

# Contents

<b>1 Introduction</b>	1
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 Interdisciplinarity (Chris Welch)	6
References	8
<b>2 Approaches and Methods</b>	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, Vienna University of Technology)	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 (Brand N. Griffin)	31
2.5.1 Architectural Versus Engineering Approach	31

2.5.2	Waterfall . . . . .	32
2.5.3	Heuristics . . . . .	34
2.6	Guest Statement: Space Architecture Education—Site, Program, and Meaning (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
	References . . . . .	51
<b>3</b>	<b>Comprehensive Planning . . . . .</b>	<b>53</b>
3.1	Introduction and Chapter Structure . . . . .	53
3.2	How to Plan a Human Space Mission and Where to Start . . . . .	54
3.2.1	Mission Goals and Objectives . . . . .	55
3.2.2	Discussion and Tasks . . . . .	57
3.3	Types of Space Missions and Their Goals . . . . .	57
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 (Manned and Robotic) . . . . .	60
3.3.4	Performed Missions: Sample Return (Manned and Robotic) . . . . .	61
3.3.5	Future Exploration Missions . . . . .	63
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	From 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 for Mockups 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 TRL-6 System/Subsystem Model or Prototype Demonstration in a Relevant Environment (Ground or Space). . . . . 88
- 3.6 Guest Statement: The Moon or Mars: Where Might We Settle First? (Madhu Thangavelu). . . . . 92
- References . . . . . 100
- 4 Habitation Systems Research . . . . . 103**
  - 4.1 Introduction and Chapter Structure. . . . . 103
    - 4.1.1 The Habitation System and Habitability . . . . . 104
  - 4.2 Basic Habitability Principles: An Introduction . . . . . 105
    - 4.2.1 Life Support and Habitability Challenges . . . . . 106
      - 4.2.1.1 Atmosphere . . . . . 106
      - 4.2.1.2 Thermal Environment and Humidity . . . . . 106
      - 4.2.1.3 Food . . . . . 107
      - 4.2.1.4 Hygiene and Waste Collection . . . . . 107
    - 4.2.2 Hazards . . . . . 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 Behavioral Implications . . . . . 109
      - 4.2.3.1 Personal Space and Privacy . . . . . 109
      - 4.2.3.2 Social Interaction Versus Isolation . . . . . 110
    - 4.2.4 Discussion and Tasks. . . . . 110
  - 4.3 Humans and Environment Interaction. . . . . 111
    - 4.3.1 Effects of Gravity . . . . . 111
      - 4.3.1.1 Consequences for Design. . . . . 112
    - 4.3.2 Anthropometric Design . . . . . 112
      - 4.3.2.1 Orientation . . . . . 113
      - 4.3.2.2 Restraints and Mobility Aids . . . . . 115
      - 4.3.2.3 Example: Sleep Station Restraints. . . . . 115
    - 4.3.3 Other Environmental 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 Discussion and Tasks. . . . . 119
  - 4.4 Human Activities and Social Interaction Design . . . . . 120
    - 4.4.1 Habitability Issues in Spaceflight. . . . . 120
      - 4.4.1.1 Stressors and Architectural Countermeasures . . . . . 120
    - 4.4.2 System Sizing and Early Volume Considerations. . . . . 122
      - 4.4.2.1 Module Types and Spatial Organization . . . . . 123
    - 4.4.3 Functional Activity Areas: Zoning and Layout . . . . . 126
      - 4.4.3.1 Stowage and Object Management. . . . . 129

- 4.4.3.2 Example: Eating and Dining in Space . . . . . 131
- 4.4.4 Discussion and Tasks. . . . . 131
- 4.5 Guest Statement: Artificial Gravity and Implications for Space Architecture (Theodore W. Hall) . . . . . 133
  - 4.5.1 What Is Gravity? . . . . . 133
  - 4.5.2 What Is Artificial Gravity? . . . . . 135
  - 4.5.3 Relative Motion in Artificial Gravity . . . . . 138
  - 4.5.4 Comfort in Artificial Gravity. . . . . 144
  - 4.5.5 Designing for Artificial Gravity. . . . . 146
- 4.6 Guest Statement: The Role of the Space Architect—Part 2 Design Integration (Brand N. Griffin) . . . . . 149
  - 4.6.1 Design Integration . . . . . 149
    - 4.6.1.1 Process Description. . . . . 149
    - 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. . . . . 152
  - 4.6.2 Developing 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 Internal Layout . . . . . 155
    - 4.6.3.1 Local Vertical . . . . . 155
    - 4.6.3.2 Zoning and Functional Adjacency. . . . . 156
    - 4.6.3.3 Utility Distribution . . . . . 157
    - 4.6.3.4 Subsystem Schematics and Component Packaging . . . . . 157
  - 4.6.4 Selecting Options . . . . . 158
    - 4.6.4.1 Constraints and Preserving Options. . . . . 158
    - 4.6.4.2 Optimization . . . . . 159
    - 4.6.4.3 Compromise . . . . . 159
    - 4.6.4.4 Synergy. . . . . 159
- References . . . . . 160
- 5 Habitation and Design Concepts . . . . . 165**
  - 5.1 Introduction and Chapter Structure. . . . . 165
  - 5.2 Siting and Transportation . . . . . 166
    - 5.2.1 Environments and Characteristics . . . . . 166
    - 5.2.2 In Situ Resources . . . . . 169
    - 5.2.3 Site Selection and Its Implications for Habitation Design. . . . . 170
      - 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. . . . . 176
  - 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 Habitats 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 Habitat Environmental Systems . . . . . 211
  - 5.5.1 Environmental Control and Life Support System . . . . . 211
  - 5.5.2 Sustainability Principals and Waste Management. . . . . 212
    - 5.5.2.1 Example: Life Support System on the ISS . . . . . 212
    - 5.5.2.2 Example: Water Walls Life Support Architecture . . . . . 214
  - 5.5.3 Greenhouses . . . . . 216
    - 5.5.3.1 Example: Greenhouses Used on Salyut and Mir. . . . . 217
    - 5.5.3.2 Example: The LADA System. . . . . 218
  - 5.5.4 Power Systems and Constraints. . . . . 218

5.6	Summary: Types of Building Systems and Requirements . . . . .	219
5.6.1	Discussion and Tasks. . . . .	220
5.7	Guest Statement: Environmental Control and Life Support Systems, from Low Earth Orbit to Planetary Exploration (Lobascio Cesare) . . . . .	223
5.7.1	The International Space Station Experience. . . . .	223
5.7.2	The Challenges of Life Support for Planetary Exploration. . . . .	227
5.8	Guest Statement: The TransHab Design and Development—Part 1 (Kriss J. Kennedy) . . . . .	230
5.8.1	Background . . . . .	230
5.8.2	Exploration Habitats . . . . .	230
5.8.3	TransHab 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	Summary . . . . .	246
5.9	Guest Statement: Engineering and Construction of Lunar Bases (Haym Benaroya and Leonhard Bernold) . . . . .	249
5.9.1	Introduction . . . . .	249
5.9.2	The Environment. . . . .	251
5.9.3	Developing Construction Technologies for the “New World” . . . . .	254
5.9.3.1	Digging and Moving Regolith to Build and Mine. . . . .	254
5.9.3.2	Glass Fiber Reinforced Sulfur Concrete to Build Protective Arches. . . . .	256
5.9.3.3	Advancing the Roman Arch for Lunar Applications. . . . .	256
5.9.4	Concluding Thoughts. . . . .	258
	References . . . . .	258
<b>6</b>	<b>Validation, Demonstration and Testing</b> . . . . .	<b>261</b>
6.1	Introduction and Chapter Structure. . . . .	261
6.2	Mission Assessment Strategies . . . . .	263
6.2.1	Example: Comparison of Habitation Schemes . . . . .	264
6.2.2	Discussion and Tasks. . . . .	264
6.3	Verification and Testing Methods . . . . .	265
6.3.1	Risk of an Incompatible Habitat Design . . . . .	268
6.3.2	Analog Habitat and Environments . . . . .	268
6.3.3	Experience from Past Space Habitats . . . . .	275
6.3.3.1	Example: Moving in Microgravity . . . . .	275
6.3.3.2	Example: Technical Greenhouses . . . . .	276

- 6.3.4 Aims of Verification Methods . . . . . 276
  - 6.3.4.1 Example: Reduced Scale Models and Full-Scale Low Fidelity Mock-up Evaluations . . . . . 279
  - 6.3.4.2 Example: Using ISS for Technology and Habitability Testing . . . . . 279
- 6.4 Guest Statement: The TransHab Project—Testing and Evaluation—Part 2 (Kriss J. Kennedy) . . . . . 280
  - 6.4.1 Background . . . . . 280
  - 6.4.2 TransHab’s Technologies . . . . . 281
  - 6.4.3 Demonstration of Inflatable Shell. . . . . 282
  - 6.4.4 Demonstration Goal One—Protect the Shell from MM/OD . . . . . 283
  - 6.4.5 Demonstration Goal Two—Full Scale Diameter Hydrostatic Test . . . . . 286
  - 6.4.6 Demonstration Goal Three—Shell Deployment in a Vacuum. . . . . 287
  - 6.4.7 Lessons Learned . . . . . 292
  - 6.4.8 Summary . . . . . 295
- References . . . . . 297
- Appendix . . . . . 299**
- References . . . . . 317**
- Index . . . . . 319**



<http://www.springer.com/978-3-319-19278-9>

Space Architecture Education for Engineers and  
Architects

Designing and Planning Beyond Earth

Häuplik-Meusburger, S.; Bannova, O.

2016, XV, 320 p. 179 illus., 139 illus. in color.,

Hardcover

ISBN: 978-3-319-19278-9