

# Chapter X: The History and Future of Housing - Evolution, Resilience, and the Path to Solar Confinement

## History of Housing

### Prehistory to Antiquity: From Caves to Monumental Stone

The history of housing traces an arc from primal necessity-seeking shelter from the elements and predators-to the built expressions of culture and technological mastery that shape our cities today. Early humans relied on **natural shelters**, notably caves, and later constructed rudimentary dwellings of **wood, grass, and earth**. The selection of building materials and methods was almost entirely dictated by **local availability** and **climatic adaptation**: for example, earth and straw in arid zones, and wattle-and-daub or thatch in temperate climes<sup>[2][4][5]</sup>. As societies formed, permanent housing emerged-mud-brick houses in Çatalhöyük (circa 6,000 BC), circular wattle-and-daub huts in Bronze Age England, and two-story clay-brick homes in Mesopotamia by 2,000 BC<sup>[2]</sup>. Ancient Egyptians advanced the use of **sun-dried adobe bricks**, favoring quadrangular plans, while Greek and Roman architecture ushered in **stone and marble construction**, introducing features such as atriums, courtyards, and the hypocaust (early underfloor heating) for comfort<sup>[6]</sup>.

**Table 1: Traditional Housing Materials by Region and Era**

Era/Region	Primary Materials	Key Features
Prehistoric (Global)	Caves, wood, stone, animal hides	Natural formations, immediate shelter
Neolithic (Çatalhöyük)	Mud-brick, wattle, timber	Windowless, clustered homes
Egypt & Mesopotamia	Adobe brick, timber, stone	Courtyards, flat roofs, orthogonal
Classical Greece/Rome	Limestone, marble, brick	Columned porticos, mosaics, heating
Medieval Europe	Timber frames, wattle and daub	One-room huts to stone castles
Mesoamerica	Stone, adobe, palm thatch	Temples, raised floors
East Asia	Timber, bamboo, clay tiles, paper	Raised, modular, flexible interiors

These dwellings consistently reflected both **locally available resources** and **functional strategies** for climate control: thick adobe walls for heat insulation, raised floors in flood-prone regions, and communal courtyards for ventilation and social cohesion<sup>[4][3]</sup>.

### Medieval to Early Modern: Vernacular Ingenuity and Regional Diversity

Vernacular architecture-developed organically by communities using indigenous materials and techniques-became the norm across continents<sup>[4]</sup>. Timber-framed houses dominated central

Europe; thatched roofs were prevalent in the UK and Japan; stone was favored in the Mediterranean and Andes. **Key features** included:

- **Thick walls** for thermal inertia in hot and cool seasons.
- **Small windows** and sloped roofs in northern regions to reduce heat loss and shed snow.
- **Central hearths**, sometimes without chimneys, for heating and cooking.

The **Middle Ages** saw the emergence of stone castles, manor houses, and urban multi-story dwellings—symbols not just of protection, but also social class. Regional variations reflected both **cultural beliefs** (e.g., courtyard-centric homes in Islamic regions for privacy) and **resource constraints** (e.g., pit houses in cold areas, stilt houses in tropics to avoid floods)<sup>[4]</sup>.

## Industrial Revolution: The Age of Mass Production

The **19th and 20th centuries** brought radical transformation. The industrial revolution introduced **brick, iron, steel, and later reinforced concrete** as standard construction materials, enabling rapid urbanization and the creation of multi-story tenements, row houses, and eventually glass-and-steel skyscrapers<sup>[1]</sup>. **Central heating, plumbing, and electrical systems** began to define modern comfort. However, early industrial housing was often synonymous with overcrowding and poor sanitation, sparking public health reforms and the eventual rise of urban planning<sup>[1]</sup>.

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## Modern Materials and Construction Methods

### Advances in Materials

Housing today is defined by a **palette of materials** evolved for performance, sustainability, and affordability:

- **Reinforced Concrete:** Dominates commercial and high-rise residential construction due to its strength and fire resistance, despite a heavy carbon footprint<sup>[8][9]</sup>.
- **Steel:** Used for framing skyscrapers and modular systems; provides excellent tensile strength and flexibility<sup>[9]</sup>.
- **Engineered Timber:** Products like cross-laminated timber (CLT) and glulam offer a lightweight, strong, renewable alternative for floors, roofs, and even multi-story structures<sup>[8]</sup>.
- **Composites and Polymers:** Used for insulation, windows, and infrastructure components—offering improved thermal and weather resistance at low cost<sup>[8]</sup>.
- **Earthen Materials (Rammed Earth, Cob, Adobe):** Experiencing resurgence for low-cost, low-carbon construction, especially in climate-appropriate regions<sup>[9]</sup>.
- **Hybrid Materials:** Combining the strengths of timber, steel, and concrete for optimized structural and environmental performance<sup>[8]</sup>.

**Table 2: Properties of Leading Modern Building Materials**

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Material	Strength	Insulation	Embodied Energy	Fire Resistance	Sustainability
Steel	High	Poor	High	Excellent	Recyclable
Concrete	High	Fair	High	Excellent	Upcyclable w/ low-carbon blends
Timber (CLT)	Moderate	Good	Low/Medium	Moderate	Renewable
Rammed Earth	Moderate	Very Good	Low	Good	Renewable
Composites	Moderate	Excellent	Low/Medium	Good	Depends on source

The selection of material is driven by **cost, local climate, building codes, and environmental objectives**. The rise of new *sustainable* materials-such as recycled plastic bricks, mycelium composites, and hempcrete-reflects the urgent need to combat the embodied emissions of traditional construction<sup>[9]</sup>.

## Construction Methods

Traditional on-site construction-where structures are built from the ground up, brick by brick or stick by stick-has given way to a spectrum of **modern methods** aimed at speed, precision, and sustainability:

1. **Prefabrication and Modular Construction:** Entire modules are factory-built and assembled on-site, slashing build times and waste. Prefabricated concrete panels, steel frames, and timber cassettes are common in residential and commercial applications<sup>[11][7]</sup>.
2. **3D Printing:** Emergent large-scale additive manufacturing enables the use of local or recycled materials (such as regolith on the Moon, see below), optimizing shapes for strength and minimal material use<sup>[13][14]</sup>.
3. **Hybrid Construction:** Integrates engineered wood, concrete, and steel for tailored performance-leveraging renewability, strength, and durability<sup>[8]</sup>.
4. **Smart Building Integration:** Sensors and the Internet of Things (IoT) provide real-time monitoring of structural, thermal, and environmental conditions, enhancing performance and resilience.

## Sustainability Focus

Modern green buildings emphasize:

- **Energy-efficient design** (passive solar, high-performance insulation)
- **Water recycling systems**
- **Use of non-toxic, low-emission materials**
- **On-site renewable energy (solar/PV)**
- **Material life-cycle thinking (circular economy)**<sup>[9][15]</sup>

This shift is driven by both **economic necessity** (cost savings, speed, local supply chains) and **regulatory/societal pressures** (carbon reduction, resilience to climate hazards).

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## Extraterrestrial Housing Plans

### Environmental Challenges: Moon, Mars, and Space

Building habitats for the Moon, Mars, or free space presents uniquely hostile challenges absent from terrestrial housing:

- **Radiation:** Intense solar and cosmic radiation in space necessitates thick shielding against ionizing particles<sup>[17]</sup>.
- **Extreme Temperatures:** The Moon and Mars see surface temperature swings from -200°C to +120°C, with little atmospheric buffer<sup>[19]</sup>.
- **Meteor/Bolide Impacts:** Lack of atmospheric protection increases the risk of micrometeoroid damage on the Moon and Mars.
- **Low Gravity/Atmospheric Pressure:** Mars (0.38 g) and Moon (0.16 g) require careful structural design for both inhabitant physiology and building integrity.
- **Resource Constraints:** All building materials ideally come from in-situ sources to avoid crippling launch costs.
- **Air, Water, and Life Support:** All must be mechanically and chemically regenerated<sup>[21]</sup>.

### Lunar Habitats

#### Concepts and Proposals

NASA and allied agencies have advanced numerous lunar habitat concepts:

- **Common Habitat:** Multi-mission pressurized modules designed for four to eight crew, with both horizontal and vertical configurations, relying on SLS Core Stage tanks as structure.
- **Regolith-Based Construction:** Use of in-situ lunar regolith, 3D-printed into thick-walled domes or layered shells for radiation shielding and structural support<sup>[13]</sup>.
- **Inflatable Modules:** Deployable soft modules shielded by regolith or engineered tiles<sup>[14]</sup>.
- **Buried/Atrium Designs:** Locating habitats in natural lunar pits or with regolith embankments for maximum protection<sup>[18]</sup>.

Critical features include:

- Airlocks and docking ports for surface mobility and resupply.
- Modular expansion via new units.
- Integration with life-support, power, and communications subsystems.

## Martian Habitats

Martian habitats must also contend with:

- **Reduced gravity** and **thinner atmosphere**, but higher risk of dust storms.
- Options include using **compressed Martian regolith** bound with polymers or ice, 3D-printed shells, or pressurized inflatables shielded by excavated overburden<sup>[14]</sup>.
- **Greenhouses** and bioreactors for partial food/water/oxygen closure, with robust ECLSS (Environmental Control and Life Support Systems)<sup>[21]</sup>.

## Space Habitats and Stations

O'Neill Cylinders and Stanford Tori

- **O'Neill Cylinder:** A massive rotating cylinder, several kilometers long, with inner surface habitats, protected by meters-thick shielding drawn from lunar or asteroidal regolith<sup>[16]</sup>.
- **Stanford Torus:** A rotating ring habitat (donut-shaped), with spokes and a central agricultural hub. Both create "artificial gravity" through rotation<sup>[22]</sup>.
- **Materials:** Radiation shields require up to 2 meters of regolith; structural shells built from steel, aluminum, or advanced composites; life-support and agricultural systems are fully closed-loop.

ISS and Real-World Precedents

The **International Space Station (ISS)** provides the most advanced, real, operational model of modular habitat construction, ECLSS operation, and microgravity living<sup>[21]</sup>.

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## Engineering Equations and Tool Improvements

### Structural Engineering Fundamentals

Design of both terrestrial and extraterrestrial habitats rely on rigorous calculation of **loads, forces, and safety margins**, adapted for unique local conditions (gravity, wind, seismicity, etc.) or, in space, vacuum and radiation environments.

#### Key Equations: Structural Load Analysis

- **Dead Load (Self-Weight):**  
(  $w_D = \gamma \cdot h$  )  
where ( $\gamma$ ) is material unit weight, ( $h$ ) is thickness<sup>[23]</sup>.
- **Live Loads, Wind, and Snow:**
  - Values depend on occupancy, exposure, and codes (EN 1991, ASCE 7, etc.).
- **Bending Moment (for simply supported beam):**  
(  $M = \frac{w \cdot l^2}{8}$  ) (UDL across span)<sup>[23]</sup>.
- **Stress, Strain, and Stability:**

- $(\sigma = \frac{F}{A})$
- Buckling: Euler's equation
- **Seismic, Wind, and Soil Loads:**
  - Calculated by code, using dynamic analysis where required.
- **Material Properties:**
  - Young's modulus ( $E$ ), density ( $\rho$ ), yield strength, ultimate strength.

Design codes increasingly demand **performance-based, not just prescriptive, approaches** especially for hybrid and modular construction.

## Thermal Regulation in Extreme Environments

For both Earth and space, **thermal analysis** determines wall/floor/roof thickness for insulation and structural integrity.

### Key Equations:

- **Heat Conduction (Fourier's Law):**  
 $(q_x = -k \frac{dT}{dx})$
- **Heat Rate:**  
 $(Q = k \cdot A \cdot \frac{(T_{in} - T_{out})}{L})$
- **Thermal Circuit Models:** Used to model multilayer walls, aggregating resistances in series and parallel<sup>[26]</sup>.

In extraterrestrial environments, thermal analysis must include:

- **Radiative equilibrium:**  
 $(q_{net} = \epsilon \sigma (T_{s}^4 - T_{e}^4))$
- **Active thermal control:** For electronics and life support systems, including **radiators**, **heaters**, and **multilayer insulation (MLI)** use (notably gold, aluminized Mylar, etc.)<sup>[19]</sup>.

**Simulation and Modeling Tools:** Modern projects use **Finite Element Analysis (FEA)** tools- Abaqus, Ansys, Femap, COMSOL, Simscale, HyperWorks, etc.-to dynamically optimize designs under multiple loading and environmental scenarios<sup>[28]</sup>. Recent improvements:

- Automation and **AI-aided optimization**.
- Integration of structural, thermal, and fluid (life-support) simulations.
- Digital twins and real-time sensor feedback.

## Radiation Shielding

### Shielding Design Principles:

- **Gamma/X-ray Shielding Equation:**  
 $(I = I_0 e^{-\mu x})$   
 where ( $I$ ) is intensity after thickness ( $x$ ), ( $\mu$ ) is linear attenuation coefficient<sup>[29]</sup>.

- **Half-Value Layer:**  
(  $HVL = \frac{0.693}{\mu}$  )
  - Space and nuclear engineering typically use **layered shielding**: regolith for high-energy particles, metal/HDPE for neutrons, water and plastic for charged particles.
  - **Dose reduction for humans:** On the Moon/Mars, at least 1-2 meters of regolith is required for adequate protection<sup>[16]</sup>.
- Tool Improvements:**
- Recent advances include software for multi-energy particle tracking; AI can rapidly optimize thickness/compositions for given mass budgets and requirements<sup>[27]</sup>.

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## Safety and Affordability Considerations

### Affordability: Strategies and Innovations

Affordable housing-both on Earth and potentially off-planet-demands creative solutions to material and construction constraints, as well as partnership with policy and finance mechanisms:

- **Low-Cost and Local Materials:** Prioritizing earth, bamboo, adobe, and recycled materials reduces both upfront and lifecycle costs<sup>[30]</sup>.
- **Prefabricated and Modular Construction:** Off-site manufacturing slashes labor costs and timelines, limiting weather delays and waste<sup>[11]</sup>.
- **Financial Initiatives:** Government programs, like the EPA's "Solar For All" in the US, leverage public and private investment to deliver solar and energy upgrades to affordable housing, reducing both construction and operating costs for residents.
- **Flexible Design:** Allowing for smaller, adaptable units-such as microhomes and tiny apartments-increases density and housing access, a critical factor in urban cores.

Table 3: Key Affordability Strategies

Strategy	Description & Benefits
Local material use	Cuts costs, CO2, empowers communities
Modular/prefab assembly	Accelerates build, reduces waste
Solar integration	Cuts utility costs, adds resilience
Resilient design	Reduces insurance/repair costs post-disaster
Policy/finance support	Grants, loans, or incentives for green upgrades

## Protection from Fire, Flood, Solar Flares, and Extremes

### Fire Resistance

- **Material Selection:** Use of non-combustible external cladding (concrete, stone, metal) and fire-retardant treatments for wood and insulation.
- **Resilient Assemblies:** Intumescent barriers and compartmentalization prevent fire spread.
- **Adherence to Fire Codes:** Compliance with standards like ICC 500 mandates 2-hour fire separation for shelters<sup>[31]</sup>.

### Flood Resilience

- **Elevated Structures:** Place buildings above historical flood levels using raised platforms, stilts, or floating designs<sup>[15]</sup>.
- **Waterproofing:** Sealing basements, improved drainage systems, water-resistant barriers.
- **Material Use:** Employing concrete, stone, and treated timber for moisture durability.

### Solar Flares/Radiation

- In space, solar particle events can deliver lethal radiation doses within hours. **Regolith/soil shielding** and **emergency safe rooms** are essential; rapid shelter-in-place drills are already routine for high-energy cosmic events on ISS and are planned for lunar/Martian operations<sup>[17]</sup>.
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### Extreme Temperature: Earth and Beyond

- **Insulation & Ventilation:** On Earth, high-performance insulation, double-glazed windows, and ventilation strategies mitigate extremes<sup>[15]</sup>.
- **Thermal Mass:** Thick walls (adobe, cob, rammed earth) buffer interior temperatures.
- **Active Temperature Control:** On Moon and Mars, habitats require heaters, radiators, cooled electronics, and active insulation layers, often controlled by onboard AI to maintain operational conditions<sup>[19]</sup>.

### Building Codes and Regulation

- Climate-resilient homes are now driven by revised codes: **ASCE 7 (wind and flood)**, **ICC 500 (storm/fire shelters)**, **ASHRAE (energy/thermal standards)**-requiring, for example, >2-hour fire separations and flood-damage-resistant materials, or design to survive "500-year" events<sup>[31][15]</sup>.



# Life Support and Water Recycling Systems

## Earth and ISS Precedents

### ISS ECLSS (Environmental Control and Life Support System)

- **Closed-loop water system:** Recycles >90% of all water (including humidity, sweat, urine), using filtration, reverse osmosis, and advanced oxidation<sup>[21]</sup>.
- **Air Management:** Removes CO<sub>2</sub> and produces oxygen via electrolysis.
- **Waste Recycling:** Converts organic waste and CO<sub>2</sub> into water and methane; experimental systems seek full closure for food and O<sub>2</sub>.

These systems have inspired terrestrial use in disaster relief and off-grid housing, and are models for designs for lunar and Martian outposts<sup>[21]</sup>.

### Key Equations in Water Recovery:

- **Oxygen from Electrolysis:**  
 $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$  (electrolysis using solar-generated power)
- **Water recovery from air:**  
Condensation via temperature differential and filtration.

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## Future Tools with Integrated Triadic Framework Technology (TFT)

### The Concept of Triadic Framework Technology

Looking forward, the integration of advanced AI and hardware-especially in the form of the **Triadic Framework Technology (TFT)**-represents a paradigm shift in architectural design, safety, and operation.

TFT draws from the **triadic decision theory** in artificial intelligence research, which advocates for processing, structuring, and explaining systems in sets of three (triads), aligning well with human reasoning and layered system logic<sup>[35]</sup>. In this context:

- **Top Level:** Social-Machine-Human triad-ensuring any housing or tool addresses societal needs, machine (technical) constraints, and human usability/trust.
- **Middle Level:** Input-Process-Output-organizing any engineering workflow from data collection, through analysis, to actionable outcomes.
- **Bottom Level:** Volume-Veracity-Validity (input), Theory-Algorithm-Implementation (process), and Symbol-Meaning-Value (output)-offering structured, explainable, robust diagnosis, simulation, and optimization capabilities<sup>[34]</sup>.

**Technical Implication:** TFT-based AI can help automatically:

- Analyze design trade-offs (e.g., cost, safety, speed)
- Optimize construction logistics (just-in-time delivery of prefab modules, adaptive 3D printing schedules)

- Simulate hazard conditions and deploy automated countermeasures
- Validate code and regulatory compliance with explainable outputs, closing the “black box” gap pervasive in today’s AI code-checkers.

Table 4: TFT Application in Housing AI Agents

Triad Level	Functionality/Service Provided	AI-Enabled Tools
Social-Machine-Human	Policy compliance, user interface, behavioral modeling	Human-in-the-loop AI, regulatory assistants
Input-Process-Output	Dynamic design analysis, risk simulation	3D/4D BIM-integrated models w/ AI diagnosis
Volume-Veracity-Validity	Sensor screening, model confidence	Smart site sensor validation, model/data audit trails
Theory-Algorithm-Implementation	Optimization, scheduling, reasoning	Digital twin and generative design (FEA, CFD, code)
Symbol-Meaning-Value	Explanation, report generation	User-facing dashboards, explainable code/check results

## Hardware Integration: 3MB TFT “Agent” Buffer in AI SoCs

The next generation of chips is rapidly moving to **integrate dedicated AI coprocessors** (NPUs, TPUs, AI-optimized GPUs)-each offering high-performance, low-power acceleration for AI workloads<sup>[37]</sup>. The vision for housing and infrastructure is that **each processor** comes with a dedicated **3MB buffer** mapped exclusively for a resident TFT “agent”:

- **Real-Time Safety Monitoring:** Constant local execution of fire, heat, seismic, and intrusion-detection AI models, enabling split-second response (ex: shutting off gas, activating sprinklers, sealing airlocks, or summoning emergency services)
- **Autonomous Thermal and Power Control:** Automated modulation of blinds, vents, and HVAC, and management of batteries and solar, maximizing comfort and efficiency
- **User Interaction and Explainability:** Providing explainable alerts, diagnostics, and maintenance recommendations to inhabitants-aligned with TFT’s trilevel structure for transparency and trust
- **Edge-Cloud Cooperation:** Local TFT agents collaborate with cloud analytics for big-picture optimization, while guaranteeing privacy and offline operation during emergencies.

Such agents are already being prototyped on the latest generation of LLM-optimized NPUs (Qualcomm, AMD, Apple, Intel)-with hybrid CPU/GPU/NPU execution for efficiency and responsiveness<sup>[37]</sup>. AI toolchains today allow simultaneous, coordinated inference for safety, energy, occupancy, and risk systems within a unified, triad-governed operational envelope.

## Impact: Towards Safe, Affordable, Climate-Resilient, and Solar-Hardened Dwellings

Adopting a **TFT-powered hardware + AI logic layer** in housing has transformative implications:

- **Cost and Safety:** Rapid FEA/CFD/thermal simulations lower engineering and regulatory costs, and reduce overdesign-making resilient, disaster-ready homes more affordable<sup>[28]</sup>.
  - **Fire/Flood/Disaster Response:** AI agents enable real-time, local event detection, enhanced by explainable backends for user and regulator trust.
  - **Extraterrestrial Readiness:** TFT-powered agents will be fundamental for closed-loop life support, autonomic MSRA (maintenance/safety/recovery/alerting) in harsh environments, and collaborative operations in remote or autonomous colonies.
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## Conclusion: Housing's Past and the Arrival of Solar Confinement Tools

From prehistoric caves to the birth of the “smart home” and the vision of lunar and Martian cities, the core human drive for safety, comfort, and adaptability has defined the evolution of housing. Today's convergence of **advanced materials, modular/prefab methods, simulation and AI tools, and the emerging Triadic Framework Technology** paves the way for a new generation of **solar-confined, resilient, and affordable dwellings** capable of thriving in the face of Earth's hazards-or the lethal vacuum and radiation of space.

### Key Takeaways:

- Housing has always adapted to local material, climate, and societal needs; this principle should guide both Earthly and extraterrestrial designs.
- The push for **affordability and resilience** in the face of climate change is driving the rebirth of vernacular materials, modular/prefab assemblies, and green/solar integration.
- For lunar/Martian/space settlements, leveraging in-situ resources, 3D printing, and robust closed-loop life support is both an engineering and logistical imperative.
- Future tools, powered by **Triadic Framework Technology** and local AI agents running on-chip, promise fully integrated safety, design, and sustainability evaluations-opening a new era of truly **safe, responsive, and adaptive habitats**, both on Earth and beyond.

With these tools, the next generation of dwellings-solar confined, climate-resilient, explainable, and affordable-will not only keep us safe from the known risks of fire, flood, solar flare, and temperature extremes but will also be able to adapt to the unknowns, learning, evolving, and protecting us wherever we may build.

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