Sandra Häuplik-Meusburger Olga Bannova

Space Architecture Education for Engineers and Architects

Designing and Planning Beyond Earth



Contents

| 1 | Introduction | | | | | |
|---|---------------------|---|----|--|--|--|
| | 1.1 | The Field of Space Architecture | 1 | | | |
| | 1.2 | Structure of the Book | 3 | | | |
| | 1.3 | Benefits for the Reader | 4 | | | |
| | 1.4 | How to Use This Book | 5 | | | |
| | 1.5 | Guest Statement: The Essence of Interdiscliplinarity | | | | |
| | | (Chris Welch) | 6 | | | |
| | Refe | erences | 8 | | | |
| 2 | Арр | proaches and Methods | 9 | | | |
| | 2.1 | Introduction and Chapter Structure | 9 | | | |
| | 2.2 | Future Tasks and Upcoming Challenges | 10 | | | |
| | 2.3 | Educational Practices | 12 | | | |
| | | 2.3.1 The Engineering Approach to Habitation Design | 12 | | | |
| | | 2.3.1.1 Engineering Classes | 13 | | | |
| | | 2.3.2 The Architectural Approach | 14 | | | |
| | | 2.3.2.1 Architectural and Design Studios | 15 | | | |
| | | 2.3.3 The Space Architecture Approach | 16 | | | |
| | 2.4 | Educational Examples | 18 | | | |
| | | 2.4.1 Master of Science in Space Architecture Program | | | | |
| | | (SICSA, University of Houston) | 18 | | | |
| | | 2.4.1.1 NASA Grants and Cooperation with Industry | 20 | | | |
| | | 2.4.2 Destination Moon Design Studio (TU Vienna, | | | | |
| | | | 22 | | | |
| | | 2.4.2.1 Evaluation Criteria for Student Projects | 23 | | | |
| | | 2.4.3 MASH—Deployable Emergency Shelter Study | | | | |
| | | (TU Vienna, Vienna University of Technology) | 26 | | | |
| | | 2.4.3.1 Prototyping and Field Simulation | 28 | | | |
| | 2.5 | Guest Statement: The Role of the Space Architect-Part 1 | | | | |
| | | (| 31 | | | |
| | | 2.5.1 Architectural Versus Engineering Approach | 31 | | | |

Contents

| | | 2.5.2 | Waterfall | 32 |
|---|------|--------|--|----|
| | | 2.5.3 | Heuristics | 34 |
| | 2.6 | Guest | Statement: Space Architecture Education—Site, Program, | |
| | | and M | leaning (Brent Sherwood) | 34 |
| | | 2.6.1 | Site | 36 |
| | | 2.6.2 | Program | 40 |
| | | 2.6.3 | Explore | 41 |
| | | 2.6.4 | Exploit | 43 |
| | | 2.6.5 | Experience | 45 |
| | | 2.6.6 | Settle | 46 |
| | | 2.6.7 | Architecting Our Path | 48 |
| | Refe | rences | | 51 |
| 3 | Con | nreher | sive Planning | 53 |
| 5 | 3.1 | | uction and Chapter Structure. | 53 |
| | 3.2 | | o Plan a Human Space Mission and Where to Start | 55 |
| | 5.2 | 3.2.1 | Mission Goals and Objectives. | 55 |
| | | 3.2.2 | Discussion and Tasks. | 57 |
| | 3.3 | | of Space Missions and Their Goals. | 57 |
| | 5.5 | 3.3.1 | Performed Missions: Orbital (Manned and Robotic). | 58 |
| | | 3.3.2 | Performed Missions: Flyby (Robotic) | 60 |
| | | 3.3.3 | Performed Missions: Surface Landing | 00 |
| | | 5.5.5 | (Manned and Robotic) | 60 |
| | | 3.3.4 | Performed Missions: Sample Return | 00 |
| | | 5.5.1 | (Manned and Robotic) | 61 |
| | | 3.3.5 | Future Exploration Missions | 63 |
| | | 5.5.5 | 3.3.5.1 Precursor Robotic Missions | 64 |
| | | | 3.3.5.2 Following Manned Missions | 64 |
| | | 3.3.6 | Discussion and Tasks. | 65 |
| | 3.4 | | Goals to Requirements to Constraints | 65 |
| | | 3.4.1 | Human Spaceflight Requirements | 65 |
| | | 3.4.2 | Technology Readiness and Habitation | |
| | | | Readiness Levels | 66 |
| | | 3.4.3 | Discussion and Tasks. | 69 |
| | 3.5 | Guest | Statement: Mockups 101: Technology Readiness Levels | |
| | | | ockups and Simulators (Marc M. Cohen) | 70 |
| | | 3.5.1 | TRL-1 Basic Principles Observed and Reported | 72 |
| | | 3.5.2 | TRL-2 Concept or Application Formulation | 74 |
| | | 3.5.3 | TRL-3 Proof of Concept | 76 |
| | | 3.5.4 | TRL-4 Validation in a Laboratory Environment | 76 |
| | | 3.5.5 | TRL-4/5 Transition from Validation in a Laboratory | |
| | | | Environment to a Relevant Environment | 82 |
| | | 3.5.6 | TRL-5 Component/Breadboard Validation in a Relevant | |
| | | | Environment | 84 |
| | | | | |

| | | 3.5.7 | | ystem/Subsystem Model or Prototype | |
|---|------|---------|-----------|--|-----|
| | | | | ration in a Relevant Environment | |
| | | | | or Space) | 88 |
| | 3.6 | | | : The Moon or Mars: Where Might We Settle | |
| | | | | hangavelu) | 92 |
| | Refe | erences | | | 100 |
| 4 | Hah | itation | Systems 1 | Research | 103 |
| | 4.1 | | | Chapter Structure | 103 |
| | | 4.1.1 | | itation System and Habitability | 104 |
| | 4.2 | | | y Principles: An Introduction | 105 |
| | | 4.2.1 | | port and Habitability Challenges | 106 |
| | | | 4.2.1.1 | Atmosphere | 106 |
| | | | | Thermal Environment and Humidity | 106 |
| | | | | Food | 107 |
| | | | 4.2.1.4 | Hygiene and Waste Collection | 107 |
| | | 4.2.2 | | ••• | 108 |
| | | | 4.2.2.1 | Micrometeoroids. | 108 |
| | | | 4.2.2.2 | Microgravity | 108 |
| | | | 4.2.2.3 | Radiation | 109 |
| | | | 4.2.2.4 | Other Specific Environmental Issues and Safety | |
| | | | | Hazards | 109 |
| | | 4.2.3 | Behavior | al Implications | 109 |
| | | | 4.2.3.1 | Personal Space and Privacy | 109 |
| | | | 4.2.3.2 | Social Interaction Versus Isolation | 110 |
| | | 4.2.4 | | on and Tasks | 110 |
| | 4.3 | Huma | | vironment Interaction | 111 |
| | | 4.3.1 | Effects o | f Gravity | 111 |
| | | | 4.3.1.1 | Consequences for Design. | 112 |
| | | 4.3.2 | Anthrop | ometric Design | 112 |
| | | | 4.3.2.1 | | 113 |
| | | | 4.3.2.2 | • | 115 |
| | | | 4.3.2.3 | Example: Sleep Station Restraints | 115 |
| | | 4.3.3 | | vironmental Factors | 115 |
| | | | 4.3.3.1 | Odors and Smell | 115 |
| | | | 4.3.3.2 | Lighting and Illumination | 118 |
| | | | 4.3.3.3 | Colors and Texture | 118 |
| | | 4.3.4 | | on and Tasks | 119 |
| | 4.4 | Hum | | es and Social Interaction Design | 120 |
| | | 4.4.1 | | lity Issues in Spaceflight | 120 |
| | | | 4.4.1.1 | Stressors and Architectural Countermeasures | 120 |
| | | 4.4.2 | • | Sizing and Early Volume Considerations | 122 |
| | | | 4.4.2.1 | Module Types and Spatial Organization | 123 |
| | | 4.4.3 | | al Activity Areas: Zoning and Layout | |
| | | | 4.4.3.1 | Stowage and Object Management | 129 |

Contents

| | | | 4.4.3.2 | Example: Eating and Dining in Space |
|---|------|---------|------------|--|
| | | 4.4.4 | Discussi | on and Tasks 131 |
| | 4.5 | Guest | Statement | t: Artificial Gravity and Implications for Space |
| | | Archite | ecture (Th | neodore W. Hall) |
| | | 4.5.1 | What Is | Gravity? 133 |
| | | 4.5.2 | What Is | Artificial Gravity? |
| | | 4.5.3 | Relative | Motion in Artificial Gravity 138 |
| | | 4.5.4 | Comfort | in Artificial Gravity |
| | | 4.5.5 | Designir | ng for Artificial Gravity 146 |
| | 4.6 | Guest | Statement | :: The Role of the Space Architect—Part 2 Design |
| | | Integra | tion (Bra | nd N. Griffin) |
| | | 4.6.1 | Design I | Integration |
| | | | 4.6.1.1 | Process Description |
| | | | 4.6.1.2 | The Myth of "the" Answer 149 |
| | | | 4.6.1.3 | Where to Begin? 150 |
| | | | 4.6.1.4 | Balance 151 |
| | | | 4.6.1.5 | Spiral Evolution and Iteration |
| | | 4.6.2 | | ing Options 153 |
| | | | 4.6.2.1 | Gap and Overlap Identification 153 |
| | | | 4.6.2.2 | Literature Search 153 |
| | | | 4.6.2.3 | Concept Generation 153 |
| | | | 4.6.2.4 | System Sizing 154 |
| | | 4.6.3 | | Layout |
| | | | 4.6.3.1 | Local Vertical 155 |
| | | | 4.6.3.2 | Zoning and Functional Adjacency 156 |
| | | | 4.6.3.3 | Utility Distribution |
| | | | 4.6.3.4 | Subsystem Schematics and Component |
| | | | | Packaging 157 |
| | | 4.6.4 | | g Options 158 |
| | | | 4.6.4.1 | Constraints and Preserving Options |
| | | | 4.6.4.2 | Optimization |
| | | | 4.6.4.3 | Compromise 159 |
| | D C | | 4.6.4.4 | Synergy |
| | Refe | erences | | |
| 5 | Hab | itation | and Desi | gn Concepts 165 |
| | 5.1 | | | d Chapter Structure 165 |
| | 5.2 | Siting | and Tran | sportation |
| | | 5.2.1 | Environ | ments and Characteristics 166 |
| | | 5.2.2 | In Situ I | Resources 169 |
| | | 5.2.3 | Site Sele | ection and Its Implications |
| | | | for Habi | tation Design |
| | | | 5.2.3.1 | Example: Landing and Construction Sites |
| | | | | on Mars 171 |
| | | | 5.2.3.2 | Example: Curiosity Rover Mars Mission 171 |

| | | 5.2.3.3 Example: Apollo Mission | 174 | | | |
|-----|-----------------------------|--|-----|--|--|--|
| | 5.2.4 | Discussion and Tasks | 176 | | | |
| 5.3 | Construction and Structures | | | | | |
| | 5.3.1 | Space Habitat Structural Systems | 177 | | | |
| | 5.3.2 | Typical Pre-fabricated Module | 178 | | | |
| | 5.3.3 | Inflatable/Expandable Modules | 179 | | | |
| | | 5.3.3.1 Example: TransHab and Bigelow Aerospace | 182 | | | |
| | 5.3.4 | Structural Openings | 183 | | | |
| | | 5.3.4.1 Windows | 184 | | | |
| | | 5.3.4.2 Example: The Cupola Observation Module | 186 | | | |
| | 5.3.5 | Radiation Shielding | 186 | | | |
| | 5.3.6 | Micrometeoroids and Debris | 190 | | | |
| | 5.3.7 | Discussion and Tasks | 191 | | | |
| 5.4 | Habita | ts and Settlement | 191 | | | |
| | 5.4.1 | Habitation Concepts. | 192 | | | |
| | | 5.4.1.1 A Comparison Between Orbital, Planetary, | | | | |
| | | and Mobile Habitats | 193 | | | |
| | 5.4.2 | Orbital Habitats. | 193 | | | |
| | | 5.4.2.1 Example: The International Space Station | 196 | | | |
| | | 5.4.2.2 Example: The Chinese Space Station | 196 | | | |
| | 5.4.3 | Planetary Habitats | 196 | | | |
| | | 5.4.3.1 Example: Lunar Module Apollo | 197 | | | |
| | | 5.4.3.2 Example: 3D Printed Habitat | 197 | | | |
| | 5.4.4 | Surface Vehicles and Mobile Habitats | 197 | | | |
| | | 5.4.4.1 Example: The Lunar Roving Vehicle | 199 | | | |
| | | 5.4.4.2 Example: The Lunar Electric Rover (LER) | 199 | | | |
| | | 5.4.4.3 Example: The Athlete Vehicle Concept | 200 | | | |
| | 5.4.5 | The Space Suit | 202 | | | |
| | 5.4.6 | Airlocks and Extra-Vehicular Activities | 203 | | | |
| | 5.4.7 | Settlement Strategies | 206 | | | |
| | | 5.4.7.1 Example: Triangular and Cruciform Layout | 208 | | | |
| | | 5.4.7.2 Additional Required Infrastructure | 210 | | | |
| | 5.4.8 | Discussion and Tasks. | 211 | | | |
| 5.5 | | at Environmental Systems | 211 | | | |
| | 5.5.1 | Environmental Control and Life Support System | | | | |
| | 5.5.2 | Sustainability Principals and Waste Management. | | | | |
| | | 5.5.2.1 Example: Life Support System on the ISS | 212 | | | |
| | | 5.5.2.2 Example: Water Walls Life Support | 014 | | | |
| | | Architecture | 214 | | | |
| | 5.5.3 | Greenhouses | 216 | | | |
| | | 5.5.3.1 Example: Greenhouses Used on Salyut | 017 | | | |
| | | and Mir | 217 | | | |
| | <i></i> | 5.5.3.2 Example: The LADA System | 218 | | | |
| | 5.5.4 | Power Systems and Constraints | 218 | | | |

| | 5.6 | | | s of Building Systems and Requirements | |
|---|------|---------|--|--|---------|
| | | 5.6.1 | | on and Tasks. | 220 |
| | 5.7 | | Environmental Control and Life Support | | |
| | | | | ow Earth Orbit to Planetary Exploration | |
| | | • | | e) | |
| | | 5.7.1 | | national Space Station Experience. | 223 |
| | | 5.7.2 | | lenges of Life Support for Planetary | |
| | | | - | on | 227 |
| | 5.8 | | | : The TransHab Design | |
| | | and De | | nt—Part 1 (Kriss J. Kennedy) | 230 |
| | | 5.8.1 | Backgrou | ınd | 230 |
| | | 5.8.2 | Explorati | on Habitats | 230 |
| | | 5.8.3 | TransHat | Architecture | 234 |
| | | | 5.8.3.1 | Level One | 240 |
| | | | 5.8.3.2 | Level Two | 242 |
| | | | 5.8.3.3 | Level Three | 245 |
| | | | 5.8.3.4 | Level Four. | 246 |
| | | 5.8.4 | | / | 246 |
| | 5.9 | Guest | • | : Engineering and Construction of Lunar Bases | |
| | | | | a and Leonhard Bernold) | 249 |
| | | 5.9.1 | • | ion | 249 |
| | | 5.9.2 | | ironment | |
| | | 5.9.3 | | ng Construction Technologies for the | |
| | | 5.7.5 | | orld" | 254 |
| | | | | Digging and Moving Regolith to Build and | 20. |
| | | | | Mine. | 254 |
| | | | 5.9.3.2 | Glass Fiber Reinforced Sulfur Concrete | 234 |
| | | | 5.9.5.2 | to Build Protective Arches | 256 |
| | | | 5.9.3.3 | Advancing the Roman Arch for Lunar | 250 |
| | | | 5.9.5.5 | | 256 |
| | | 501 | Constant | Applications. | |
| | D.f. | 5.9.4 | | ng Thoughts | |
| | Refe | erences | | | 238 |
| 6 | Vali | dation, | Demonst | ration and Testing | 261 |
| | 6.1 | Introd | uction and | Chapter Structure | 261 |
| | 6.2 | Missic | n Assessn | nent Strategies | 263 |
| | | 6.2.1 | | : Comparison of Habitation Schemes | |
| | | 6.2.2 | - | on and Tasks | |
| | 6.3 | | | Testing Methods | 265 |
| | | 6.3.1 | | an Incompatible Habitat Design | 268 |
| | | 6.3.2 | | Habitat and Environments | 268 |
| | | 6.3.3 | | ce from Past Space Habitats | 275 |
| | | 2.2.0 | 6.3.3.1 | Example: Moving in Microgravity | |
| | | | 6.3.3.2 | Example: Technical Greenhouses | |
| | | | J.J.J.J. | The second contraction of the second contrac | <i></i> |

| 6.3.4 | Aims of V | Verification Methods 2 | 76 |
|------------|---------------|--|-----|
| | 6.3.4.1 H | Example: Reduced Scale Models and Full-Scale | |
| | Ι | Low Fidelity Mock-up Evaluations | 79 |
| | 6.3.4.2 H | Example: Using ISS for Technology | |
| | a | nd Habitability Testing 2 | :79 |
| 6.4 Gue | st Statement: | The TransHab Project—Testing | |
| and | Evaluation— | Part 2 (Kriss J. Kennedy) | 280 |
| 6.4.1 | Backgrou | nd | 280 |
| 6.4.2 | | 's Technologies | |
| | | ation of Inflatable Shell | |
| 6.4.4 | Demonstra | ation Goal One—Protect the Shell | |
| | from MM | /OD | 83 |
| 6.4.5 | Demonstr | ation Goal Two-Full Scale Diameter | |
| | Hydrostati | ic Test | 286 |
| 6.4.6 | | ation Goal Three—Shell Deployment | |
| | | um | 287 |
| 6.4.7 | Lessons L | earned | 292 |
| 6.4.8 | | | |
| Reference | | | |
| | | | |
| Appendix | | | 299 |
| References | | | 317 |
| | | | |
| Index | | | 319 |