best compromise and bring all involved disciplines and professionals to consensus.

2.1. Engineering approach

The design engineering approach is usually narrowed by specific tasks and scope of work (for example, designing HVAC (heating, ventilation, and air conditioning) or mechanical systems for a certain facility or a building type). Though teamwork is very important, finding compromises between solutions sometimes requires reconsidering essential aspects of design solutions because engineering collaboration mostly occurs between engineers who work on some particular problem.

Traditional space engineering usually considers humans from human–machine interactions perspective, where humans are machine operators. The architectural paradigm treats humans as inhabitants, focusing more on human needs and values as a major optimization and design criteria.

2.2. Architectural approach

There are two common values of architecture as a discipline: use of a system of elements of a project, and design itself. This may include all but is not limited to: functionality of systems and interior arrangements, cost effectiveness, and esthetics. The final product – design of a habitat or other types of facilities – cannot be considered a successful experience if any one of these

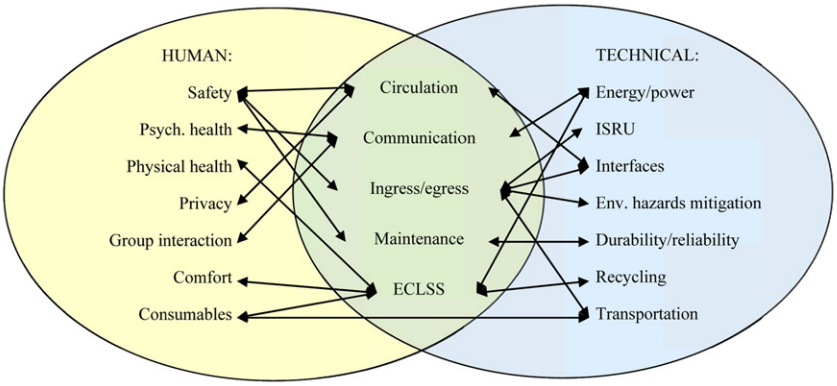

Fig. 1. Functions' relationships example.

aspects does not satisfy the client's needs or meet his expectations.

All space facilities are technologically advanced structures and include robotic and human operated systems with multi-level complex human–machine interactions. Safety and crew work performance efficiency depends on simplicity and ergonomic design. Recognition and classification of required interactions, identifying when, where, and how they are happening are the first steps in the design optimization process.

The diagram below (Fig. 1) is an example of possible relationships between different groups of functions inside a habitable volume. Linking arrows demonstrate expected interactions between functions from different groups. Although these connections may not necessarily always be present, and they all are not necessarily at the same level. The list of these functions can be much longer and more detailed; there is also a hierarchy of functions that may have several levels of relationships and interactions between themselves. Understanding these relations and their sequences is a key to program formulation during the design process.

3. Design process

Even though each school, program, and class differs from each other, in general, space architecture courses or classes may be based on architectural processes. For example, masters students in Sasakawa International Center for Space Architecture (SICSA) [3] defined their student project in the 2009–2010 academic year as follows:

- Explore and define an architectural framework through which to study space architecture, space operations and mission planning, and functional relationships of systems, elements and people.
- Facilitate multi-disciplinary and cooperative study involving numerous students pursuing discrete aspects of architecture.

Although a detailed design stage can be hardly completed within a short period of time in most academic programs, feasibility of project solutions has to be studied and included in the main course curriculum. These studies should be approached from many perspectives:

- Engineering systems optimization;
- Budget feasibility;
- Science objectives and perspective applications of outcome;
- Crew work performance index;
- Crew physical and psychological comfort and functioning;
- Launch mass and volume optimization;
- Overall design product.

During a design process a customer may modify his requirements and even re-define goals and objectives. An architect and his team have to refine the design accordingly while still trying to stay within a given timeframe. This process may go as far back as re-programming the whole mission.

The design process with interdisciplinary inputs may be described by the following diagram (Fig. 2). It starts with establishing goals and objectives by a group of engineers, clients, scientists and may be with some involvement of architects. Next step is data collection and its analysis done by the same group of professionals and invited experts. This will lead to determining the overall mission requirements and developing preliminary concepts that will be tested during the next stage of the process. The last three stages may require extra data collection and analysis. Clients and experts are expected to provide input and feedback during the whole design process.

3.1. Engineering methodology

Usually in engineering curriculum, aerospace engineering principles are reinforced and integrated through design assignments and "hands-on" experience hopefully with the latest in test equipment and the modern experimental methods. The learning experience may be based on exploring several major engineering systems of a spacecraft [4]:

- Structures and mechanisms;
- Guidance, navigation and control;

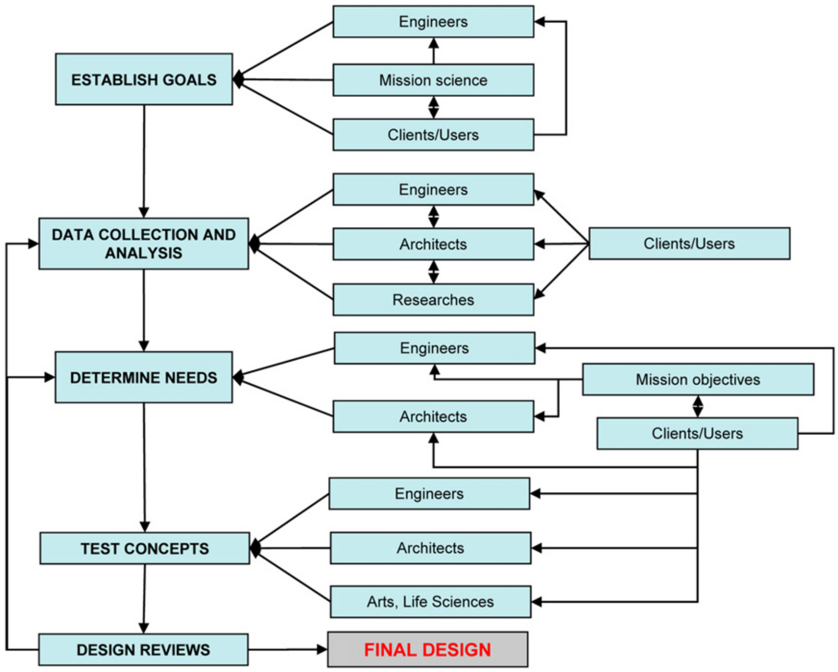

Fig. 2. Interdisciplinary design process.

- Communication and tracking;
- Command and data handling;
- Environmental control and life support.

Students typically specialize in designing a specific element or system. Critical subsystems include:

- Pressurized elements;
- Non-pressurized elements;
- Mechanisms;
- Robotics;
- Thermal control;
- Power systems.

Design issues addressing costs, performance and constraints are also addressed in relations to a specific subsystem or component.

3.2. *Architectural methodology*

In addition to the aerospace engineering approach, aerospace architecture teaches students to consider a complex approach in design, imagining a "big picture" and keeping it in mind while designing even a very small unit or detail. That helps students to find atypical and sometimes even extraordinary design solutions where all elements enhance each others roles.

An important component of space architecture as a discipline is modeling the technology of tomorrow with an accent on sustainability. Sustainability is a crucial aspect of design for space, at some point it is a matter of people surviving long-term missions where new supplies are out of reach.

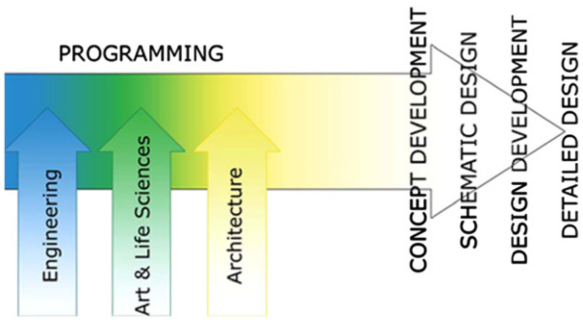

Fig. 3. Design stages and disciplines involvement.

An architectural approach is centered on humans and their needs. This approach is multidisciplinary by nature where a habitable element can be referred as a crew's "artificial ecosystem". [5] A multidisciplinary approach has to be introduced early in the design process as a programming stage and remain applicable throughout the whole design process. (Fig. 3).

4. Conclusions

Introducing the architect's approach into engineering programs at universities could be done via a series of "Space Architecture Issues and Concerns" courses. [6] Topics of focus may include human factors and ergonomics, extreme-environments constraints and influences, and psycho–social factors. In conclusion, several steps could be done to enhance aerospace engineering learning processes and to boost public interest in space education in general:

- The field of space architecture should become integrated into aerospace curricula through required courses.
- Undergraduate and postgraduate students can be a source of creative potential for large, multilateral space projects.
- Space companies involve space architecture students in their design processes to anticipate and accommodate international, interdisciplinary, and inter-institutional cooperation at all design stages.
- The increasingly multinational nature of space exploration, as well as continuing trends toward undergraduate curricula standards (i.e., the Bologna Process in the E.U.), make it advisable for students to acquire experience with full-scale international collaboration via their required and elective projects and undergraduate research.
- Collaborative, international student projects with a space architecture component have to be a required component of aerospace education curricula.
- A number of student and young professional space design contests in the recent years have demonstrated advantages as a tool for stimulating students and encouraging them to proffer their designs in a competitive environment.
- Enhancement of international space architecture student contests as a productive way to emphasize multidisciplinary and system-design approaches, and views Academy conferences as appropriate venues to promote such contests.

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