A moon base may seem like a far-off promise from some vote grabbing space race politician but now it is being reconsidered as a possibility by the major national and private space agencies across the world. A moon base would not only act as a possible 'service station' on long-haul trips to Mars but as a place of research and potentially a future manned colony. But how could we build a moon base? What physical problems would we face? And would it truly be economically viable for someone trying to make a living?

Humans need 3 fundamental things to survive: water, food, and shelter (and keeping up with the Kardashians in my sisters' case). Food is relatively easy to transport to the moon compared to the other two, you just launch it up on million dollar space rockets, tons at a time, and land it safely on the moon's surface within half a mile of your base. Easier said than done, I know, but then again, it's been done before. But shelter and water are a different story. With a surface gravity of $1.62N.Kg^{-1}$ and a surface pressure of $3*10^{-15}$ bar[1] conditions on the moon make it harder to engineer any sort of structure with the same tools as we use on earth. The moon's lack of atmosphere means any dust thrown up by drilling or digging could suddenly become a high-velocity particle. Dust could also contaminate the inside of the base as it adheres to the spacesuits with ease. The abrasive nature of dust could greatly reduce the life of airlock seals, therefore some form of brush or vacuum cleaner would be needed to clean the suits and seals after every mission. There is also the problem of moonquakes; these can be considerably more powerful than those on earth and are hard to predict, this requires the structure of the base to be flexible and strong. The lack of water on the moon means that temperature is less regulated, leading to exaggerated temperature swings of -84.4^oC - $+48.8^oC$. Any moon base would have to be able to endure and counteract these swings in order to keep its interior temperature constant. This is a phenomenon already experienced on the ISS and presently is managed by thermal engineering.

The moon has no atmosphere and no magnetic field consequently the moons' surface is exposed directly to the suns' solar winds that carry harmful radiation. So to use the word shelter is to say it's a little bit more than propping some branches up against a tree. First, the problem of radiation, currently on almost all spacecraft and on the ISS, aluminium is used as a structural shell that helps protect against ionising radiation but it is expensive and heavy. There has been researching into polyethylene to protect against ionising radiation because it has a high hydrogen content which is good at absorbing and dispersing radiation, it can also be manufactured into bricks that weigh half as much as aluminium[2]. Although polyethylene would be a good material the volume that you would have to transport to the moon makes it uneconomical despite its weight.

So if there isn't a material practical enough for both transportation and protection what other option might we have? The answer lies in the very place that the base is being built, the lunar rock itself, the Regolith. Per unit areal density Lunar Regolith is only slightly less effective than aluminium and about half as effective as polyethylene[3]. But who cares, when you're counting the beans, lunar regolith is what's in abundance on the moon and so an unlimited, penniless resource. A study lead by Dr. J Miller made synthetic compounds that were of the same/similar chemical composition to Lunar Regolith and measured how far highly ionised radiation could penetrate into it. They found that with less than half a meter of lunar soil compacted to a density of $1.4g.dm^{-3}$ is sufficient in

[1] http://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html

[2] www.nineplanets.org

[3] Miller,J., et al, lunar soil as shielding against space radiation, radiation measurements(2009), doi:10.1016/j-dadmeas.2009.01.010

almost every case to stop primary GCR ions. So if you had walls 2-3 metres thick you are guaranteed both protection from ionising rays and micrometeorites.

A method, first suggested by Larry A. Beyer in 1985, for processing the regolith in order to turn it into a building resource was a wondrous thing called Lunacrete. Which could then be 3D printed around the metallic shell of the base by a robot such as the one that Foster and Partners is building in association with the ESA[4]. Normally with cement you heat limestone and clay at around 1500^{o}C, the limestone breaks down into lime and clay reacts further to form calcium silicates and calcium aluminates. Cement can be made from any proportion of $CaO:SiO_2:Al_2O_3$, on earth we would mix them with 65%CaO, 23%SiO_2 and 4%Al_2O_3 but lunar regolith has a CaO content of <20% although there are methods for enriching the soil[5]. So we have a possible way of making cement and can use the regolith as a sand substitute. We are just missing one key substance, a binding agent, water. Alternatives suggest using sulphur or epoxy resin but recently discoveries would suggest that water is present on the moon.

Water is fundamental to our survival, it's used in respiration and transports essential molecules around our body. But we also need it for chemistry, and cleaning, and flushing a toilet, and… water is everywhere. Therefore for people to live on a moon base for any period of time they would need water. We could transport it there by launching large chunks of ice and then 'crashing' them into the ground around the moon base as suggested by S. Alan Stern with his appropriately named SLAM program. Or figure out how to access water that may be trapped in the regolith and deep craters. In 1998, NASA's Lunar Prospector detected hydrogen deposits at both poles suggesting a presence of water. This was disproved by the ESA's space probe SMART-1, launched September 2003[6], it measured the Albedo of light reflected off the moon's surface in order to infer the chemical composition of the regolith. It found no trace of water. Despite this, it has been proved that at both the moon's poles there are craters in an almost permanent shade, the average floor temp being estimated at 90K so if ice were to have been deposited there in the past it could exist as an ice-regolith mixture. So, if we could find a way to cheaply and efficiently process the water that may be trapped on the lunar surface we could harness a resource that would have otherwise cost millions.

A moon base would be a huge resource in terms of the type of research we could perform, the moon's lack of atmosphere and light pollution means that observatories could take much clearer photos of the night sky. There could be research into very sensitive low-frequency radio astronomy that could detect cosmic background rays and thermal radiation from distant stars that previously would have been obscured by the earth's thick atmosphere. There could also be research into radiation, electromagnetism and effects of dust exposure to name a few from NASA's 'main lunar exploration objectives' study released December 2006.[7]

Although the Apollo missions brought back samples from the moon there is still a question of how was the moon formed. There is also the question of why does one side seem to harbour the most mountain ranges compared to the other? Its history suggests it once had a spinning iron core and moonquakes that have been recorded suggest it might have tectonic plates but we cannot prove these things without having a permanent base to do research that could take months to carry out.

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[4] www.esa.int

[5] https://www.researchgate.net/publication/283048239_ADVANCES_IN_MANUFACTURE_OF_MOONCRETE_--_A_REVIEW

[6] http://www.esa.int/ESA/Our_Missions

[7] http://www.nasa.gov/pdf/163560main_LunarExplorationObjectives.pdf

The moon has the potential to be a huge commercial sector in itself. Whether as a possible holiday destination, base camp for Mars missions or as a source of materials like aluminium and titanium, the moon has a lot of potential as a new conquest for the private sector. In September 2007 Google's Lunar XPrize announced it is offering $30million to the first team to land a space probe on the moon and complete a series of challenges,[8] this competition could lead to huge advancements in space robotics that might one day help support a moon base, such as help with building or searching for an appropriate site for the moon base to be located it will also help with the logistics of landing on the moon by providing data from the competing teams' successes and failures. This is an interesting venture as it'll be the first time the moon is targeted by the commercial sector, with small privately run teams building, launching and landing the craft rather than a whole space agency.

With many big names already trying to commercialise space like Richard Branson's: Virgin Galactic and Jeff Bezos': Blue Origin, it is only Elon Musk's SpaceX that has built and launched a craft that could leave earth's orbit. Currently, a Falcon Heavy rocket would cost $90Million that SpaceX claim could carry a load of up to 13.6 Tons to Mars.[9] But $90million is a little expensive for a start-up company to launch its first little base of operations. Even if they were to use the less powerful Falcon-9 rocket they would still have to raise $62Million and these cost increase dramatically when you start having to transport people. So would the early years of space colonisation be run by the big business owners? Even if the technologies became cheaper as more investment goes into space, by the time a small business owner can afford to set up shop on the moon the commercial giants would be looking at the next planet to colonise. Start-ups would have to crowd fund by getting people to deposit money in exchange for a place on the first stay in the moon base or for having a piece of memorabilia taken up with the first people, while also renting out research space to universities or space agencies. It's quite obvious it's a huge venture that could do without the huge costs and one that might see many companies coming together to focus on certain aspects of the project.

Bigelow aerospace is an American company founded by Robert Bigelow, they are on a NASA contract to build expandable, pressurised habitats. They launched their BEAM module on SpaceX's falcon9 in the unpressurized compartment of a Dragon spacecraft. Weighing in at 1,400kg it's obvious it would not cost huge amounts of money to transport many of these modules in one mission. Bigelow's next generation B330 module can house up to 6 people and has a 20-year lifespan, its walls are designed to reduce ionising radiation and offers 210% more space than the current ISS Destiny module with only 33% more mass.[10] Many modules like this could be connected up to each other and maybe, in future, be used as the first stage of building a moon base. A future version of this kind of expandable module could be inflated then a robot could 3D print a protective regolith shell around the module. I think this kind of module will become very popular with future manned space missions and may well be used in the first permanent habitat on the moon, and maybe even Mars.

Currently, none of the world's big national space agencies have any plans set in stone for building a moon base. NASA has compiled a list of objectives under 'What do we hope to achieve through lunar exploration?' and have said that they will take ideas and 'begin to lay out (their) timeline'. The ESA had their SMART-1 probe orbiting the moon on a 3-year mission in 2003[11]. They have plans to maybe install a base using robots but haven't confirmed any plans or a schedule. ROSCOMOS are apparently

[8] http://lunar.xprize.org/

[9] http://www.spacex.com/about/capabilities

[10] http://www.bigelowaerospace.com/b330/

[11] http://www.esa.int/ESA/Our_Missions

planning to install an exploration base on the moon[12] although their website doesn't offer much detail. India's ISRO has not declared whether they are looking at the moon. China's CSNA plans to launch a rover called Chang'e-4 in 2018 that will explore the far side of the moon,[13] but any mentions of a plan for a lunar base are currently just rumours.

A moon base could be both a huge scientific resource and a large commercial venture. Its prospects as a Mars base camp are fruitful for the moon's escape velocity is only 2.38km/s compared to the Earth's 11.2km/s[14]. It would have to be cheaply built by a mixture of inexpensive materials and as few journeys as possible. Sending robots forward to build the base before humans arrived would be the most efficient method. The base could consist of interlocking expanding chambers that are surrounded by a 3D printed Lunacrete shell. The base could be slightly elevated off the floor to protect it from any violent moonquakes, a feat that wouldn't be that hard due to the moon's low gravity. A moon base could act as the base of operations for potential exploration that covers far more area than any of the Apollo missions did. Water may be able to be extracted from locations such as Shackleton crater near the South Pole. The South Pole is in almost permanent daylight so a small area of solar panels would provide sufficient power. It may once have been some pipedream but I for sure am hoping to see the first permanent structure on the moon and will try my hardest to be that man who steps in first.

[12] http://izvestia.ru/news/618876

[13] http://www.planetary.org/blogs/emily-lakdawalla/2016/06220913-plans-for-change4.html

[14] http://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html