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A Dangerous Precedent; the Geodesic Dome as a Credible Space Architecture Typology

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Abstract

There is persistent employment of the geodesic dome as an architectural typology for use in the environment of outer space and in an extra-terrestrial, planetary surface context. So persistent is the geodesic dome typology in this context that it presents itself as an established vernacular architecture, regardless of the lack of tangible evidence of its functionality. This typology has been used in illustrations within NASA's 1977 publication, *Space Manufacturing Facilities (Space Colonies)* to herald, at the time, near-future prototypical concepts of lunar architecture. The typology has permeated the genre of science fiction and appeared in countless films and television series to describe realistic and credible examples of a potential space architecture to a global audience. Examples include, but are not limited to, *Earth II*, *Silent Running*, *Slaughterhouse 5*, *Battlestar Galactica*, and recently *The Expanse* television series. In a terrestrial and realistic context, designer Buckminster Fuller had championed the geodesic dome as a highly versatile structure capable of supporting a multitude of programs. More recently, Bjarke Ingels and his terrestrial architecture firm, BIG, has used the geodesic dome typology as the foundation for the 2017 Mars Science City project, where he seeks, 'to explore what a Martian Vernacular will look like.' The reality of the geodesic dome typology in the context of space is that it is an inefficient structure due to aspects that include construction, maintenance, and performance inefficiencies. Even when deployed within an extreme environment in a terrestrial setting the geodesic dome has underperformed, with the now deconstructed Amundsen-Scott South Pole Station in Antarctica an example of the form's underperformance. The station could not withstand the stresses placed upon it, by such extreme environmental conditions. Yet, the geodesic dome typology as a technologically credible habitat solution persists even though within architectural history and theory, it is emblematic of a failure of a *persistent* modernism and the architectural movement's development, of which the space architecture program finds itself birthed. This paper explores the development of the typology within the context of space architecture, the ramifications of such a pervasive architecture for the discipline of space architecture, and concludes with several directions that the discipline of space architecture might consider in order to progress in a constructive manner, away from such culturally embedded and destructive typologies.

Keywords: Geodesic dome, Buckminster Fuller, space architecture, vernacular, architectural ideology, cultural study.

1. Introduction

1.1 History of Buckminster Fuller & the Geodesic Dome

Buckminster Fuller (1895-1983) was an America designer who was interested in preventing the Earth's ecological destruction through energy-saving designs and an application of systems thinking to global management strategies [1]. Though Fuller has had considerable architectural impact through his integration of technology and design, his work did not initially receive universal support [2]. Fuller worked as an advisor for NASA from 1963 until 1968 as a part of the Advanced Structures Research project [3].

Though the geodesic dome existed long before Buckminster Fuller employed it to great effect, it became synonymous with the designer as he managed to register a patent for its use within structural applications in 1954 [4]. Aligning itself to Fuller's belief in doing more with less ideology the geodesic dome structure's appeal lay in its ability to be assembled from smaller components to allow for efficient transport. Geodesic domes can be constructed with relatively little material used when compared to the volume of internal space that is captured within them. With more than 300,000 geodesic domes of his patented structures constructed globally, Fuller is irrevocably linked to this structural typology [5].

Fuller sought to apply his patented geodesic dome structure technology to some very aspirational projects. Some of these involved encapsulating entire cities including Manhattan, as he believed this strategy of mass-systemization could bring efficiency to a city that was in dire need of it. Fuller's *Dome over Manhattan* (figure 1) occurred at a time when global awareness of limited resources and the concept of sustainability were rapidly developing [6].

Figure 1: Fuller’s *Dome over Manhattan*

In the 1970s, with Fuller’s input, futurist Athelstan Spilhaus proposed a self-sustaining domed city in north central Minnesota that was to house 250,000 inhabitants, nuclear power plant, and high-intensity vertical cattle farms [6]. The geodesic domes quickly began to represent systems of totalitarian control and the systematization of human life.

Figure 2: Montreal Biosphere

1.2 The geodesic dome in outer space

The geodesic dome has a long association with the extreme environment of outer space and extra-terrestrial surfaces of our local solar system. After the success of the Apollo lunar missions, there was much interest shown in the possibility of imminent and substantial lunar development.

The US Pavilion at Expo 1967 often referred to as the Montreal Biosphere (figure 2), played host to the exhibition *Destination: Moon* complete with simulated lunar terrain, together with mock-ups and used modules of former space missions. This exhibition exposed the public to the association of the geodesic dome and the space program [7].

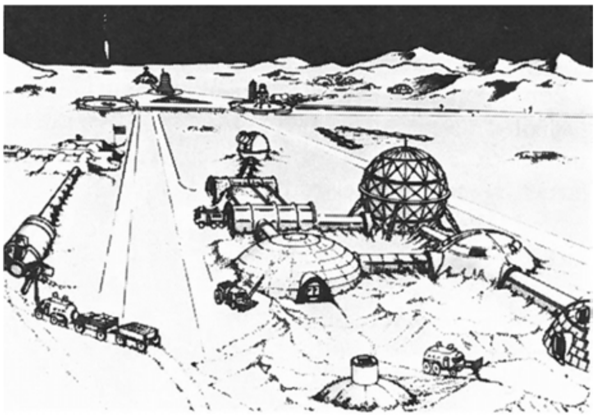

Figure 3: Illustration of lunar settlement.

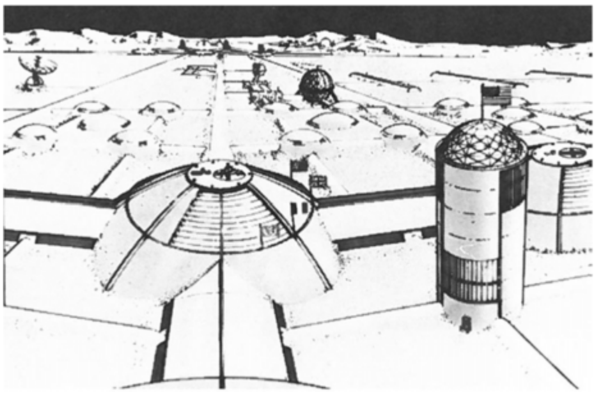

Figure 4: Illustration of lunar settlement

Proceedings from the 1974 Princeton conference *Space Manufacturing Facilities (Space Colonies)* concerning space colonization presented illustrations (figures 3 & 4) that depicted geodesic dome structures as significant components of this speculative lunar expansion. German aerospace engineer, Jesco von Puttkamer, who worked alongside Wernher von Braun at NASAs Marshall Space Center was responsible for the inclusion of these illustrations, framed within a presentation concerned with the development of space occupancy and the future of NASAs space program planning [8]. Geodesic domes have been suggested as independent structures or as part of a system to suspend local regolith (ISRU) above for deployment on the surface of Mars [9].

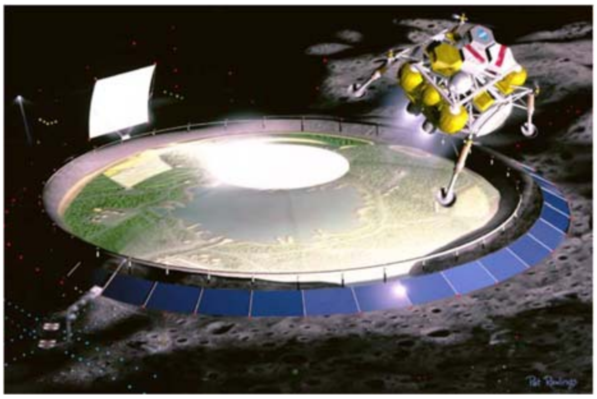

Figure 5: Shackleton Dome illustration, Pat Rawlings

In 2005, an illustration (figure 5) by NASA artist Pat Rawlings depicted a domes lunar settlement that covered the entire Shackleton Crater [10]. The dome had become manifest as a typology within the discipline of space architecture despite having never being proven to be effective under such extreme environmental conditions.

2. Cultural Readings

Figure 6: Geodesic radome, Misawa, Japan

2.1 Military industrial cultural readings

The structural and logistical advantages of the geodesic dome rendered it suitable for military purposes. Some of the most well-known military-purposed geodesic domes were the radomes (figure 6) that formed a networked line of defence that saw the domes house radar equipment along a 5000km stretch of the Arctic from Alaska to Greenland. This line of defence was termed the Distant Early Warning system and was a preliminary line of Defence for the US and Canada against long-range missile strikes from the former USSR during the Cold War. The geodesic dome became emblematic of the Cold War [11].

Geodesic domes were used by the US Navy as shelters for their marines. The dome shelters were assembled on aircraft carriers prior to being helicoptered ashore [1].

The geodesic domes also became emblematic of the technological and military might of the US as the domes were employed to cover US trade fairs around the world [11]. They functioned as lightweight and efficient gallery spaces for the technology yet were themselves technological exemplars that were absorbed by popular culture. An impression was made on the public imagination that could be likened to that caused by Joseph Paxton's *Crystal Palace* that was constructed in London for the Great Exhibition of 1851 [12]. It also heralded a new paradigm for the influence of technology on structures for public consumption.

Figure 7: Drop City, Colorado

Figure 8: Drop City, Colorado

2.2 Low-tech & US counterculture cultural readings

During a period that lasted from the mid-1960s until the mid-1970s the geodesic dome became symbolic of the US counterculture who valued a newly established environmental and ecological consciousness. Though it might seem counterintuitive that Fuller's geodesic dome structures could so easily be transferred from the military industrial complex to that of the counterculture it is a transition that is easily rationalised [13]. Fuller saw the geodesic dome structures as a universal means of efficient inhabitation regardless of who was to use them. They were to be of benefit to all.

The most well-known of this low-tech application of the geodesic dome was the Drop City commune (figures 7 & 8) that was located in south-eastern Colorado. Though Fuller was supportive of the, 'poetically economic architecture,' he distanced himself from the opposition of mainstream society that was symbolised in the domes of Drop City [14]. The inhabitants of Drop City sought to develop a development capable of social transformation, their, 'intention was to forge a holistic consciousness, not a proletarian one' [13]. Their suggestion was that the mainstream was not sustainable and that a more sustainable alternative was necessary.

Figure 9: Poster of the film, *Silent Running.*

Figure 10: A model of the Valley Forge spaceship from the film *Silent Running.*

Figure 11: Scene from Slaughterhouse Five

2.3 Science fiction cultural readings

With its association to innovative technology and the space program, the geodesic dome was appropriated by the science fiction industry where it proliferated as a seemingly ubiquitous typology capable of working in a diverse array of scenarios.

The geodesic dome structure lent itself especially well to the science fiction chapter of the entertainment industry as its practicality and efficient nature meant that not only was it emblematic of cutting-edge military technology but that is was an inexpensive set piece.

Featuring heavily in science fiction films from the early 1970s that include *Earth II* (1971), *Silent Running* (1972) (figures 9 & 10), *Slaughterhouse 5* (1972) (figure 11), *Logan's Run* (1976), and *Battlestar Galactica* (1978) to name a few, the geodesic dome has never strayed far from film and television. Geodesic dome structures have recently appeared in the *The Expanse* (2015-Current), and *The Martian* (2015) (figure 12).

Figure 12: A scene from The Martian, 2017.

The geodesic dome as it has been deployed within all these examples is channelling the concept of a controlled environment within the context of an extreme environment such as outer space (*Silent Running)* or the surface of another planet (*The Martian*). Each of these examples do so however in the context of a 'doom scenario' that involves the threatening of a single life, multiple lives, nature, or all of human life as we know it.

2.4 Contemporary architectural cultural readings

The geodesic dome entered the architectural discipline alongside Buckminster Fuller in 1960 with strong academic representation from architectural historian Reyner Banham. Banham championed Fuller in what was to become a definitive text on the modern movement [15]. Fuller's dome was adopted along with many other of his architectural ideas that included the Dymaxion House, the 'home without a house' and the link between the closed system of a building to that of the closed system of the Earth, or *Spaceship Earth*, as Fuller termed it. With Fuller's systems thinking ultimately having greater value within the architectural discipline, the geodesic dome is better understood as an industrial vernacular architecture or a vernacular typology of the military-industrial complex [16].

Though not designed by an architect, built by the US Navy Seabees, and yet attributed to Buckminster Fuller, the *South Pole Dome* (1975-2003) is still a considerable contemporary expression of this vernacular typology [17]. Of importance is that it was constructed in the extreme environment of the Antarctic and as such defines a weak relationship to the proposed of-Earth geodesic dome installations of the 1970s and found in science fiction.

Figure 13: *The Eden Project*, Nicholas Grimshaw, 2001.

The 2001 *Eden Project* located in Cornwall is one of the most well-known geodesic dome-based architectures designed by a respected architect; in this case Nicholas Grimshaw (figure 13). Grimshaw is considered a figurehead (in the lineage of Joseph Paxton and Isambard Kingdom Brunel) of the British high-tech architecture movement and considers his architecture less of a style and more representative of functionality. The *Eden Project* consists of two lots of four adjoining geodesic domes that are home to an array of diverse climates, environments and the flora associated with each. The project was well-received and continues to be well-attended to this day [18].

Figure 14: BIG's *Mars Science City* proposal, 2017.

Contemporaneously, the geodesic dome has had a recent resurgence within well-known international architecture office Bjarke Ingels Group's (BIG) 2017 *Mars Science City* proposal to be situated in the United Arab Emirates (figure 14). The project is to operate as a, 'space simulation campus near Dubai where scientists will work on humanity's march into space.' [19] Reminiscent of the internalised cities from the film, *Logan's Run*, the project's four domes that enclose 17.5 hectares also integrate 3D printed elements from the local desert, no doubt as a way to develop the potential to understand the use of Martian ISRUs.

Though not commonplace, the geodesic dome remains popular in its original role as a lightweight, temporary structure used for a variety of situations much as Fuller had originally intended it to be. Geodesic domes are still utilised for emergency shelters with companies including Pacific Domes supplying 'mid-sized' domes for medical clinics and emergency food distribution [20]. The company Freedomes provides geodesic domes for corporate events and were responsible for supplying the geodesic dome that was used in *The Martian* to act as a part of the Martian base camp [21].

3. Dangers inherent in the geodesic as a space architecture typology

3.1 Lack of practicality

While the geodesic dome is extremely light for its weight, is structurally stable if constructed correctly, and encloses the greatest volume for the least amount of surface area, much as a sphere does, these are all qualities that lend themselves effectively to a solely terrestrial application. Fuller never developed the structure for extra-terrestrial applications and nor has anyone else developed it or tested it under such extreme environmental conditions. The South Pole Dome (1975-2003) took over three years to create in the extreme environment of the Antarctic and though there was no doubt plenty of room for improved efficiency in its construction, the Antarctic is not an environment where delays are invited.

Figure 15: Complexity in traditional dome construction, South Pole Dome construction.

Figure 16: The Montreal Biosphere fire, 1976.

There are many individual components required to be assembled in order to construct a traditional geodesic dome with many individuals required to carry out the labour (figure 15). Substantial site work and preparation is necessary to provide an accurate foundation as there is little margin for error if the dome is to be constructed with uniformity throughout. If a dome of significant dimensions is being constructed, supporting structures are necessary to aid in the construction of anything higher than the lower portion of the dome. This makes for a very labour-intensive structure which is not recommended on the surface of a planet or Moon. Such extreme environments place substantial restrictions on human activity makes regular activities into incredible challenges. The geodesic dome, while able to encapsulate considerable space, does not define much in the way of practically divisible space and results in a roof space that varies considerably due to its inherent semi-spherical form [22].

The Montreal Biosphere, though initially deemed a success after it played host to the US Pavilion, suffered a catastrophic fire in 1976 (figure 16). Started during structural renovations by a worker with a welding torch, the dome's transparent, acrylic membrane quickly and completely burned away leaving only the structure to remain [23].

The South Pole Dome suffered significant damage to its foundation base ring beam in 1988. Due to stresses caused by a dynamic and unpredictable environment, particularly snowdrifts and the weight of these on the dome over successive winters. To make matters worse, as a loud crack was heard to signal a problem and the damage could not be seen, the entire base ring had to be dug out of the ice and snow and every node and beam had to be checked. The numerous elements meant a lot of checking highlighting the difficulty in the inherent complexity of the geodesic dome design [24].

Though perfectly suited as a terrestrial replacement for tent-like and tent-scaled structures, anything beyond this type of temporary application has seen many significant complications arise. Each of the examples of failure mentioned did not result in any casualties as due to their terrestrial locations the inhabitants could retreat to the safety of the outside environment. On the Moon or on the surface of Mars, however, this is not going to prove to be so simple. These are environments that are not as tectonically well-understood as the Earth's and require oxygen-rich pressurized atmospheres that each provide their own hazards that the geodesic dome does not completely mitigate.

3.2 Ideological & cultural concerns

Though the discipline of space architecture has its ties to disciplines that include naval engineering, the ultimate goal is to support human life for indefinite periods time, not merely temporary periods. In this way, the discipline of space architecture finds itself under the influence of ideological and cultural concerns that would normally be reserved for traditional, terrestrial architecture, or architecture that is necessary to be conducive for a good life. As with terrestrial architecture, space architecture can also be representative and hold meaning. Even though the geodesic dome may have been casually used in illustrations that depicted future lunar settlements, the typology regardless of its hypothetical practicality also communicates ideals that could be in conflict with contemporary values.

The geodesic dome has, therefore, come to represent many things. From their initial deployment as lightweight emergency structures and then as radar housing they have come to represent the military industrial complex.

From their use in science fiction films the geodesic domes were not only used to represent the conservation of biological life but also as an optimiser of a biological system that often meant the there was no room for the weak, old, or sick. This was indeed the case in *Logan's Run* along with the added caveat that all inhabitants were put to death once they reached thirty years of age [25]. Here the domes had become representative of death chambers adding pressure to their inhabitants to maintain an optimum health less their existence be deemed unsatisfactory and that they be put to death. They had altered life to become operational and commodified.

Figure 17: *Biosphere 2* project, Arizona.

Though *Biosphere 2* was not entirely composed of geodesic domes the typology did feature in its design (figure 17). It was designed as a highly publicized research project concerning closed ecological systems, remaining the largest ever closed ecological system ever attempted [26]. Its considerable public failure (scientifically also) much like that of the Montreal biosphere fire and the South Pole Dome has instilled a lack of confidence in these structures ability to protect human life here on Earth let alone on another planet.

Fuller's dome has also come to represent the colonial and expansionist mentality of the West through the domes use in the illustrations to depict NASAs, at the time, plans for space colonization. While these depictions were produced at a time when issues with the 'frontier' mentality were still being unpacked, more recently, BIG's *Mars Science City* project has seemingly disregarded any concerns for the negativity associated with the frontier attitude [27].

Anthropologist Lisa Messeri believes that using 'nationalistic language of the frontier and settlement,' is limiting and suggests the condition of emptiness [28]. This false condition of emptiness that is conjured up with the term frontier is maintained by Ingels open intent to, settle foreign worlds. Though he states an interest in vernacular architecture that adapts, 'to the local climates and landscapes,' he practically immediately contradicts himself an dismisses these ideals stating, 'When you begin to inhabit a world that has no existing eco-system, environmentalism takes on a whole new meaning. The challenge is not to preserve the existing environment, but rather to design and engineer a whole new man-made ecosystem, making us take the step up from custodians to creators of our own little Martian circle of life.'[27] This is nationalist rhetoric on a techno-global scale representative of humanity. Ingels has now related the geodesic dome with territorial procurement and a contempt for the altruistic scientific motivations for exploring Mars appearing to be expansionist at best. Ingels' domes are clearly for Earth and may never see the Martian surface, but if someone of Carl Sagan's intelligence took issue with 'frontier' language in the context of space exploration then perhaps it would be wise to heed his posthumous caution [29].

Contemporary architecture's use of the geodesic dome has seen it become emblematic of a blind technocratic thinking commonly associated to high modernity. Even the space program eventually felt the need to acknowledge the damage that this association could have when it ceased painting the main stage of the Shuttle Transport System; white being the uniform of the moderns [30].

4. Directions

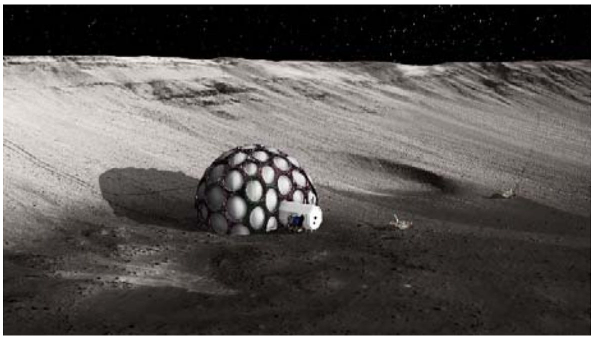

Figure 18: Perspective of exoskeletal geodesic structure with pressurized internal membrane project, Zachary Taylor, 2018.

Figure 19: Section of exoskeletal geodesic structure with pressurized internal membrane project, Zachary Taylor, 2018.

4.1 Define specific architectural typological research

Quite simply, NASA and other relevant engineering and design firms could define research into suitable architectural technologies. While this paper is examining the geodesic dome as a space architecture typology from a cultural perspective the dome has been deployed as a – stop-gap' rather than having been scientifically validated in the historic examples given. The geodesic dome could then simply be ruled out as a viable option, or ruled in if used in specific ways or is found to be structurally suitable. For example, there is certainly much potential for geodesic structures being used as an exoskeleton restraint for an inflatable bladder (figures 18 &19).

Figure 20: Instagram post of a prototypical inflatable geodesic habitat, Pneuhaus, IFAI 2019 tradeshow, Orlando, 2019.

Recently, Pneuhaus presented an inflatable habitat design based on a geodesic structure at the Industrial Fabrics Association International 2019 in Orlando, Florida. NASAs soft-goods department invited Pneuhaus to design an inflatable habitat design for microgravity (figure 20).

There is a huge benefit to being specific about pursuing viable space architecture technologies as construction methodology greatly affects mission architecture. There is a substantial difference in a mission that can support the transport of a 3D printer capable of utilising ISRUs in habitat construction versus a mission that transports all of the habitat components to be constructed by astronauts and/or robotic assistance.

Figure 21: NASA 3D Printed Habitat Challenge winner

The recent 3-D Printed Habitat Challenge held by NASA and partners is a successful example of such proactive advocacy for specific space architecture research (figure 21).

4.2 Openly communicate the viability of successful or potentially successful typologies

It is fundamentally important to communicate the viability of various space architecture typologies to ensure that it is widely known where efforts should be directed regarding suitable structures for off-Earth habitats. If untested and unviable space architectural typologies are permitted to proliferate this may certainly affect and limit novel and viable alternatives from being pursued. Although even though there may be viable and higher-performing alternatives this does not infer that they will be pursued. The TransHab concept developed by NASA in the 1990s is such an example that although rigorously tested and proven to be superior to the established habitat architecture was not implemented on the International Space Station until 2016 [31].

4.3 Increased integration of space architects within the commercial film and television industry

Figure X: Scene from 2019 film, *Ad Astra*, depicting ISRU structures that appear to be functioning as an anechoic chamber.

Realism (as long as it serves the story) is currency within the entertainment industry. Recent successful films that include *Ad Astra* (figure 22), *The Martian, Gravity, Solaris, Moon, Sunshine, Interstellar, and High Life* have been praised for high degrees of audience perceived reality.

The precedent for the successful incorporation of technical fidelity and realism in science fiction movies is Stanley Kubrick's *2001: A Space Odyssey*. It is still considered, 'perhaps the most thoroughly and accurately researched film in screen history with respect to aerospace engineering.'[32] Several technical advisers from Marshall Spaceflight Center worked on the film [X].

With considerable budgets for set designs to be exploited, it would seem like a mutually advantageous partnership between the space industry and entertainment industry could be reached. The film and television industry could be seen as a resource to assist, develop, and produce high-fidelity prototypical mock-ups that can actually feed into the space architectural development alongside the public's knowledge that their entertainment possesses an increased reality.

French philosopher Jacques Ellul (1912-1994) understood science fiction to be coping mechanisms that aid in the acclimatization, 'to the technological society as it really is.'[33] Though certainly aspirational, this also presents commercial entertainment as a vehicle to not only advocate for space architecture but also to potentially garner support for the continued development of space architecture, and potentially away from the geodesic dome.

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