A comprehensive blueprint for the settlement of Mars

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Artist's rendition of future astronauts and human settlements on Mars. Credit: NASA

Throughout the 20th century, multiple proposals have been made for the crewed exploration of Mars. These include the famed "Mars Project" by Werner von Braun, the "Mars Direct" mission architecture by Robert Zubrin and David Baker, NASA's Mars Design Reference Mission studies, and SpaceX's Mars & Beyond plan. By 2033, two space agencies

(NASA and the CNSA) plan to commence sending crews and payloads to the Red Planet. These and other space agencies envision building bases there that could eventually lead to permanent settlements and the first "Martians."

This presents several major challenges, not the least of which have to do with exposure to radiation, extreme temperatures, dust storms, low atmospheric pressure, and lower gravity. However, with the right strategies and technology, these challenges could be turned into opportunities for growth and innovation. In a recent paper, a Leiden University researcher offers a roadmap for a Martian settlement that leverages recent advancements in technology and offers solutions that emphasize sustainability, efficiency, and the well-being of the settlers.

The proposal comes from Florian Neukart, an Assistant Professor with the Leiden Institute of Advanced Computer Science (LIACS) at Leiden University and a Board Member of the Swiss quantum technology developer Terra Quantum AG. The preprint of his paper, "Towards Sustainable Horizons: A Comprehensive Blueprint for Mars Colonization," was recently posted to the *arXiv* preprint server and is currently being reviewed for publication by Elsevier.

Evolution of a plan

Beyond exploration, many proposals have been made since the dawn of the Space Age to transform Mars into a second home for humanity. Some of these proposals have involved geological engineering (aka "terraforming") to make Mars habitable for terrestrial organisms. What's more, the history of proposals has reflected the history of exploration and our growing understanding of the Red Planet. Other factors include technological advancement, scientific discoveries, and socio-economic and political developments. As Nuekart explained via email, the earliest ideas were largely embodied in science fiction.

Examples include H.G. Wells' War of the Worlds, Edgar Rice Burroughs' Barsoon Series, Ray Bradbury's The Martian Chronicles, Arthur C. Clarke's The Sands of Mars, and Robert A. Heinlein's Red Planet and Stranger in a Strange Land. These books depicted Mars with limited scientific accuracy and reflected popular perceptions about Mars at the time. This included Schiaperelli's maps (that included Martian "canals") and Percival Lowell's speculations about a Martian civilization. They were also influenced by political events on Earth, which contributed to feelings of xenophobia, the decline of civilization, and environmental concerns.

However, things began to change with the dawn of the Space Age, where robotic exploration dispelled old myths and led to major discoveries about Mars's past and present. As Nuekart explained:

"The latter part of the 20th century and early 21st century marked the deployment of various robotic missions to Mars, such as the Viking program, rovers like Spirit, Opportunity, and Curiosity, and orbiters like Mars Odyssey. These missions provided invaluable Martian geology, climate, and potential habitability data. Post-2000, discussions about Mars have increasingly leaned towards human exploration and settlement.

"The strategies entailed harnessing in-situ resources, understanding potential health implications for astronauts, and developing the necessary technologies to support human life on Mars. The recent era has also seen the burgeoning involvement of private entities, such as SpaceX, in Martian settlement plans. Elon Musk's vision of making humanity a multi-planetary species, with particular emphasis on establishing a city on Mars, has introduced new perspectives and significant investment in Mars-related technologies."

Today, more space agencies are contributing to the exploration of Mars than ever before. Whereas the 20th century saw only NASA and the Soviet Union send missions to the Red Planet, the past two decades have seen new missions sent by the European Union, China, India, and the United Arab Emirates. This has contributed to a growing recognition that Martian settlement will likely be an international endeavor based on partnerships and cooperation rather than competition. And as Nuekert adds, our growing sense of climate awareness has had a noticeable effect on planning:

"Recent plans have emphasized sustainability more, ensuring that Martian settlements are self-sufficient and have minimal reliance on resupply from Earth. This includes considering closed-loop life support systems, in-situ resource utilization, and psychological sustainability for inhabitants. Martian settlement plans have evolved through these stages from speculative and primarily science-fiction-based ideas to more concrete, scientifically informed, and technologically feasible concepts rooted in actual data and evolving technological capabilities. As we progress, plans continue to become more refined, pragmatic, and inclusive of various scientific, social, and ethical considerations."

The challenges

To break it down, the challenges of creating a human settlement on Mars include the vast distances between our two planets, which means resupply missions would be infrequent, and communications would suffer latency issues. Launch windows would be restricted to every 26 months, coinciding with Mars and Earth being closest to each other (Mars Opposition), and transits would take up to nine months. Beyond that, there are the human factors, which (as Neukart indicated) are myriad:

Physiological Adaptation to the Martian Environment:

- Radiation Exposure: The Martian surface is exposed to higher radiation levels than Earth. Prolonged exposure poses severe health risks, including increased cancer susceptibility.
- Microgravity Effects: The reduced gravity on Mars (about 38% of Earth's gravity) can profoundly impact astronaut musculoskeletal and cardiovascular systems.

Psychological and Emotional Well-being:

- Isolation and Confinement: The protracted isolation and confinement during Martian missions can have psychological implications, potentially impacting the crew's mental health and group dynamics.
- Communication Delays: The significant communication lag between Mars and Earth (ranging from four to 24 minutes one way) requires the crew to operate with a high degree of autonomy, which might impact decision-making and stress levels.

Social and Interpersonal Dynamics:

- Team Cohesion: Ensuring stable and supportive interpersonal relationships among the crew is paramount for maintaining morale and effective collaboration.
- Conflict Resolution: Establishing mechanisms to manage and resolve conflicts within the crew becomes vital in the confined and isolated environment.

Human Performance and Workload Management:

- Task Design and Workload: Ensuring that task designs are cognizant of the physical and psychological strains of the Martian environment and manage crew workload to prevent fatigue and burnout.

- Skill Maintenance: Devising strategies to maintain and enhance the diverse skill sets required during the mission, especially given the autonomy necessitated by communication delays.

Habitat Design and Usability:

- Ergonomic and Human-centered Design: Crafting habitats and tools that are ergonomic and conducive to the physical and psychological well-being of the astronauts.
- Private and Community Spaces: Balancing the design to provide private spaces for individual respite and community spaces to foster social interaction.

Health and Medical Management:

- Medical Preparedness: Ensuring the crew has the necessary training and resources to address medical emergencies, given the limited possibility of evacuation or immediate external support.
- Health Monitoring: Continual health monitoring to preemptively address any medical or health-related issues.

Cultural and Ethical Considerations:

- Diverse Crew Composition: Navigating through the cultural and individual diversities within the crew and ensuring an inclusive and respectful environment.
- Ethical Decision-making: Establishing frameworks for ethical decision-making, especially in scenarios of resource scarcity or medical emergencies.

What can we do?

Addressing the challenges of sending humans to Mars and establishing an outpost of our civilization has historically led to some interesting proposed solutions. Things have also evolved historically here, mirroring our growing awareness of the Martian climate and environment, but much of the impetus has remained the same. "Ensuring the feasibility and sustainability of establishing a human presence on Mars necessitates a multi-disciplinary approach that synergistically combines advancements across various scientific and engineering domains," said Neukart. "Innovations must cater to the harsh Martian environment in the technological domain and facilitate human survival and productivity."

Since the 1990s, proposals have emphasized the need for In-Situ Resource Utilization (ISRU) to minimize the amount of supplies and building materials transported from Earth. Considerable research has also been dedicated toward creating closed-loop systems that maximize resource utilization, minimize waste, and are self-sufficient. To this end, researchers are looking to bioregenerative life support systems (BLSS) inspired by nature—i.e., they rely on organic components, such as algae, microbes, or artificial photosynthesis. Said Nuekert:

"Achieving this involves refining technologies that enable effective recycling and reuse of resources within the habitat and minimizing dependency on supplies from Earth. From a broader perspective, a thorough risk-management framework that anticipates potential crises and provides robust mitigation and adaptation strategies is vital. This includes developing technologies and protocols to manage unforeseen challenges, whether they be technical malfunctions, medical emergencies, or resource shortages."

Naturally, several technical developments need to happen before these challenges can be addressed. As to what those are, Nuekart emphasized the following:

Robust Technology Development:

- Life Support Systems: Perfecting closed-loop life support systems that can reliably sustain human life through resource recycling and regeneration.
- Habitat Technology: Developing durable habitats that protect inhabitants from radiation, maintain pressure integrity, and ensure overall livability.

Advanced Space Travel:

- Transportation: Enhancing spacecraft technology for more efficient, safe, and feasible transportation between Earth and Mars, such as through the MFPD we discussed below.
- Entry, Descent, and Landing (EDL): Achieving reliable and precise EDL systems for safely landing payloads and humans on the Martian surface.

In-Situ Resource Utilization (ISRU):

- Resource Extraction and Utilization: Establishing viable technologies and methodologies for extracting and utilizing Martian resources (e.g., water-ice).
- Energy Production: Ensuring sustainable and reliable energy production on Mars, potentially harnessing solar and nuclear power.

Astronaut Health and Safety:

- Countermeasures: Developing effective countermeasures against the detrimental effects of microgravity and radiation exposure on human health.
- Medical Facilities: Establishing comprehensive medical facilities

and protocols to manage health contingencies.

Scientific Exploration and Understanding:

- Geological Studies: Conducting thorough geological studies to understand Mars' terrain, subsurface, and potential resources.
- Search for Life: Further exploration to understand the Martian environment, mainly focusing on life's potential existence or historical presence.

Psychosocial Preparations:

- Crew Selection and Training: Establishing robust selection, training, and support frameworks for astronaut crews to manage psychological and social dynamics.
- Mission Simulations: Conducting extensive mission simulations to understand and prepare for various mission scenarios and challenges.

Logistical Planning:

- Supply Chains: Establishing reliable supply chains, ensuring the consistent availability of essential resources and spare components.
- Communication Systems: Developing robust communication systems to facilitate effective communication with Earth despite the substantial delay.

Global Collaboration:

- International Partnerships: Fostering international collaborations to pool resources, expertise, and share responsibilities and benefits.

- Knowledge Sharing: Enabling a global knowledge-sharing framework to enhance collective understanding and technology development.

Societal and Cultural Aspects:

- Public Engagement: Engaging with the global community to establish a collective vision and gain public support for Martian settlements.
- Cultural Preservation: Considering how to preserve and convey Earth's cultural and biological heritage on Martian settlements.

Is it worth it?

This question is fundamental to any major undertaking and must be asked before (and after) all the challenges are considered and addressed. Much like proposals for exploring and establishing permanent infrastructure on Mars, numerous reasons have been given as to why the risks are acceptable and the endeavor a worthy one. As Nuekart addresses in his paper, these range from the need to ensure our survival to the scientific breakthroughs it will enable. Nevertheless, the process of permanently settling on Mars is fraught with challenges and hazards.

But as proponents of Martian settlement will argue, these same hazards represent an opportunity for innovation, development, and our growth as a species and civilization.

"The potential settlement on Mars holds numerous benefits that warrant undertaking the assorted risks and challenges. These benefits, among others, help elucidate why the pursuit of Mars settlement, despite the inherent risks and challenges, garners interest and investment from governmental and private entities globally. The endeavor is not just about establishing a human presence on another planet, but I also see the advancements, knowledge, and collaborative efforts that the journey there facilitates," said Neukart.

More information: Florian Neukart, Towards Sustainable Horizons: A Comprehensive Blueprint for Mars Colonization, *arXiv* (2023). DOI: 10.48550/arxiv.2309.16806

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