SPACE ARCHITECTURE

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Space Architecture

- How can we live and work in space?

- Space Architecture definition
- Environments
  - Space environments
  - Planetary surface environments
  - Earth extreme environments
- The space architecture challenge
- Phased approach to space construction
  - Class I: Pre-integrated
  - Class II: Prefabricated
  - Class III: ISRU-derived
- Future directions
Space Architecture Definition

• spacearchitect.org defines Space Architecture as encompassing “architectural design of living and working environments in space-related facilities, habitats, and vehicles. . . Designing these forms of architecture presents a particular challenge: to ensure and support safety, habitability, human reliability, and crew productivity in the context of extreme and unforgiving environments.”

• Comfort Zones for human habitability:

<table>
<thead>
<tr>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>22.5°C</td>
</tr>
<tr>
<td>Humidity</td>
<td>20%</td>
</tr>
<tr>
<td>Light</td>
<td>-</td>
</tr>
<tr>
<td>Sound</td>
<td>0dB(A)</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Various oxygen/nitrogen mixes</td>
</tr>
<tr>
<td>Air movement</td>
<td>0.1 m/s</td>
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<tr>
<td>Air pressure</td>
<td>10 psi</td>
</tr>
<tr>
<td>Gravity</td>
<td>0.0G</td>
</tr>
<tr>
<td>Gravity Vector</td>
<td>Flat</td>
</tr>
<tr>
<td>Radiation</td>
<td>-</td>
</tr>
<tr>
<td>Volume</td>
<td>1m³</td>
</tr>
<tr>
<td>Durnal Cycle</td>
<td>20hr</td>
</tr>
<tr>
<td>Particulates</td>
<td>-</td>
</tr>
<tr>
<td>Micrometeoroid</td>
<td>Zero penetration</td>
</tr>
<tr>
<td>Resource Inputs</td>
<td>Chaotic inputs</td>
</tr>
</tbody>
</table>
Resource Input Comfort Zone

- "TOP DOWN" SPECIFIED ORDERING
- "BOTTOM UP" CONFIGURATIONAL ORDERING

RESOURCE INPUT "COMFORT ZONE"

HIGHLY ORDERED INPUT

GOAL: INCREASED CAPACITY FOR LESSER ORDERED INPUT

MATERIAL CONCENTRATIONS

EARTH INPUTS

MARS INPUTS

MOON INPUTS

UNORGANIZED CHAOS
Realms of Space Architecture

- Space Environments
  - Orbital
  - Deep space
  - Small-scale to large-scale urbanism
- Planetary Surface Environments
  - Lunar, Mars, etc
  - Outposts to colonization
- Earth Extreme Environments
  - Polar bases, under sea
  - Emergency housing, structures
The Space Architecture Challenge

• Create an environment for human habitation that mitigates all the extremes and continually maintains the comfort zone
  – Must understand the extreme environment
  – Must design habitat, the means of construction, and how it is to be delivered
  – Work within the capacity of the transportation system
    – *It is the same as requiring all the building materials, construction equipment, power-generation capability, fuel, air to breathe, water, gases, kitchen, food, clothes, medical equipment, and workforce to all fit on only one truck*
  – Must use deployable mechanisms, kit-of-parts, and lightweight materials
  – Must use robotic labor, that has no need of pressurized environment
  – Take advantage of found materials as much as possible
Phased Approach to Space Construction

- **CLASS I:**
  - Preintegrated, Hard Shell Module
- **CLASS II:**
  - Prefabricated, Surface Assembled
- **CLASS III:**
  - ISRU Derived Structure w/ Integrated Earth components

Evolution by Time
Class I: Pre-integrated Construction

- Fully usable
- No assembly required
- Limited by payload size
Class II: Pre-fabricated Construction

- Assembled onsite
- Robust joints
- Replacable
- No size limit
Class II Concepts: Plug-in Accessories

- Actuated solar panel
- Robotic arms
- Radiators
- Common power/data/structure interfaces
- Modular pressure vessel
- EVA platform and equipment
- Heavy articulated limb based mobility systems (ATHLETE-based)
- Modular bulkheads
- Self-leveling systems
- High-speed, high-draft mobility systems (Chariot-based)
Class II Concepts: Commonality

RCS Sled PEV → Taxi → MAV Cabin

Phobos Hopper PEV → Mars Surface Rover PEV

Keck Institute for Space Studies, 3D Additive Construction  SPACE ARCHITECTURE  A. Scott Howe, PhD  24 August 2015
Class II Concepts: Docking and Connections

- Longitudinal Leveling and Module to Module alignment
- Axial Alignment
- Passive
- Active-Active
- Passive

- Clamping Mech (4)
- Pressure Bladder
- Compliance Mech
- Clamping Flange
- Inflatable Seal
- Valve
- Female connector
- Male connector

- N2
- O2
- Waste H2O
- IMV
- Pot H2O
- Elec
- Data

- 40” square hatch with circular clamping interface
- Active-active adapter stowed (0.2m long) deployed (0.8m long)
- Active-active adapter with clamping frames (shown without membrane)
- Stewart Platform linear actuators
Class II Concepts: Deployable Systems

- Machined aluminum or composite end domes
- Inflatable membrane
- Fold-out partitions with scissor truss support and fabric side walls
- Folding floor system

- Folded ramp
- Winch frame
- Folding handrails
- Deck panel
- Ramp panel
- Deployable subframe with extendable legs to support its own weight
Class II Concepts: Logistics-2-Living

- Inflatable habitat walls
- Hard core
- Hydrogen-impregnated CTBE material draped against wall
- ISS rack – total capacity 16 racks
- Lightweight snap-together kit-of-parts frame system
- Unfolded CTBEs used as partitions
- ECLSS racks
- Rack-based crew quarters
- Membrane Forward Osmosis (FO) filter water wall derived from used CTBEs
Class II Concepts: Flexible Outfitting

Random Access Frame (RAF) concept
Class II Concepts: Repurposing

- Upper longeron
- Movable frames: can be slid or shifted on demand. Nominally allows for tightly packed stowage, while at the same time allowing for random access
- Unfolded CTBs, available for L2L, heat melt, or radiation shielding
- Folded CTBs in use, mounted to frames
- Lower longeron

3D printable construction kit (similar to 8020 frame system) elements available for alternate configurations, or recycle into 3D printer feedstock
Class II Concepts: In-situ Assembly

- Solar arrays optional each STAR Node
- Space Technology & Advanced Readiness (STAR) Node (open loop ECLSS, air ventilation, fire suppressant, thermal, limited PMAD): STAR Node is central open loop ECLSS module for rovers as well
- Cockpits or end cones
- Modular mobility systems
- Active-active adapter
- Additional volume
- Core Hab (closed ECLSS, air / water revitalization, thermal, PMAD, avionics)
Class II Concepts: Expandable Outpost

### Modular Horizontal Midex Outpost

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume/Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitable Volume (m³)</td>
<td>121.8</td>
</tr>
<tr>
<td>Non-habitable Volume</td>
<td>78.7</td>
</tr>
<tr>
<td>Pressurized Volume</td>
<td>200.5</td>
</tr>
<tr>
<td>Core Hab Module</td>
<td>9827.0</td>
</tr>
<tr>
<td>Midex Module</td>
<td>11280.0</td>
</tr>
<tr>
<td>Inflatable Airlock</td>
<td>3464.0</td>
</tr>
<tr>
<td>Total Mass</td>
<td>49469.0</td>
</tr>
</tbody>
</table>

- Core hab module
- PEV rovers
- Modular midex modules
Class II Execution: Robotic Construction

• Encapsulate infrastructure where none is available
  – Materials, Power, transportation, labor, material handling
• Encapsulate complexity into simply manageable units
• The devil is in the details
  – Understand material handling of even the smallest parts

• Smart constructor, dumb parts
  – Constructor is high cost
  – Parts are low cost
  – Constructor is bottleneck

• Smart parts without constructor
  – Self-construct
  – Parts are high cost
  – Faulty parts can be ignored
  – No bottlenecks

• Smart constructor, smart parts
  – Parts assist with their assembly
  – Constructor is medium cost
  – Parts are medium cost
Class II Execution: Robotic Assembly

[Images of robotic structures]
Class II Example: Lunar Outpost

- Solar arrays
- Fuel cells and reactant tanks
- PEM excursion module
- Radiators:
  - PCM 24m²
  - PEM 5m²
  - PLM 5m²
- Inflatable airlock
- LER (4 x)
- PCM core module
- PLM logistics module
Class II Example: Mobile Outpost
Class II Prototype: Habitat Demonstration Unit
Class II Prototype: HDU Configuration

- Lift upper hand railing
- Overhead stowage
- Atrium Plant Growth system
- Radial Internal Material Handling System (RIMS)
- Lift column
- Lift platform and lower hand railing
- X-HAB LOFT
- DUST MODULE
- LAB MODULE
- HYGIENE MODULE
Class II Comfort Zones: Working in Space
Class II Comfort Zones: Working in Space

X-Hab Inflatable Loft

Photo: James W. Young
Class III: In-situ Construction

- Need up-front technology
- Onsite effort
- Unlimited resources
- Sustainable

Sinterhab

Sandbag domes (courtesy CalEarth)
Class III Concepts: 3D Additive Construction

- 7 DOF umbilical / material handling
- ATHLETE limb
- Print head hardware
- ATHLETE tool grasp
- Layering of printed material (print path shown in red)
Class III Concepts: 3D Additive Construction

Technical Approach / Expected Accomplishment: Using ATHLETE’s precision positioning capability, four technologies can be used to make a print head and material handling system to adapt/utilize large-scale 3D printer technologies consisting of: fiberoptic solar concentrator, microwave sintering, foam hardening, and in-situ concrete. The FACS system is expected to be capable of printing modular ‘bricks’, panels, or in-situ structures out of native regolith.

Task Objectives: Develop a large-scale 3D additive printing capability and build upon ATHLETE precision mobility system. The 3D print head becomes a modular tool for ATHLETE that can be autonomously mounted on one of its limbs for the purpose of paving and stabilizing native surfaces by sintering or melting regolith.

Infusion Path: Proposals for capturing a small NEA are currently being considered for both science and human spaceflight as part of the NASA Asteroid Redirect Mission. This technology can be used to enhance ATHLETE’s ability to anchor to an NEA. The technology can also be used to pave surfaces, print domes, vaults, and other structures for Lunar or Mars surface human missions.

Primary Technical Hurdles: Fiberoptic solar concentrators are currently at TRL 6 and can be quickly integrated with ATHLETE for a demonstration. Additional effort will be needed to integrate microwave sintering and foam hardening systems. In-situ concrete can only be worked out conceptually, because hardening agents are currently not well understood. However, partners/collaborators (KSC, USC, etc) have been working on potential technologies in this area.
Class III Concepts: Precision Positioning

Customizable pallet: can be used as a platform for power plants, reservoirs, mixing, filtering, and other processing

6-DOF or 7-DOF articulated limb: can be used primarily for mobility, but also as a robotic arm

Tweel: allows for wheeled mobility

Tool adapter: available on each limb, can grasp tools and provide mechanical power through the power take-off, borrowing the motor in the wheel
Class III Concepts: Precision Positioning

ATHLETE limb grasping a tool -- drilling into a rock cliff -- tools can be lifted well above main body

Payload on modular pallet (showing a mockup habitat with 60” high door)

Tri-ATHLETE vehicle with three limbs x2 = six limbs total

Limbs

Wheels on limbs for mobility
Class III Concepts: Modular ISRU Processing

- Tri-ATHLETE vehicle
- Dedicated FACS pallet
- Tri-ATHLETE vehicle
- Stowed umbilical
- Print head holster on end of pallet
- ATHLETE limb reaches up to grasp print head with tool adapter
Class III Concepts: Material Handling

7-DOF Umbilical facilitates printing in multiple degrees of freedom

Articulated Archimedes screw
Core of Archimedes screw can function as conduit for cables, fiberoptics

3-DOF Umbilical facilitates printing only in the vertical orientation

Tri-ATHLETE vehicle
Dedicated FACS pallet

ATHLETE limb
Conveyor belt with deep bucket pockets

Print head
Material handling umbilical

7-DOF Umbilical

3-DOF Umbilical
Class III Execution: Printed Shells

1. Airlock module with docking ports
   - Inflatable liner stowed
   - ATHLETE mobility system

2. Tri-ATHLETE vehicles set Airlock module and pallet in target location
   - Proposed habitat location (blue dashed)

3. Airlock module and pallet in permanent location

4. Tri-ATHLETE vehicles pick up FACS pallet to begin printing of habitat shell
Class III Execution: Printed Shells

- Ultraflex solar arrays
- FACS production plant on pallet
- ATHLETE mobility system
- Airlock module w/ pallet
- Partially printed shell, diagonal print pattern allows the printing of vaults without scaffolding
Class III Execution: Printed Shells

- Printed regolith shell
- Liner inflates after shell is completed
- Airlock module / pallet
- Additional modules can be placed for outpost
Class III Execution: Printed Shells

“Sinterhab”
Class III Execution: Prefab Panels

- Modular panels, arches, beams printed on the ground
- FACS system
- ATHLETE mobility system
- In-situ printed paving blocks for lander pads
- ATHLETE can lift and manipulate panels into in-situ structure
- Modular archways and scaffolding assembled from in-situ printed panels
Class III Execution: Prefab Panels

- Tilt-up construction
- Support scaffolding
- ATHLETE system
- Partially constructed vault
- Vault structure buried under loose regolith
Class III Execution: Prefab Panels

- Unpressurized garage constructed in advance
- Habitat rolled into garage by ATHLETE mobility system
- ATHLETE separates from habitat to go perform other work
- Habitat in shielded environment
Questions?

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- Concepts and Discussions are based on material from AIAA publication:
  - “Out of This World: The New Field of Space Architecture”