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Lunar Land Use and a Levanah Zoning Code

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Abstract

This research paper presents a Levanah Code for land use classification and zoning on the Moon. Zoning regulations on the Moon must be flexible and permit adapting to evolving technologies, population growth, and settlement needs over time. Lunar planning and zoning must consider incentives for activities or developments contributing to the lunar settlement's sustainability, innovation, and well-being. These lunar land uses must be interconnected and carefully planned to ensure the colony's functionality and sustainability. Safety zones must be specified around each of the lunar zoning classes.

Among the land uses and zoning classes are residential/habitat uses, resource extraction, transportation, historic sites, and power generation. The Moon's canvas is vast, and the land use and zoning decisions we make on it will echo for years. The Moon offers us a blank canvas—how we choose to use it will define how land use and zoning will be implemented on Mars.

1. Introduction

The word “Levanah” is a Hebrew word meaning moon. The Levanah Code specifies what can be built on plots of lunar land, especially in the NASA-recommended area between the deGerlache and Shackleton craters near the Moon’s south pole. This area's regolith (soil) is mostly oxygen, iron, and silicon.

Zoning is a subset of land use planning that assigns specific regulations regarding the form and bulk of structures and the placement of structures within lots [1].

Land use planning considerations include the separation of incompatible uses, the governance of externalities from land and subsequent use activities, the efficient and productive coordination of transportation and land use, the production of public parks and preserves, environmental stewardship, equity, and housing goals, and many others.

Many urban planners have not been vocal enough about how urban planning can help space settlements. Creating a lunar zoning system is not a task for one entity; it needs collaboration with all lunar stakeholders. Ongoing collaboration and research will be essential to refine and adapt these land-use approaches as we venture into space. This approach ensures that all stakeholders are part of the process, facilitating shared responsibility and commitment to the success of lunar settlements.

Zoning regulations on the Moon must be flexible and permit adapting to evolving technologies, population growth, and settlement needs over time. For example, specific zoning maps must be created using three-dimensional lunar regolith maps and geology. Lunar soils have been characterized, but a soil classification system must be developed, including soil chemistry and particle size. Land use and zoning will depend on the soil map. There must be a system of “stepped down” uses to ensure adjacent zoning classes consider safety and resource intensity.

The success of any zoning approach on the Moon will depend on its ability to balance flexibility with the need for regulation, ensuring the responsible and sustainable development of lunar resources while providing a framework for the diverse activities of a lunar settlement.

Lunar planners can create temporary zoning designations for initial settlement phases, allowing for adjustments as the lunar community develops.

The settlers of the Moon must review lunar plans and zoning. Often, charrettes are implemented to seek consensus on comprehensive plans. Charettes can be used to review draft zoning maps and comprehensive plans. However, settlements on the Moon and elsewhere in our solar system “will not stand immune to the pitfalls of urban planning practice at any scale”. Moreover, addressing potential ethical and legal considerations is not just a formality but a crucial step in establishing a sustainable and responsible framework for lunar activities, ensuring that our space exploration is conducted with the highest ethical standards.

Lunar planning and zoning must consider incentives for activities or developments contributing to the lunar settlement's sustainability, innovation, and well-being. While lunar colonization is still being planned, crafting potential zoning categories for lunar activities involves considering safety, sustainability, and resource management. The zoning categories would need to address scientific and commercial activities and the well-being of the lunar colonists. Further, establishing a regulatory framework for lunar land use requires careful consideration of extraterrestrial settlement's unique challenges and opportunities. Establishing a colony on the Moon involves careful planning to ensure the settlement's well-being sustainability, and functionality. Various land uses are essential to support the colony's diverse needs.

These lunar land uses must be interconnected and carefully planned to ensure the colony's functionality and sustainability. Safety zones must be specified around each of the lunar zoning classes.

As technology advances and lunar colonization becomes a reality, these land use categories may evolve and adapt to meet the colony's and its inhabitants' changing needs. It is essential to emphasize that the specifics of zoning on the Moon would depend on technological advancements and scientific understanding as lunar colonization plans progress. Moreover, addressing potential ethical and legal considerations will be crucial in establishing a sustainable and responsible framework for lunar activities.

Zoning on the Moon presents a unique opportunity for innovation. Traditional zoning models developed for Earth may not be directly applicable, and new frameworks must be designed. This challenge offers a chance to push the boundaries of urban planning and create zoning types that best regulate land uses on the Moon, inspiring us to think beyond our current limitations.

Lunar planners must create integrated and self-sufficient communities that use mixed-use residential, commercial, and recreational spaces within specific zones. They should encourage the coexistence of various activities that maximize efficiency and minimize resource consumption.

2. Lunar Land Use And Zoning Classes

2.1 Residential Uses and Additions to Habitat Areas

Initially, lunar planners must designate areas for building habitats and living quarters for lunar colonists. These zones must consider factors such as the proximity to essential services. Because everyday life on the Moon would be "psychologically demanding and monotonous, the project [must] connect inhabitants from all lunar bases with each other" [2].

Caution that the size of land parcels is critical when crafting a land use, including "road [specifications], aspect ratio, relative block access, and block coverage. The defining elements of zoning classes for lunar planning should be based on finding complementary uses and resource uses. The separation of lunar land uses should only be necessary to protect historic sites and conserve lunar features for convenience, safety, and productivity. Zoning has spurred "recklessly inefficient allocation of land uses across cities; to avoid such realities for the Moon, the focus should be on maintaining a flexible and efficient growth pattern".

Massachusetts Institute of Technology (MIT) collaborated with Skidmore, Owings, and Merrill (SOM) to design a self-sufficient "Moon Village at the rim of the Shackleton Crater on the Moon's south pole". The need for specialized habitat and infrastructure for settlers, scientific laboratories, and resource use is a crucial aspect that we must prioritize in our planning and execution. In another study, the Lacus Veris inflatable dome habitat would be considered a mixed-use zone because it provides four living and working area levels. The dome's first three levels would include private and group activity quarters, the wardroom, the galley, and hygiene facilities. "At the top of the dome, Level Four would house more specialized "crew support" functions, notably health and recreation facilities" [3].

Cohen (2002) mentions that any lunar architecture of habitats must overcome the threats to health, life, and safety from the extraordinarily hostile environment. On the Moon, these threats include "vacuum, radiation, micrometeoroids, extreme thermal cycling, and partial gravity" (p. 5). To protect settlers from these hazards, sub-surface lava tubes have been suggested as a habitat alternative to surface construction [4].

Brick houses, archways, and walls depend on the combined compressive strength to support the structure. Lunar materials would have "six times the load-bearing capacity on the Moon. The strengths of sintered lunar brick samples produced would far exceed the strength performance of standard construction bricks on Earth".

Some lunar land planners suggest clustering habitat modules that would be connected to enable "seamless mobility between structures". The multi-story modules would provide a habitat for each family. They would be constructed from lunar regolith and include an outer protection shell. Green (2020) also reminds us that "inflatable structures would provide resistance to extreme temperatures, projectiles, regolith dust, and solar radiation" (para. 5).

Spaces chosen for living quarters, habitats, and accommodations for lunar colonists must be zoned as residential uses, considering radiation shielding, temperature regulation, life support systems, and proximity to essential services. A safety zone must be specified around each residential zone.

3. Business and Commercial Zones

Areas for trade, commerce, and economic activities are essential for the lunar settlements.

A business and commercial zone class would be designated for these uses. This includes provision for commercial facilities such as shops, restaurants, and service facilities.

Mixed uses can include housing, commercial, and office spaces in vertically integrated buildings next to other uses. A mixed-use space business park with residential uses would consist of lunar real estate offices, “facilitating the economically viable establishment and growth of diverse spacefaring enterprises from the start”.

4. Industrial and Resources Extraction Zones

Lunar industrial facilities can “manufactu tools, advanced materials, rocket components, and fuel from the Moon's resources”. However, areas rich in lunar resources are necessary for extraction and use and will require an environmental assessment of their impact and sustainability. Facilities for manufacturing and processing materials for construction and other needs will require storage infrastructure [5].

An industrial and resource extraction zone includes areas for extracting and processing lunar resources, including water, ice, minerals, and regolith. This would require facilities for manufacturing and processing materials for construction and other needs. Reports that furnace sintering of lunar regolith can create a substance like concrete. “Porosity, determined by particle size distribution, is known to have one of the primary influences on the strength of sintered regolith. The increased packing density of fine regolith particles results in improved strength of sintered material”. Concentrated solar energy has been used to sinter the Lunar regolith.

The lunar regolith is suitable for engineering and manufacturing because of its elements and compounds. These include oxygen, iron, titanium, silicon, magnesium, and aluminum.

Silicon can be used to create high-strength glass. Titanium, iron, magnesium, and aluminum are valuable components of structural materials. The Moon has deposits of Thorium- and uranium, which can be extracted to produce radioactive fuel. Some “iron oxide (FeO) deposits might contain thorium” [6]. Oxygen can manufacture ceramics.

If lunar mining is conducted before communication sites are established, these mine sites will require communication stations “to enable robotic systems always to receive mining operations commands and downlink data” [7].

Water ice is a crucial resource for sustaining life on the Moon. Cold traps within deep craters at the lunar poles could yield as much as one billion tons of water. “The coldest of the cold traps reach temperatures as low as 25 degrees above absolute zero, at which point oxygen becomes a solid”. Lunar planners must designate regions where water ice may be present for extraction and processing.

Oxygen and electricity could be produced on the Moon using oxides and photovoltaic cells. The photovoltaic systems should be located on tower structures to prevent obstacles to the lunar land and enhance illumination. This zoning class consists of sites for extracting and processing lunar resources, including water, ice, minerals, and regolith. The processing plant would process “the concentrate to extract volatiles, purify the volatiles to isolate the water ice and remove contaminants, and finally separate the water ice to produce LOH and LOX to produce rocket propellant”.

The resource extraction and industrial zone would be linked by surface transportation or short-duration spacecraft hops facilitated by a robust landing pad, refueling infrastructure, and road network at each location. Regolith would be available at both locations for civil engineering projects, and oxygen locked up in that regolith could be extracted given enough energy inputs.

In any event, buffers and safe zones must exist between habitat, commercial and business, and industrial zones.

5. Agriculture and Farming Zones

Lunar settlements rely on the sun to grow food. Areas must be zoned for cultivating crops and producing food for lunar colonists. Settlers must integrate controlled environment agriculture to address challenges such as low gravity and limited sunlight. Plants can be grown underground or in a regulated greenhouse.

Lunar temperatures, lack of nitrogen compounds, compaction of wet regolith, and gravity concerns will challenge planting in the lunar regolith. However, using elements from the regolith, hydroponic farming may prove viable.

6. Historical Sites Zone

The U.S.G. and NASA have mapped legacy sites on the Moon. Lunar planners must establish a historical zone class to protect sites of “scientific, aesthetic, historical, cultural, environmental, and spiritual value, including the significant historical sites of lunar exploration”.

Six Apollo missions include historical materials. These materials should be preserved and protected as on Earth. Preserving Apollo 11’s Armstrong and Aldrin’s footprints and other artifacts is essential and should not be damaged by new lunar settlers and their vehicles [8].

The historical zone can include other historical sites of hard and soft landings. These sites must be protected “with NASA’s 2 km minimum distance (radius)” buffer. Contamination by depositing chemical, biological, or physical material onto the historic zone is prohibited.

7. Institutional Zones

An institutional zone class would be for educational institutions, training centers, and facilities for skill development. This includes spaces for learning and training programs for colonists.

Within the institutional zone are facilities for healthcare services, medical treatment, emergency response, and designated emergency shelters and evacuation areas. Areas for accommodating tourists or visitors and spaces to showcase the achievements and activities of the lunar colony are included in this zone class. The institutional zone has administrative facilities, including decision-making and governance, law enforcement, and coordination of colony activities.

Report that this zone can incorporate "storage, programmed area layout, food supplies, clothing management systems, fire suppressants (to prevent and control fires in the lunar environment), hygiene systems, housekeeping, workstations, and other human-related functions" (p. 10) [9].

8. Energy Production and Communication Zones

The crucial role of energy in successfully establishing a lunar settlement cannot be overstated. The meticulous planning for sustainable and efficient energy sources to meet the colony's power needs is a testament to the thoroughness and dedication of lunar colonization planning. This level of planning should reassure you of our commitment to the success of this project.

Without energy plants generating a constant flux of power, "most lunar operations will be limited to just one lunar day (about 4-Earth days) due to the frigid temperatures of the lunar night, which can go as low as -220 degrees Celsius. Mining or manufacturing will require much energy, up to 20 kWh per operation" [10].

The Energy Production and Communication Zones have areas designated for installing solar panels or other energy generation facilities to meet the colony's power needs. Battery storage and power distribution centers are within this zone class.

Communication and data transmission facilities are crucial for a lunar colony's success.

These zones will enable seamless communication between the colony and Earth, as well as within the colony itself, fostering connectivity and collaboration. The seamless integration of communication infrastructure is a testament to the connectivity and cooperation within the settlement and with Earth.

9. Waste Treatment and Recycling Systems Zones

Lunar settlement infrastructures will further require advanced life-support systems, such as recycling and waste treatment, to ensure the survival and well-being of the lunar colonists. Areas for processing, managing, and recycling/reusing waste that the colony produces are within this zoning class.

It makes sense to envisage an intelligent combination of water treatment technologies (membrane-based filtration, nitrification) integrated with a photosynthetic reactor [11]. Lunar planners can use AWT with clean water to irrigate vegetables and fruits in the greenhouse.

10. Lunar Conservation Zones

Naturally occurring urban boundaries on Earth are usually rivers or bodies of water historically used for transportation during a city's formation. Lunar settlements will be initiated next to Permanently Shadowed Regions (PSR), limiting urban growth in at least one direction.

Lunar planners must set aside environmental conservation areas, preserve the natural lunar landscape, and ensure minimal moon geology disruption. Lunar conservation zones are areas set aside to protect natural lunar features and for specific scientific research. These zones are crucial for preserving the lunar environment and ecosystems, and their implementation demonstrates a commitment to environmental conservation in the context of lunar colonization.

Zoning should be used to preserve high-value natural sites and manage the intensity of activities. Unique and scarce lunar sites should be identified and preserved in perpetuity. "These could include specific PSR and Peaks of Eternal Light (PEL)".

11. Research and Science Zones

The research and science zones are designated for scientific research, experimentation, and observation. These include laboratories, observatories/telescopes, and other scientifically equipped facilities for studying lunar geology, astronomy, and other scientific disciplines.

12. Lunar Transportation Zones

Roads, pathways, and other transportation infrastructure must be constructed for mobility within the colony. This includes planning rovers and other transportation routes to facilitate movement across the lunar surface. Lunar planners must zone areas for evacuation routes and procedures in emergencies. Establishing landing pads, bridges, berms, and roads will require substantial resources for permanent settlement.

Roads and bridges increase the ease of expansion and breadth of exploration. "Landing pads stabilize the surface and reduce the risk of take-offs and landings. More superficial structures, such as berms and walls, can mitigate dust and ejecta". The site should provide a recharging station if humans are transported from the landing site to the base using surface vehicles. The size of a safety zone depends on the quantity of dust and its size, how far the dust travels, and appropriate mitigation to protect other zones. NASA (2011) recommends a 2.0 km exclusion radius for landing and takeoff zones.

The lunar transportation zone consists of landing and takeoff zones for spacecraft.

Lunar planners should zone specific areas for spacecraft landings and launches, considering safety, logistics, and potential interference with other activities. Following refueling, "a power station at the spaceport will become necessary to power the landing site's systems and recharge spacecraft batteries in case of unexpected discharge" [12].

Lunar planners must consider safety protocols and traffic management in and around these areas.

13. Leisure Activity Zones

Leisure activity zones will facilitate the integration of facilities to support mental well- being and social interaction among lunar colonists. This zone class will consist of sites for recreation, leisure, community gatherings, parks, entertainment activities, and spaces for physical activities.

14. Safety Areas and Emergency Zone

Zoning safe zones and emergency shelters in case of unforeseen events is essential and is designated for lunar settlers' safety and well-being. These safety areas protect the colonists and lunar operations from harmful interference. Lunar planners must define areas around critical infrastructure and habitats where certain activities may be restricted to ensure the safety of residents and operations.

Establishing, maintaining, or ending a safety area should be accomplished to "protect public and private personnel, equipment, and operations from harmful interference" [13,14]. States that safety areas are for "protecting the security or economic interests, operational health, and safety areas around specific activities, and "notice-and- deconfliction" zones to prevent conflict" (p. 3). Buffer zones are necessary to mitigate the impact of human activities on the lunar environment, especially in sensitive areas. These zones can be one, two, three, and four dimensions (x-y-z and t).

Activities in radio-quiet zones should be staggered to create lengths of time with little or no activity to preserve the valuable nature of this zone type [15-40].

15. Conclusion

As humanity stands on the brink of establishing a permanent presence on the Moon, the question of how we manage its resources and territory becomes ever more pressing. Thoughtful lunar zoning and land-use policies will ensure this new frontier is developed sustainably and equitably. By fostering international cooperation, respecting the spirit of existing treaties, and anticipating future challenges, we can lay the foundation for a lunar society that benefits all of humanity.

The Moon presents a rare opportunity to apply the lessons of Earth's past to a new frontier. It challenges us to think beyond borders, rivalries, and short-term gains to envision a shared future that benefits humanity. How we approach the zoning of lunar land today will not only define the success of this endeavor but also set a precedent for our interactions with the cosmos beyond.

The Moon's canvas is vast, and the land use decisions we make on it will echo for millennia. The Moon offers us a blank canvas—how we choose to use it will define how land use and zoning will be implemented on Mars. Will we rise to the challenge and create a framework that reflects the best of human values?

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