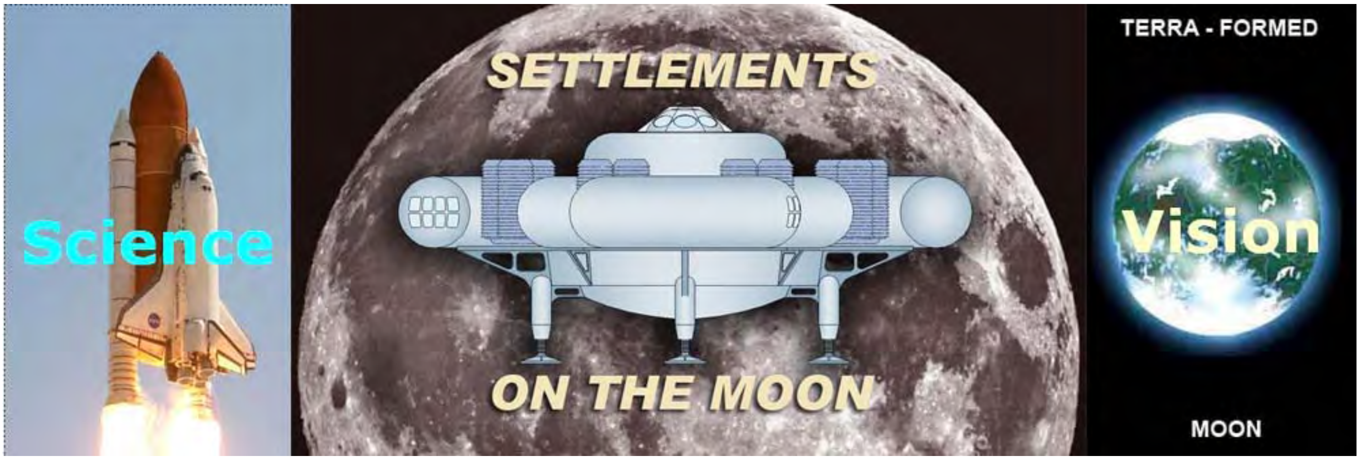
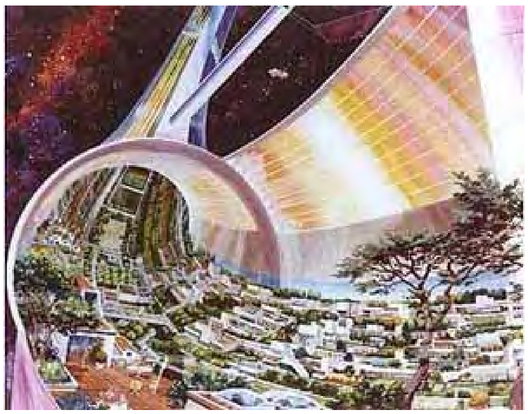


The first Science Vision book at last!

by: Rudolph N.J. Draaisma – rev. Febr 08, 2009



Many visionaries have designed and are still designing Moon base projects, such as Moon bases, settlements, ways of moon landing and space stations around Earth, but, as is usual in many such presentations, ignore the basics of physics, engineering and specific conditions, often in ignorance, or with a wishful "no problem" attitude. See for example this artist presentation of a huge torus shaped rotating space colony.
http://www.nas.nasa.gov/About/Education/SpaceSettlement/index.html

In the 1970's, Princeton physicist Gerard O'Neill, with the help of NASA Ames Research Center and Stanford University, "showed" that we can build giant orbiting space stations and live in them.

In my view, only the artist showed this in his presentation. Surely, nobody ever calculated on what forces would be at work in such a giant rotating structure? I haven't either, but by intuition as an engineer, I say this cannot be done. Just imagine that a steel cylinder at say 500 meter in diameter (the assumed torus cross-section) at 1 bar overpressure would need a wall thickness of around 10 inches (250 mm), just to hold against air pressure against vacuum alone and without any safety factors included (then it would become thicker) - all around glass panels to let in sunlight (what about green-house effect as well)?

Even if we assume a lighter construction of a multi-layered hull with stiffening frameworks in between, when we bring the rotational forces of the masses of the hull and its interior structures as shown into account, I don't need to calculate any further. Anyway, we are talking about tenths, if not hundreds of millions of tons of materials here, that have to be brought into one location and assembled there - how many centuries do we want to spend on building this? (it took decades to build the Dutch sea-water works, after the storm flooding in 1953 - peanuts compared to this space colony) Long before such a structure ever would be ready for use, so much time has elapsed, that its original objectives have become obsolete by other, likely economical developments during the time, such as Moon bases having become more profitable - this is fiction only!

Besides, also on Earth we could not construct column-shaped buildings of several kilometers high - they would collapse under their own weight (this is why the steel structure of the Eiffel tower in Paris has its funnel shape - steel has far less compressive strength than concrete and bricks and is four times more heavy).

Since the Apollo moon landings, we know quite a bit more about the conditions of the Moon's surface, but the artist-designers do not take these into account and are still in the science fiction phase, or rather, fiction only . On the web you can find statements like these:

"The Moon has everything needed to sustain life. To build the first Moon base we need take nothing with us. It's all there: aluminum, iron, hydrogen, helium and oxygen."
http://news.bbc.co.uk/1/hi/special_report/1999/07/99/the_moon_landing/395447.stm

If it now not had said "the FIRST Moon base", I would have agreed, but it will definitely not be the first one that doesn't need to take anything with it - it will basically have to take everything with it. All those nice materials that are on the Moon, do not lie readily available around, but are contained in strong chemical bonds of various kinds in various locations, that need quite some equipment and most of all, much energy to collect and to make them free for use in large quantities, plus a Moon based industry, to make useful products of those materials.

In fact we're talking about an infra-structure here and it will take decades to build up. To do that under vacuum conditions, is not the easiest thing either, to say the least.

As the engineer in electrics, mechanics and energy conversion systems that I am, I make in the following a more realistic analysis of what is possible and develop a program that can lead to establish the first bases and settlements on the Moon, showing designs of such structures and transport systems, with all the functions needed to live there and as can be done with today's technology. This is neither Science yet, nor is it Science Fiction. This is Science Vision instead, the vision of what is, or may be possible within known laws of physics and today's technology, but is yet to be done.

MOON SURFACE

The first thing that should be considered is the observation that its whole surface is covered with a powdery dust layer (regolith, that appears to vary between 2 and 20 meters thick, even up to hundreds of meters, as I've read. The lunar soil (or regolith) covering the Moon's surface is a complex material that is sharp and abrasive - with interlocking glass shards and fragments.

It is a powdery grit that gets into everything, jamming moving parts and seals and abrading spacesuit fabrics. It also readily picks up an electrostatic charge. This characteristic causes it to float or levitate off the lunar surface and stick to faceplates and camera lenses. It can also get into living spaces, where it is impossible to brush off, due to ease with which lunar dust picks up electrostatic charges and can even irritate the lungs of astronauts.

From this we can understand that regolith must be removed from working places. I quote from this NASA - page:
http://lunar.arc.nasa.gov/education/teacher/teacher3.htm

"The Moon's surface is charcoal gray and sandy, with a sizable supply of fine sediment. Meteorite impacts over billions of years have ground up the formerly fresh surfaces into powde . Because the Moon has virtually no atmosphere, even the tiniest meteorite strikes a defenseless surface at its full cosmic velocity, at least 20 km/sec. Some rocks lie strewn about the surface, resembling boulders sticking up through fresh snow on the slopes of Aspen or Vail. Even these boulders won't last long, maybe a few hundred million years, before they are ground up into powder by the relentless rain of high-speed projectiles. Of course, an occasional larger impactor arrives, say the size of a car, and excavates fresh rock from beneath the blanket of powdery sediment. The meteoritic rain then begins to grind the fresh boulders down, slowly but inevitably."

The word "powder" is a bit misleading as to its behavior, that is different on the Moon from Earth. On Earth there would be air molecules between the powder particles, which allows you to pack it, by pushing out the air. On the Moon this powder is packed already and thus you would not sink deep in it, only in as far a some powder can be pushed away laterally. This could happen when walking up a rather steep hill, where the powder has freedom to move further downwards, you would probably glide away, or even fall flat down on your face. The rotating wheels of a vehicle though, would easily dig themselves down, because they cause plenty of lateral movement in the powder. A caterpillar vehicle would not do this and would be the preferred one on the Moon in my view.
Surely the astronauts had problems with the regolith, as I quote from aforementioned page:
"The blanket of regolith also greatly obscures the details of the bedrock geology. This made field work during Apollo difficult."

Likely, the exhaust gases of the landing LM's rocket engine blasted away the powder under it, so the LM landed on solid (rather sandy) ground of a limited area. It can well have been a few hundred meters in radius, considering the exhaust speed of the rocket gases, exiting the nozzles at around 4 km/sec and no air turbulence to break that speed, as would be on Earth. Thus these exhaust gases, after hitting the ground, would have expanded in vacuum as a horizontal 'blanket', blowing away most powdery dust on its way, or just an upper, rather thin layer of it, as deeper layers are heavily packed and possibly held together by electrostatic force between the particles as well?

Anyway, the astronauts couldn't drill more than just a few inches into the ground - the regolith surface appears to be very hard, not at all what one would expect from "powder". It's packed like no press on Earth could accomplish.

Let's stop a moment here and first look at some basic physics and conditions. If you know all that already, you can omit this section, but please return to it, if the rest of this chapter would bring you in disagreement - you may have overlooked something. Of course, I'm not an oracle and can have overlooked quite some things myself also, for which I apologize on forehand. Nevertheless, a simple test would be to read point 1c and d below. If you knew that already, you're "qualified".

BASICS SECTION
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1. Mass, Weight and Inertia.
a) In the MKS system the kilogram (kg) is the unit of mass, though in everyday life it is used as a unit of weight and this is confusing. Weight is the force by which Earth's gravity keeps an object on the ground. Any mass object in free fall gets an acceleration by gravity and this acceleration is independent from the object's mass. Already some 500 years ago, Gallileo Gallilei made the experiment by simultaneously dropping a wooden and a iron ball of the same size from the leaning tower in Pisa (Italy) and observed that they hit the ground simultaneously. These balls had the same shape and size and therefore the same air resistance during falling, but they had a different mass and therefore a different weight on the ground (or a scale). The unit of force and thus of weight is the Newton (N), as per Newton's second law: **F = m•a**, where **F** is the force in Newton, equal to the range of mass **m** in kg and acceleration **a** in m/s^2 (meters per second square). Thus the Newton has the dimension: $kg.m/s^2$ See a short tutorial on all that here (including a conversions calculator SAE - MKS units)
http://www.draaisma.net/alternative_engineering\conversions.html

b) For gravitational acceleration, the character **g** is used instead of **a** and so weight is given by **F = m•g** Earth's gravitational acceleration is 9.80 m/s^2 , which thus means that every second the speed of an object in free fall increases with 9.80 m/s (that's why m/s^2) If your body has a mass of 80 kg, your weight is thus 784.8 Newton, say 785 N) On the Moon your body still has a mass of 80 kg, but your weight with g = 1.62 is there 129.6 N, say 130 N, thus around 6 times less than on Earth. Question; if you would jump down from say a chair, would the impact of your feet on the floor be 6 times less on the Moon, compared with on Earth? I guess you would think so, but it is not.

c) It is here where inertia comes in. Inertia actually involves all three laws of Newton, but is calculated with the second one. Any mass object persists in its state of motion (Newton's first law) and resists any change of it by setting up a reacting force equal to the range of its mass and acceleration (Newton's second law), being equal to and in opposite direction of the acting force that brought about the change of motion (Newton's third law). The force of impact is an inertial force (a reaction force) and the difference with an identical situation on Earth is just the speed of touch down and this speed is given by $\sqrt{2.S.g}$, where **S** is the falling height.

Thus the force of impact becomes proportional with the square root of the ratio of gravitational accelerations, thus $\sqrt{\frac{1.62}{9.80}}$ = 0.40 , hence 2.5 times less than for the same situation on Earth, not 6 times less! However, to have the same impact on the Moon as on the Earth, thus the same touch down speed, the falling height is 6 times larger, because $\mathbf{S_1 g_1 = S_2 g_2}$. Surprised?

d) Let's now consider what is the case with an object in 'centrifugal' rotation. It is said that such an object is subjected by a centrifugal force, pointing outwards, away from the center of rotation and is kept in its circular path by a centripetal force, pointing inwards to the center of rotation, to which it is mechanically attached, both forces being equal and in opposite direction. This fully complies with Newton's third law and also with Newton's second law, that allows us to calculate the forces, but it is in conflict with Newton's first law.

As the centrifugal and the centripetal forces balance each other out, there is no resulting force that could keep the object in its circular path, though it evidently does that. There is only one conclusion possible, which is that centrifugal forces do not exist, only centripetal forces exist. Hence, when you are in a car that makes a sharp curve, your body is not pressed outwards against the inside of the car, but the inside of the car pushes your body into the curve (your body wants to follow a straight path, as per Newton's first law). Now, what happens if the mechanical connection of the rotating object with the center of rotation suddenly is broken? Does the object fly out radially or tangentially? If you say radially, please read again, or throw this paper in the nearest trash bin.

An object in gravitational orbit is quite a more complicated situation, only explained by curved space in General Relativity, that we won't discuss here.

Just know that there is no balance between centrifugal and gravitational forces (but of energy instead), even though the orbit calculates (almost) correctly that way. If you say this is pure nonsense (some would do), you don't even have to read again, just throw this paper in the nearest trash bin and be glad you didn't pay for it. Otherwise, you may instead study this calculation sheet on gravitational motions:
http://www.lunar-union.org/space-tourism/gravitational_orbit_calculations.html

e) If you're reading further, next question. Why can you move a table by pushing against it, though it pushes back with the same force as per Newton's third law and there thus is no resulting force to move it? Moreover, as it pushes back, why can't the table move you instead? The answer simply is that your muscles do work and by that apply energy to the table and that makes it to move. The table cannot do work and is thus passive, it can't move you (now don't argue, if the table stands on a sloping and slippery floor.....).

2. Energy and Power

a) Energy, or work **W** is the range of force **F** and traveled way **S**, thus **W = F•S** and the unit is the Joule (J). The dimension of it becomes: $kg.m^2/s^2$ Power is the work done per unit of time, which is the second and the unit of power is the Watt, or Joules/sec, with the dimension $kg.m^2/s^3$.

b) Although this sounds simple, there is much confusion among the public about it, especially in connection with temperature. Many see temperature as a measure for power and capacity (energy). If some system has, or generates a very high, or very low temperature, it is seen as a powerful thing, but really, what would you prefer to have in your hand, a hot, red glowing small needle, or a big steel bolt of the same temperature?

In the latter case you won't have a hand any more, whereas the needle may just cause you a small blister. The difference is energy, not temperature. The small mass of the needle gave off most of its energy within a second, whereas the much larger mass of the bolt contained enough energy to destroy your whole hand during a longer time. Take lightning as another example. A flash of lightning can be far more powerful than the largest power station on Earth, but it has just enough energy to split a tree apart. The flash lasted for a fraction of a second only, whereas a power station runs all the time, giving off much more energy. Thus lightning is not a suitable energy source, if someone would think that?

c) What is an energy source? Sounds like a stupid question, but if you believe that for example hydrogen is an energy source, the question is far from stupid. IF we could pump up free hydrogen somewhere on Earth, just like crude oil, yes, it would be a great energy source, but unfortunately all hydrogen on Earth exists in chemical bonds, water being the strongest and the most abundant one. Therefore most people think that extracting hydrogen from water through electrolysis would give us an inexhaustible energy source, but those who think that have no good understanding of the First law of Thermodynamics. It is generally known in the formulation that energy cannot come from nothing and not disappear into nothing.

However true, it doesn't give any understanding of its implements. This shows most significantly in the widely used terminology of "energy production", which of course is impossible. We can only convert energy from one form into another, but not produce it in whatever way. A similar confusion lies in the term "waste heat", suggesting that the useful energy (heat) was "consumed". No, only the fuel was consumed, not the energy it released, that will be around for ever and ever. All energy that we "use" in whatever way, finally decays to heat at ambient temperature. On Earth we can't trace it any more, but it's still there. In a space craft however, especially a manned one, "waste" heat is more than traceable - it heats up the thing.

The "waste" energy must either be recycled to "useful" energy (which is generally deemed to be rather much impossible), or cooled off to the vacuum and that is not so very easy to do at room temperature - more about this further on.

d) The correct, scientific definition of the First Law is, that if you take energy out of a system to bring it into another condition, the same amount of energy must be put in again to bring it back into the original condition (the conditions must be at equilibrium, but that we can ignore here). Now, if the start condition is water and the end condition is the same water, no matter what happened in between, the First Law says that there cannot be any energy output from the process - it would have come out of nothing.

I know this sounds odd, because there was indeed mechanical energy on the shaft and the exhaust steam has indeed condensed back to the original water again. However true, the sum of that mechanical energy and that of the condensation heat of the exhaust steam, was exactly the same as the electrical energy that split the water into oxygen and hydrogen - you gained nothing and that is what the First Law says. In fact you lost, as follows: The electrolysis process needed 40% more energy than what actually is needed to break the bond between oxygen and hydrogen, because its chemo-electrical efficiency is only 60% (it develops heat, that must be cooled off during the process).

The whole system needs thus far more input energy than there is output on the shaft. In other words, you could better have used the applied electrical energy directly, to power an electrical motor for example. We can however use electrolysis to store electrical energy, in the form of free hydrogen and oxygen. Just when we use that later in a combustion process, or in a fuel cell, we have the same low overall efficiency again - see point 4c below.

e) But then, there is hydrogen in other chemical bonds, such as natural gases. If that is the start condition and the end condition becomes water, then there could be a net energy output. Provision is though that it took considerably less energy to extract the hydrogen from natural gas, than what was gained on the shaft of a combustion engine, when it oxidized to water in there - the difference (part of) is usable energy. However, as we can burn natural gas directly, there isn't much use of going the complicated way over hydrogen, at more or less the same overall efficiency. There is "only" the environmental aspect that favors hydrogen technology, but there isn't much economy in it and as money governs the world.... But this has nothing to do with the Moon, assuming there is no natural gas there, right?

3. Cooling

a) A little about temperature first. The Celsius scale takes the freezing point of water as zero and the boiling point at atmospheric pressure as 100. It has been proved that the lowest possible temperature is -273 °C, nothing can get colder than that and which therefore is the zero point for the Kelvin scale. One degree Kelvin in temperature difference is thus the same as one degree Celsius difference, just that the Kelvin scale sets -273 °C to zero. The temperature measured in Kelvin is therefore an absolute temperature and °K = °C + 273. A similar relationship exists between the Fahrenheit and the Rankin scales, the latter also being absolute temperature and thus 0 °R = 0 °K.

b) The most effective way to cool is through convection, which is contact heat transfer from one material to another. In general, liquid-to-liquid is best and gas-to-gas is worst (solid-to-solid is called conduction). The only material available on the surface of the Moon is the regolith and the bedrock under it. On Earth one can have quite a good heat transfer through pipes in the ground, but this is because there is water in there. I a desert like the hot Sahara, the dry sand is an insulator and the same we can expect from the regolith on the Moon. Moreover, during the Moon day the surface gets very hot in the sun, around 120 °C (not the parts that lie in the shadow - they can be very cold). This basically leaves us with radiating heat to the vacuum, which has no temperature.

c) Most people think that the vacuum and thus space is very cold, but only matter can have a temperature, vacuum can not. Nevertheless, vacuum is a sink close to 0 °K and it can transfer heat through radiation, just as it is with visible light and all electromagnetic energy.

Heat radiation is infra-red "light" and thus electro-magnetic energy. Heat transfer through radiation in Watt is given by the basic formula: $\mathbf{A \cdot 5.67 \cdot C \cdot (T/100)^4}$, where **A** is the radiating area, in m^2 , **C** is the emission factor for the radiating material, which varies between zero and one and **T** is the absolute temperature of the radiating surface.Hence, if we have a radiator at room temperature, say 298 °K and we have a perfect radiator material (so called "black body" (with **C = 1**) the radiated heat is $5.67 \times 2.98^4 = 447$ Watt/m^2

This is about what the human body at work gives off. If there thus are quite many people in a settlement structure on the Moon, or in a spacecraft, you are either looking at rather large radiator areas, or using heat pumps instead, that brings the waste heat on a higher temperature. But those need drive power, that also must be cooled off. This requires a larger power generating system and is one of the present problems with the ISS, for which reason now research is going on in NASA, to develop heat pumps, that need very little drive power (you can say air conditioner, or refrigerator also - it is the same basic machine, just different use).

All energy that is brought into the system in whatever form, will decay to heat at cabin temperature and in order to keep that temperature constant, all that energy MUST be cooled off, at the same rate as it comes in, every single Joule of it. There is thus no "waste" heat and "useful" energy in this respect, because also the useful energy decays to "waste" heat at cabin temperature. We can consume fuels, but not energy and thus what comes in, must go out. (if you say this is nonsense - your trash bin please, don't read further!)

4. Energy management

a) We could store solar energy with hydrogen, to use it during the long Moon night. On the Moon we could produce hydrogen by heating the regolith and to my understanding at rather high temperatures, around 800 °C and higher, but I don't know how much energy is needed for this. To do this with solar energy would be possible with focusing mirrors. Then we need to liquefy this hydrogen for storage, that means to cool it down to 20 °K. Say the gas was released from the regolith at 1073 °K. Its specific heat is around 15 kJ/kg•K thus cooling energy needed is (1073 - 20) x 15 = 15.8, say 16 MJ/kg. To liquefy it, its fusion energy is just 0.45 kJ/kg and can thus be neglected. This 16 MJ/kg must be cooled off to the vacuum!

Say we process only one gram hydrogen per second, the needed cooling power would then be 16 kW (16 kJ/s). The only way to quickly liquefy the hydrogen is initially by radiation, to get it quickly a few hundred degrees down, but then further with a liquefaction machine (a kind of super refrigerator-freezer), that takes a lot of drive power, which has to be cooled off also, not to mention that this drive power has to be generated first and thus the overall efficiency becomes very low, IF it can be done at all. Then we have to do the same with oxygen, that is said to be in the regolith as well. We must also store this oxygen in liquid form, so we can use it later together with the hydrogen.

b) A problem with hydrogen is that is very difficult to handle. As a gas it is not only very explosive with oxygen, but it takes a large volume at atmospheric pressure, 10 times more than air and it also tends to exude through most metals. Certain car manufacturers therefore are developing materials that can absorb hydrogen gas in large quantities, to store it there at a lower temperature and release it again at higher temperatures. But these are temperatures between normal air temperature and a few hundred degrees up, thus we still have a heavy cooling problem with the hot hydrogen supply from the regolith. Then we still have the oxygen to liquefy, unless that also can be stored in a similar way as the hydrogen - I don't know. Besides, the big talk is that from the regolith we can produce vast amounts of rocket fuel and for that we need to store both hydrogen and oxygen in liquid form - it may show to be cheaper on Earth to do.

c) We can also store solar energy, with voltaic cells converted to electricity, that powers an electrolysis process, but then we still need liquefaction machines to get the hydrogen and oxygen in liquid form, again at very low overall efficiencies (the electrolysis process must be cooled also and not a little, 40% of the applied energy). If we then burn it later, or feed it to a fuel cell, we get much less useful energy out than initially was stored, decreasing the efficiency further, plus an additional cooling problem, as fuel cells get very hot.

To store it in regular electrolytic batteries, at a far higher efficiency, appears to be the better way in the end. Whatever way we turn it, energy storage will remain to be a big problem, that is far from solved as yet. Basically this has to do with the Second Law of Thermo, saying that energy tends to spread out, unless it is prevented to do so. Because perfect insulation does not exist, there are only two ways to prevent energy from dispersing, to store it permanently and that is either to store it chemically at ambient temperature, or to place a weight on a certain height. It can lay there for thousands and millions of years, but when finally someone throws it down, it will do the same work as was done to lift it up (ideal case, of course).

d) To generate electrical energy from anything else but solar and nuclear, or brought fuel from Earth, would be by burning the released hydrogen and oxygen from the regolith, but that would make it an energy source, which is generally denied, nevertheless...... point e.

e) In summarizing, obtaining and handling hydrogen from the regolith is a problematic thing, because it is so hot.
Then it is said that the regolith contains oxygen also - wouldn't it react immediately with the freed hydrogen, already inside the regolith, that then would give of very hot steam, instead of hydrogen gas? In that case, we can't get the hydrogen out of the regolith by heating it - an other way must be found. The bond energy between hydrogen and oxygen is 120 MJ/kg, which is released when they fuse to water, good three times more than what the combustion of gasoline and diesel develops and at a temperature of around 2000 °C. That can have very interesting consequences, as I discuss at the end of this chapter.

// So far the basics section.

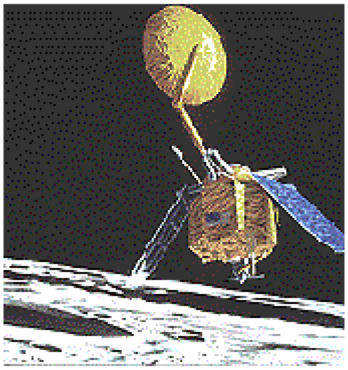
Landing spacecrafts follow a ballistic path and in order to have the maximum possible payload, will have just enough fuel to bring their speed down to zero for a smooth landing on the Moon, but the exact location of touch down is quite unpredictable. To make it exact, they would have to keep themselves 'floating' over the ground by rocket power, which is of course six times less than would be needed on Earth, but that is weight only. If they want to maneuver sidewise, they have to use rocket power in the desired direction, by which the craft gets speed and thus gains kinetic energy. When a craft wants to stop at the desired location, it must reduce that speed to zero with opposite pointed rocket power and the amount of fuel for the whole operation has nothing to do with the Moon's gravity, but with the mass of the craft only, its inertia, which is the same as on Earth, or anywhere in the Universe.

Not having enough fuel for this, but for a soft landing only, a deviation of a mile around the calculated 'point' would be rather accurate. Therefore, a rather large safety-distance must be taken into account, to avoid the risk of crashing on existing installations and so the various crafts will land a few miles away from each other.

As to the surface of the Moon in general, how can we know from just a few landing sites and claim that the whole Moon's surface is covered with a dust layer, varying between a few centimeters and twenty meters, even hundreds of meters?

Naturally, as the Moon's surface is equally hit by solar radiation all over (on the same latitudes, of course), and there is no wind and water, nor anything that can move material around on the surface, the regolith layer must be of a rather uniform thickness everywhere on the same latitude and if not, variations in thickness could only be due to different compositions of the bedrock at various locations, by which it pulverized to a larger or a lesser extend.

Hills of dust cannot be for that reason and such apparent dust hills likely are of solid rock, that is covered with a dust layer. Naturally, on steeper hill sides there cannot be much dust, as most of it slid down and thus, at the foot of such hills and mountains, indeed very thick dust deposits could be present, possibly hundreds of meters locally.



Hence, prior to any settlement units landing on the Moon, its surface must be explored by unmanned robots, to find locations with the thinnest dust layers. Possibly this also can be done and better by radar mapping from orbiting robots, but the areas to explore are huge - it may take years to find more or less suitable locations for a Moon base settlement. Moreover, for an orbiting radar robot, a 20 meter thick dust layer is almost undetectably thin, let alone just a few meters, or less. New technology has to be developed, to measure thickness gradients.

This seems now to have been done with the Lunar Reconnaissance Orbiter (LRO), as shown on the left, that is scheduled to be launched in October 2008 and will orbit the Moon to scan the surface at an altitude of as little as between 50 and 30 km. The project has been delayed though and the LRO will be shipped to NASA's Kennedy Space Center in Florida in early 2009 to be prepared for its April 24 launch aboard an Atlas V rocket. See the announcement here: http://www.nasa.gov/mission_pages/LRO/news/lro_milestone.html

TEMPERATURE CONTROL

There is an other basic condition, totally ignored by the artists-designers and SF-writers, which is the matter of temperature control. I have never seen any for the purpose designed radiators on such presentations. Instead nicely lined space crafts, often with large windows for scenic views and that's it. More realistic presentations of bases on the Moon show cylindrical structures, apparently having been parts of previous fuel tanks and space crafts and they look good, like this one here below.

This designer has clearly thought of what can be done and what not. Shiny reflecting white cylinders and no large windows. But yet no radiators, unless this base is thought to be near the poles, where the sun stands very low over the horizon. Then the roofs could be radiators and as they appear to be black, I think this is indeed the case, so I'm fully in agreement with this presentation.

To judge of the "footsteps" in the foreground, it even appears as if these cylinders can "walk", which would indeed be a low-energy method to move them to desired locations - smart!

A totally reflective surface is also a non-radiator and thus the temperature inside the settlement structure would quickly rise above allowable levels. Therefore, the idea of covering a habitat with a thick layer of Moon soil, as to isolate it from the "cold" Moon night, is about the worst thing one could do. Covering the habitat with a layer of Moon soil (regolith) to such a thickness that its temperature in the central contact volume with the habitat wouldn't change by day and night conditions, would mean a perfect insulation and is thus useless, unless the habitat is connected to some kind of cooling radiators outside the soil cover. Any lesser thickness of that cover, that would do to cool the habitat during the Moon night, would inversely heat it up during day time, when it absorbs solar heat and thus turns it into an oven. Also then cooling towers will be needed and thus the only advantage of a soil cover would be protection against meteorites, which is quite an important feature nonetheless (I would prefer a cave or deep ravine for that purpose).

As to temperature control of a habitat, the only feasible way is it to have a shiny polished outer shell, that neither absorbs, nor gives off any radiation and has a separate radiator device (cooling tower), turned away from the sun during day time, that radiates off the energy that has decayed to heat at room temperature inside the habitat. This radiator is then the warm side of an air conditioner. A typical value for a radiator to vacuum is around 800 Watt effective per square meter, at 100 °C (212 °F) and only half of that at room temperature (no air conditioner used). A convective heat exchanger of the same size on Earth, would have a multiple of that capacity. So, you can imagine what the size of a practical cooling system on the Moon becomes for a craft having many people on board (not to mention the energy supply to power it).

If the shell of the habitat would be a perfect reflector (which it can't be), its temperature would be the same as that inside the habitat, regardless whether the sun shines on it or not. As thus a practical shell will exchange some radiation heat with the vacuum and thus will have a varying temperature, an inner insulating layer is needed, but nothing much excessive - a few inches thick would do (I have used a sandwich design, with much thicker insulating material, but not for the purpose of insulation, but for mechanical strength and protection – follow the link at the botom of this paper).

Likewise, when you see artist-designs of space-stations orbiting around Earth and the like, having large glass-areas to provide 'magnificent' views, these window structures, if not shielding off everything but visible light, would most of all cause a "green-house" effect, that would turn the inside of the craft into an oven. Of course, sufficient temperature control systems in such fantasy designs are conveniently assumed (if at all thought of), without any thoughts if such is feasible to do from an engineering point of view. Believe me as a thermo engineer, temperature control in vacuum is not the easiest thing to do, to say the least. Thus the problem is not how to keep the temperature of the interior up, but rather how to keep it down.

The only way is by radiation and therefore there must be separate radiators (the opposite of reflectors) mounted on, or around the settlement structures and be of such a design, that they always face away from the Sun and heat radiating surface materials around. Ideally they should be directed straight up, vertically into outer pace, to radiate the excess heat into 'nothing'. I have designed such 'cooling towers', that are mounted vertically, shielding of all radiation around. Such towers could not be used on the Moon's equator, where the sun radiation would enter from above at "noon", but then, as people would like to have a view on Earth, which at the equator would be straight above their heads, you rather would want to have a settlement on higher or lower latitudes, where the Earth stands lower over the horizon (it doesn't change its position on the "sky" - only the Sun does).

Because no perfectly reflective surfaces can be made in practice, the thin shell will alternately become warm and cold. This causes considerable tensions in the shell material (if metallic) - must be designed for to cope with. A basic design feature is to have several smaller units connected together, instead of an equivalent bigger one, because the temperature-tensions in materials increase with the size of the shell. Another one is to have a liquid layer, circulating in contact with the shell, to obtain a rather uniform temperature of the whole shell all around. This however would complicate the design, with resulting hazard risks of failure (leakage, etc). Keeping a design simple is the first thing to strive for, the simpler it is, the less can go 'wrong' (Murphy's Law - ever heard of?). On the Moon and in space, you don't want anything to go wrong, because 'death penalty' is placed on it.

From all this follows that the outer surface area of settlement structures should be the smallest for the largest enclosed volume. The sphere is the optimal shape for this condition and so one would want to design spherical settlement structures (and space crafts). However, when larger volumes are involved, such spheres (parts of) likely become difficult to launch and assemble in orbit. Cylindrical structures with half-spherical end caps, are the next best alternatives, more easily to build and to handle. Moreover, spherical structures are difficult to navigate with a just one-direction rocket engine only, because the mass center can easily deviate quite a bit from the geometrical one, causing a momentum. With cylindrical structures, having a diameter quite smaller than the length, such deviations are considerably less sensitive.

What also should be considered is that reflection increases significantly with shallower angles - grazing incidence. Also for this reason flat surfaces are very unfavorable - curved surfaces give the best conditions. No artist-designer, being unaware of, or wishfully ignoring physical and engineering basics, has any consideration with such basics. See such a "qualified" artist impression for a structure on the Moon at the left.
(taken from: http://www.rombaut.nl/engindex2.htm)

Among other things, you see there large, flat, glass-like surfaces, which not possibly can have the mechanical strength required to withstand the pressure force (10 metric tons per square meter at 1 bar pressure difference). Apart from this, there is the air pressure sealing problem. Leakage is not a function of pressure difference, as most laymen think, but from pressure ratio ...which is infinite to vacuum. Of course this doesn't mean that the leakage becomes infinite, just that against vacuum 1 bar pressure would leak as much as 100 bar, or any higher pressure would do, because in all cases the pressure ratio is infinite (divided by zero).

However, the Moon actually does have an "atmosphere" with a pressure so low (3 •10-15 bar) that it approaches absolute vacuum, but is not. Hence the pressure ratio does not become infinite, but is still a 15 digit figure. A tiny leak, that would not be serious for a submarine at far greater pressure differences, would be lethal for a space craft ..or a space-suit.

Therefore all sealing lines between movable and connecting joints, much be 'unbroken' ones (circular, ellipsoidal, or at least rounded - no sharp corners) and therefore you won't see any rectangular pistons in pneumatics and hydraulics either - ye can't seal them sufficiently. Just look at all these none-but-corners cubicles here, it gives me the shivers.

Moreover, also largely ignored by all artist-designers, the solar radiation on the Moon's surface is of a DEADLY nature. In consequence, the flat "windows", seen on pictures of the Apollo's LM are in fact radiation filtering screens. The actual windows behind them, are rather mall rounded ports of a transparent material ("glass"), that has the required mechanical strength. Thus forget large glass-like structures on the Moon, unless a futuristic material would combine all the required properties of mechanical strength and radiation filtering, also keeping out the heat radiation, that otherwise would turn these structures into ovens, rather than "green-houses" only.

ENERGY SUPPLY

This may be the most ignored part of all artist-designer concepts. Most of them assume that there is plenty of solar energy available on the Moon's surface. Surely true at day time, but night and day on the Moon last 14 earth-days each - no solar power available during two weeks (unless at the Moon poles)! Whoever is skilled in the problematics of energy storage, will realize that this is a major prohibitive factor for a continuous power supply from solar energy only.

Most artist-designers have heard of fuel cells and even that the Moon's dust and rocks contain large amounts of oxygen and hydrogen - problem "solved". Alas, erroneously they see hydrogen and fuel cells as energy sources, but these are in fact energy converters only - the prime energy source is a whatever other one (see basics section, 2c). Fuel cells need a continuous supply of oxygen and hydrogen, to produce electricity and water (steam). These elements do not occur in free form on the Moon, but in rather strong chemical bounds in silicates - I quote from aforementioned web page:

" The nearest star [the Sun] puts out prodigious amounts of particles called the solar wind. Composed mostly of hydrogen, helium, neon, carbon, and nitrogen, the solar wind particles strike the lunar surface and are implanted into mineral grains. The same solar wind gases may prove useful when people establish permanent settlements on the Moon. Life support systems require the life-giving elements: hydrogen and oxygen (for water), carbon, and nitrogen. Plenty of oxygen is bound in the silicate, minerals of lunar rocks (about 50% by volume) and the solar wind provided the rest... "

and from this page: http://www.uswaternews.com/archives/arcglobal/9resthi8.html"

"*..... Hydrous minerals do contain water, but it is so tightly bound chemically to the crystals that it would take temperatures up to 1,500 degrees Fahrenheit (815 Celsius) to break those bonds and extract useful water, he said ."*

Hence, available energy to do all this is #1 to provide and if fuel cells thus would have to provide there own energy source, the net result even becomes negative. The Moon's energy and other resources are not for free - they have to be processed before usage and that takes energy (investment goes before profit)! However, it doesn't have to be like this, because a simple theory says that the regolith actually could be a self-sustaining fuel, powered by the Sun and as such no different from fossil fuels on Earth, apart from that it contains its own oxygen for burning - read more about that further on.

Apart from this, in absence of any sophisticated Lunar production technology to process the regolith, the first settlements have to do without these resources. If these first settlements would have to rely on fuel cells, the according fuel has to be delivered from Earth. The same of course is valid for building any solar plants on the Moon. Some visionaries think that solar panels, or mirrors in stationary orbit around the Moon, to focus solar energy on settlement locations, is a possibility. Not possible because the Moon rotates so slowly around its own axis, that such a stationary orbit would have to have a radius of around 86.000 km from the Moon's center and that brings the orbiting object into the gravitation field of the Earth, that ends on just around 40.000 km from the Moon's center (where the Moon's and Earth's attractions equal each other out).

Launching an object to orbit the Moon at a larger than 40.000 km distance, would thus bring it into a lasso orbit around Earth AND Moon, which is a suitable one for a future shuttle station between them. Of course, an orbit in a plain perpendicular to the Earth-orbit plane, or at whatever 'suitable' inclination, could have any size, but that would not be a lunar-stationary one and a thus orbiting mirrors would not have a fixed position over the Moon's surface.

Moon settlements have thus to rely on an other continuous energy source and the only available one today would be stored hydrogen and oxygen, to feed fuel cell converters, supplying electricity and fresh water as well.

A major cooling problem follows with it, as fuel cells are hot and produce steam (to be condensed to water, typically 2500 kJ per kg of mass.), a major cooling problem in a vacuum environment.

Would a small nuclear reactor be an alternative? Mind that a nuclear reactor only produces heat, which has to be converted into electricity under Moon conditions, requiring a conversion technology that still has to be developed. In addition, such a nuclear power station must be located far away from habitual locations (radioactive radiation hazards), where the energy is to be delivered to. Nuclear reactors have to be developed, that are not cooled with water only, but ultimately with regolith (Moon dust), in order to free the chemically bonded oxygen and hydrogen. These can then be used in fuel cells, to produce water and electricity (actually not, see basics section 4e) . Also the temperatures involved, cause a major design problem.

Breeder reactors are often cooled with liquid natrium, but still at around 600 °C - not enough to fully brake the chemical bonds and the higher temperatures required for that, cause a severe construction materials problem. Nuclear Moon reactors for this purpose, are still in the far future.

Steam turbines, to produce electricity from a heat source, need excessive cooling for the condensers. Easy to do on Earth, where an atmosphere and free surface water is available, but how to do in vacuum on the Moon? Moreover, the smallest steam turbines range in the megawatts (cannot be scaled down) - too much for a first settlement. However, I do have a basic concept for the use of steam power with displacement machines instead of turbines, that would be feasible on the Moon. It is based on a property of wet and saturated vapors, firstly measured by nobody less than James Watt, who in his days had not the technology available to do anything with it and later forgotten by all engineers after him. It would allow to recycle most of the dissipated heat from people and equipment, making a settlement self sufficient on energy and greatly reducing the need of cooling capacity. I refer to it as the COMPEX-system (see below).

Apart from this, fuel cells therefore appear to be the only feasible converters that can be made with today's technology. But as mentioned, the cooling problem could prohibit larger units to operate. In fact, I only see the COMPEX as the only feasible energy solution that can be done with to-day's technology. From all this follows that the first settlement units that land on the Moon, must have an own power supply system, partially consisting of auxiliary solar panels (voltaic cells) and have enough oxygen and hydrogen stored to run fuel cells with, especially during the long Moon night.

However, an eco-system with animals like fish and chickens, in combination with biogas generation from a waste-water system, could provide some energy to run fuel cells with. Methane can be produced in the process, that a certain type of fuel cell can use to generate electricity. See a description of that here:
http://www.nature.com/nature/journal/v400/n6745/full/400649a0.html

This I see as a far better alternative than using hydrogen fuel cells, because human and animal wastes actually produce much methane and other carbon hydrates. Therefore, the first habitual units landing on the Moon must be hotels, that provide a one or two week's stay for their guests. These hotels will prove that one actually can live on the moon and also will give the experience needed to develop the according settlement structures and systems for permanent inhabitation.

Due to as yet non-existing service facilities on the Moon, these hotels must be fully self-supporting over a certain time interval between receiving new supplies, not being able to use any of the Moon's resources, but solar power only. This of course means that regular supplies of life support utilities must be delivered by service units to those hotels, together with arriving new guests and then the question becomes, how? In addition, these service units must have enough rocket fuel left to bring themselves in Moon orbit again, where they can meet with other space crafts coming from and returning to Earth, to get refueled and to load new cargo and to exchange leaving and arriving guests.

THE FIRST MOON SETTLEMENT UNIT

It will all start with tourism, that not only generates the money to develop and build Moon settlements, but that also is an important stage in the technical development itself. The only way in my view to transport people from Earth, firstly into Earth orbit, is with using the pickaback-principle:
http://www.dfg.de/aktuelles_presse/ausstellungen_veranstaltungen/raumtransportsysteme/mission1_basis_e.html

preferably to a rotating space hotel, that I made a basic design of, as shown here:
http://www.lunar-union.org/space-tourism/space_hotel.html
and that one could be in a lasso Moon-Earth orbit, so the guests will have a comfortable journey to the Moon, that will take around four days (you wouldn't want to travel under Apollo-astronaut conditions, would you?).

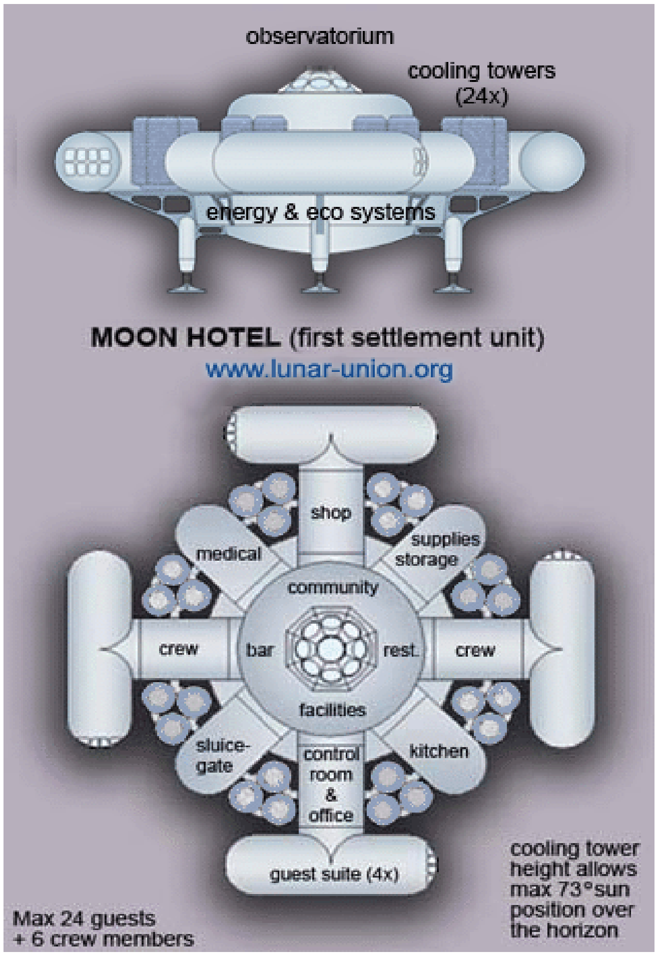
I'm using the same modules of this rotating hotel for my design of the Moon based hotel, as shown on the next page. This enables uniform production with lower manufacturing and maintenance costs, but most of all lower development costs. Once the orbiting space hotel is in operation, the structural development of the Moon based hotel is largely done at the same time.

This way moon tourism could start already before there is anything on the Moon itself yet, just orbiting around the Moon, prior to returning to Earth orbit. In the same time it will be a major stage of the actual moon-base development. After the first Moon hotel has landed with a basic crew only, more supplies and equipment will be brought in by supply shuttles from a Moon orbiting space station, that also consists of the same modules as the Moon and space hotels. This and other future space stations will be the support, maintenance and emergency centers for Moon bases and also serve as space ports for arriving and leaving travelers.

Most of these supplies, not in the least water, will be installed in the now empty, torus-shaped fuel tanks of the hotel, in order to complete an energy and eco system.

I'm thinking of algae cultures as a source of oxygen and to farm fish, the wastes from that feeding the algae growth. There are several types of algae. One type needs only carbon dioxide and sunlight to grow and produce oxygen. This is what plankton in the oceans does and it stands for 60% of the Earth's oxygen production.

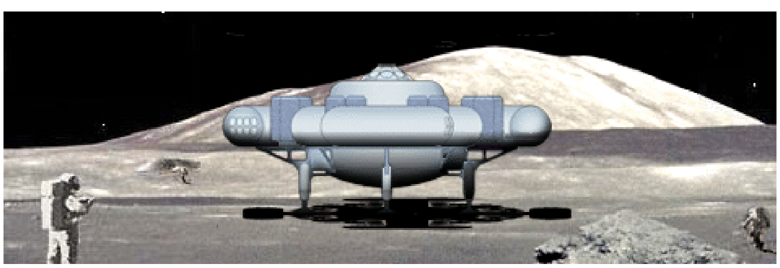
Thus there will be water tanks having artificial "sunlight" above and cabin air is blown with diffusers into that water, in order to let the algae remove the carbon dioxide and produce oxygen, thus keeping the cabin air breathable.



Moreover, people breath out water vapor also en thus the humidity of the cabin air increases. The recirculation of cabin air thus first goes through a cooler (radiators to vacuum, no drive power needed - some of the cooling towers shown in the illustration above), by which the water condenses out and this is pure potable water for reuse. The thus dried air is diffused into the algae tank, where it comes out oxygen enriched and is humid again - a second condensation phase recovers more potable water. The water in the algae tank is replenished with non-potable water from other recycling systems.

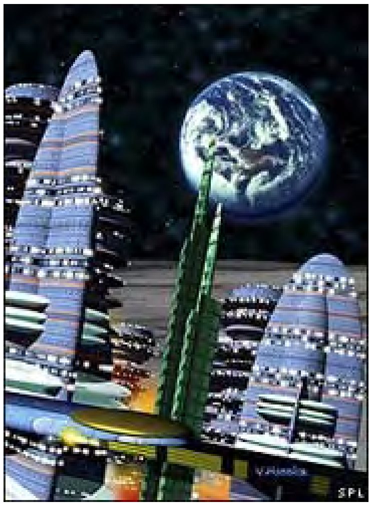
In Thailand I once saw a chicken farm over a pond with a certain kind of fish in it - "pla dook" it's called in Thai, I don't know the English, or Latin name. This is a very popular consumption fish and it can actually feed on the chicken shit, dropping into the water, as I observed. This could be done in the Moon hotel too. The chickens are fed with prepared food rests from the people and whatever else can be recirculated. The water in the fish tank below contains another kind of algae, that feed on the fish wastes, thus cleaning the water there and possibly producing oxygen as well. Thus we can process cabin air with oxygen and removed carbon dioxide, recover potable water and produce food (meat and eggs) in the same time.

Naturally, the hotel is too small to become fully self-sustaining on around 30 people staying there and thus will need regular additional supplies, but the eco and energy systems that are there, will give useful experience to improve them later on in larger systems. Once the conditions for more people to stay at least a week are created, the hotel can be used for hosting paying guests - the onset of an oncoming Moon colonization.



a first moon hotel landed on the site http://www.lunar-union.org

SUMMARY



With the above I have roughly outlined what the basic conditions would be to start colonizing the Moon. It will be a long process, starting with one hotel, becoming the core of a future city - more of them will follow. These cities will look like nothing present artist-designers envision, such as shown on the left. Imagine what one tiny meteorite could do to these towers under pressure? Apart from how to build them - concrete? Yes, there are concepts of making Moon-concrete from regolith and that doesn't contain water, but how to poor it as a fluid in vacuum?

Surely they are fluid in the laboratories on Earth, but to my knowledge there is no fluid substance known that would not evaporate in vacuum. Moreover, how to control the temperature in the concrete during pouring and curing? Moon concrete would have to be a material that is independent of temperatures and vacuum conditions - I want to see them do it. Steel, or whatever suitable metal(?) would have to be produced on the Moon and for this we definitely do not have the technology to-day and thus this sky-scraper city is pure Science Fiction, but it looks nice, doesn't it?

Another thing are the forces of air pressure inside the structures, that actually tend to lift them up from the ground. The sky-scrapers actually could have weight enough on their relative small ground surface to counter act that upwards force, but look at these cupolas here, on another fantasy design below.

It's difficult to estimate the size of the largest one, but a good guess would be around a 100 meter in diameter? Let's say 50 to be on the surer side and that it has 40% of the according sphere's volume. In that case the upwards air pressure, being 10 metric tons per square meter would be around 20.000 tons. The volume of this cupola would be around 30.000 m^3.

If it were of solid material and because of the lower gravity, the Earth-weight of that would have to be 6 x 20.000 = 120.000 tons, which gives a density of 4 tons/m^3, which is 4 times that of water (The Moon's own density is 3.3).

As we may assume that at least 90% of the cupola is supposed to contain air = useable space, the construction material of the shell would have to have a density of 40. If less, this cupola will lift from the ground!

Sure, it can be closed on the bottom with a ground plate - no more lifting force. True, but that ground plate will have to be very thick to provide the mechanical strength, unless this cupola is just the part of a spherical design, the rest of which is under ground? Yes, that I could believe in, but not in the ground works needed for this, nor in the construction works of the rest, at least not with today's technology. Observe the large blue area, which most likely are solar voltaic cells to generate electricity - at least the same area would be needed for cooling off all that energy again and it must be shielded from sunlight falling on it - it seems to be missing here. But sure, also this design looks nice, doesn't it?

It will take decades, a century to establish an infra-structure, that would allow such huge complexes to be erected and operated, using mainly local resources. Furthermore, the idea of huge buildings contains a totally unacceptable risk, in case any misfortune would happen that could decompress these buildings, e.g. a larger meteorite impact - hundreds op people would die in the event.

For pure safety reasons, many smaller habitual units must be used. That is what we have to start with anyway on today's technology level. But perhaps there are caves on the Moon? That would be a perfect shelter, if we can seal and control the temperature in it. On the other hand, if such a large cave, possibly with hundreds or thousands of people living in it, would get decompressed, they will all be dead (the seal may break). Better to leave the cave open and have the same units in there as would be elsewhere on the surface - the cave protects against sun and meteorites just the same.

Using local resources is imperative in the longer run, because a larger Moon society cannot be supplied with materials from Earth only. The huge funds needed to establish and maintain a large infra-structure must inevitably come from income of local production - a Lunar independent economy.