Space-Time and Architecture

Francis Field[1]
Jon Goodbun[2]
Victoria Watson[2]

[1] Department of Ontological Theatre, Royal College of Art, London, UK
[2] Faculty of Architecture and the Built Environment, University of Westminster, London, UK

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SPACE-TIME AND ARCHITECTURE

FRANCIS FIELD*, JON GOODBUN AND VICTORIA WATSON
Dept of Ontological Theatre, Royal College of Art, Kensington Gore, London, UK.
Email: francisfield@hotmail.co.uk*

Architects have a role to play in interplanetary space that has barely yet been explored. The architectural community is largely unaware of this new territory, for which there is still no agreed method of practice. There is moreover a general confusion, in scientific and related fields, over what architects might actually do there today. Current extra-planetary designs generally fail to explore the dynamic and relational nature of space-time, and often reduce human habitation to a purely functional problem. This is compounded by a crisis over the representation (drawing) of space-time. The present work returns to first principles of architecture in order to realign them with current socio-economic and technological trends surrounding the space industry. What emerges is simultaneously the basis for an ecological space architecture, and the representational strategies necessary to draw it. We explore this approach through a work of design-based research that describes the construction of Ocean; a huge body of water formed by the collision of two asteroids at the Translunar Lagrange Point (L2), that would serve as a site for colonisation, and as a resource to fuel future missions. Ocean is an experimental model for extra-planetary space design and its representation, within the autonomous discipline of architecture.

Keywords: Architecture, asteroid, ecology, interplanetary superhighway, lagrangian points, ocean

1. INTRODUCTION

The project presented here describes the construction of an ocean in space, formed by the collision of two massive asteroids at the Translunar Lagrange Point (L2). The proposal for Ocean, emerged out of an investigation into socio-economic and technological trends framing current approaches to space. It was conducted from within an architectural design studio (The Department of Ontological Theatre (DOT) [1]) at the *Royal College of Art*. Within the school context this project was devised as a means of *escape* from the designing of *toroidal colonies* and *space stations* that continues to haunt our imaginations as designers today. In the context of this paper, Ocean should be understood as a new kind of space settlement: a complete but open-ended ecosystem that could be engineered in any way we choose - whether this be a site for terraforming, a reservoir for a Lunar colony, or a gateway to Mars.

If we are to take this project out of the milieu of architectural design research and present it within another discursive context - say that of aeronautical engineering - it is incumbent upon us to say a few words about the nature and possibilities of the *architectural project* as understood within DOT. Architecture is a practice that has a tension at its core in that it is an autonomous field of knowledge of, and investigation into, the production, occupation and perception of all modes of form and space. Yet architecture's very autonomy is relational in that it is constituted out of a series of interdependencies with other disciplines (including various engineering sciences, mathematics, art, philosophy (Fig. 1)), available agencies (including the *social* and *ecological* forms of matter available to use [from wood to paper to brick to steel]), and various modes of practice (building etc).

Traditionally architecture has primarily been concerned with the production of buildings, and the discipline has developed

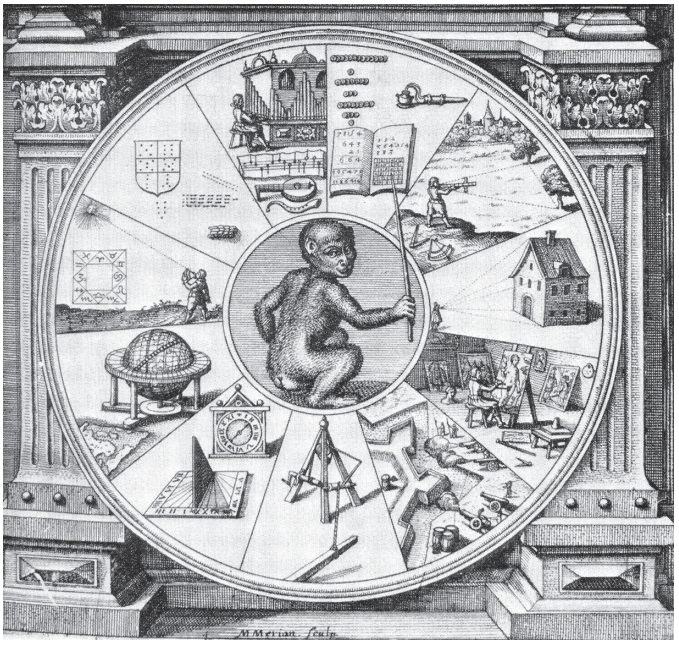

Fig. 1 We suggest that the nature of the relationship between architecture and other disciplines has its root in their shared ancestry, as diagrammed by Robert Fludd.

a conventional (i.e. socially shared and communicable) set of persuasive *representational strategies* that both allow it to communicate with other disciplines and trades (from engineers and scientists, to builders, to clients with the power to realise). It also creates an imaginative medium; a space of potential projects which is independent of any single one of these various disciplinary relations. It is important to note that while techniques of drawing have arisen out of architecture's interdependence with others, once they existed they have conferred a certain degree of *imaginational autonomy*. Therefore historically, through acts of drawing, architects have

been able to imagine and speculate upon potential futures, different from (though related to) whatever was the currently existing material and social reality.

This project is one such project. It draws together moments of existing research within other disciplines, but also suggests and specifies new or incipient materials and technologies, and gives them a social form through a persuasive set of representations (which themselves might also shift and expand the conventions of architectural drawing [and our social imagination]).

Ocean (like all oceans) is a vast, roughly defined quantity of water and other compounds (Fig. 2); it is best described as an unfolding *process of dynamical events* in space, rather than an *object of determinate proportions*. As such, this project entails a paradigmatic shift in the thinking about space design, in that it proposes a *process object* as opposed to the kind of *mechanistically conceived object* that tends to be assumed in architecture culture. For the purposes of this paper the project is presented as a work of design research that attempts to bring the space of NASA closer to that of the architect, by taking on some aspects of near future technologies and needs, and staging them as technical, material and poetic questions.

Here poetics (and *aesthetics,* since it belongs to the same *mode* of enquiry) is conceived as those aspects of perception rooted in felt experience rather than *knowledge*, of space. The concept of extraterrestrial habitation therefore, is treated as an inquiry into notions of *place*, human experience and *quality* [2] of life. The phenomenon of water in space is largely unexplored in terms that go beyond its technical application as radiation shielding etc. (as employed in the *Water Walls* [3] project). Ocean however, describes the manipulation of this elemental material in a manner that is not *industrial*, but *ecological* in method – in this sense, the project is believed to be unprecedented [4].

The minimum conditions that give rise to any architecture

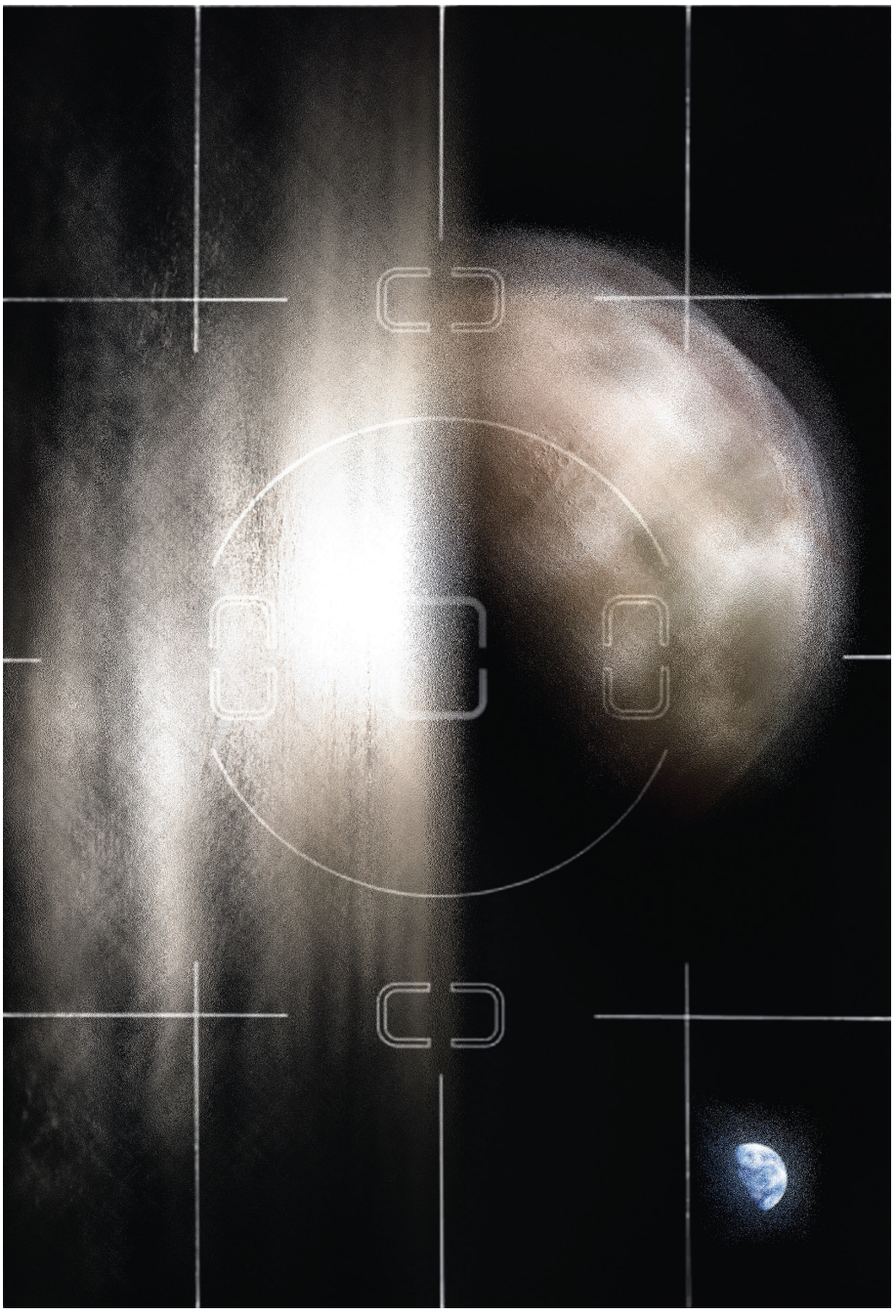

Fig. 2 It is through mythology and story telling that the human creature comes to understand the world in its own terms. In order to bring distant asteroids into a human frame of reference, familiar naming conventions are often adopted. In the case of the two swarms of asteroids borne (at L4 and L5) in Jupiter's orbital path, naming conventions were assumed based on opposing sides of the Trojan War, described in the Iliad - who's author, Homer, appears to have pre-empted Ocean:

"Full in the mouth is stopp'd the rushing tide,
The boiling ocean works from side to side,
The river trembles to his utmost shore,
And distant rocks re-bellow to the roar."

specific to a place in time are threefold: *material, infrastructural and socio-economic.* In space these conditions still apply, but their parameters are as yet undefined. On Earth there is a fourth parameter, this being *gravity*, which binds architecture to the *datum* against which it is normally read - the ground. These are the first principles of architecture that we must address if we are to develop an architecture of space. One ambition of this project then, has been to reassess these conditions in order to define parameters within which to practice. Once a framework is established, the construction of Ocean simply follows as the logical consequence of the initial distinctions formed within the new system – it being only one of an infinite number of trajectories that may unfold.

The projected value [5] of space no longer lies in political showmanship, but in its commercial exploitation (whether this be to facilitate holidays in LEO or a long-term lunar colony). The contracts recently agreed between NASA and *Deep Space Industries* [6] (a private company that plans to mine asteroids for precious metals and water) are indicative of the commercial approach to space exploration. They are also a product of the recognition that in order to step further into the Solar System (or even just beyond LEO) it will be necessary to harvest resources from space and construct habitable environments - rather than simply blasting them up there at great environmental and financial expense.

As the robotic spacecraft, *Rosetta*, prepares to land on comet *67P/Churyumov-Gerasimenko* [7], the space industry is closer than it has ever been to accessing the new and seemingly limitless material resource: *ice water*. Whether water is mined from asteroids, comets or the Moon, it is undoubtedly the most valuable resource in space. Being used to fuel both rocket engines and life processes, water is essential to all future missions – a prospect that does not go unmissed by the likes of *Deep Space Industries* and *Planetary Resources* [8].

Given this trend, it is not unreasonable to ask what *form* a future human presence in space might take, and whether it is one that should be endorsed? In their promotional video, DSI announced (with the vigour of a Hollywood blockbuster) *"We will be the gas station, the oasis for air and water, and the building supply centre for the frontier."* [9], occupying a series of near Earth outposts in huge rigs anchored to even larger asteroids (Fig. 3). Their vision may well come true, but is this the future we want to see, and as architects, is it possible to suggest an alternative?

Ocean simply proposes, rather than build a *gas station* to store water, why not construct an *ocean in space?* To do so would entail using infrastructural resources that, in recent years, have become available; these being the *Lagrangian Points* and the *Interplanetary Superhighway* [10]. The proposal also entails conceiving of the ice based asteroids as raw materials. The feasibility of situating the next space station at one of the five Lagrange Points of the Earth – Moon system (either L1 or L2) is already under investigation [11], because it would enable low energy transfer to the Moon and beyond using the Interplanetary Superhighway (IPS) – a term coined by Martin Lo and others at NASA's *Jet Propulsion Laboratory,* to describe the *labyrinthine* network of free or low energy transfer 'tunnels' that connect all Lagrangian Points in the Solar System. To maintain position at either L1 or L2, a body (or craft) of comparatively negligible mass (relative to the Earth and Moon) must perform a 'halo' orbit [12]; a kind of *chaotic dance* with the Moon. Once the dance is perfected, the body may maintain its position beside the Moon, expending little or no energy in the process. In this project, situating Ocean at one of these points has the effect of transforming datum into *land* (Fig. 4).

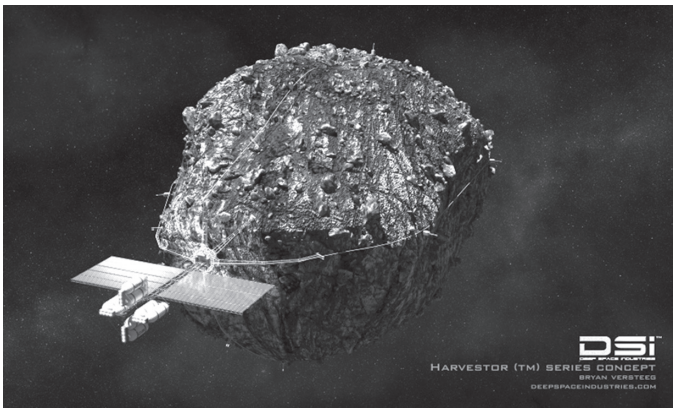

Fig. 3 A still taken from Deep Space Industries 'Promo' video, depicting the mining of an asteroid. (Deep Space Industries)

2. PHASED CONSTRUCTION

For the purpose of illustrating the proposal, the construction of Ocean has been split into three distinct phases, or *temporal episodes*. Each phase assumes a particular time-scale, or measure, appropriate to the events described. Phase I and II may be measured in tens and hundreds of years respectively, phase III assumes a geological time-scale. It is intended that the process outlined here should serve as a set of *structuring principles* in terms of the project's *scope* and *specification*, rather that a set of absolute instructions. Initial stages of construction are based in technologies currently available, or under development – latter stages assume greater degrees of technical sophistication.

During phase I, asteroids are surveyed and two are selected, based on their relative size and water content. Known candidates are the Jupiter Trojans, *617 Patroclus* (Trojan swarm) and *624 Hektor* (Greek swarm). Their mean diameters are 234km and 203km respectively [13]. Patroclus and Hektor are de-orbited and steered through the Interplanetary Superhighway towards Earth. Using current propulsion technology this process would take in the order of 4-5 years. The asteroids are then corralled into halo orbit either side of the Moon, where their movements are synchronised over a period of months. Finally a collision is staged at the Translunar Lagrange Point (Fig. 5). Heat from the impact will release water at various degrees of excitation: at this stage Ocean is a boiling cloud that figures the Lagrange Point as emulsion in void. Ocean is then allowed to coagulate under the influence of its own, self induced, gravitational and material forces (Fig. 6).

Phase II sees Ocean as surveyed and its halo orbit stabilised. The viscosity of Ocean's surface will be engineered (from the molecule up) so as to separate the waters from the waters, or an *inside* from an *outside*. It now has a skin (or *integument* (Fig. 7)) necessary to sustain its body. Skin formation may be achieved though accelerating the chemical processes initiated at impact, so that Ocean's water becomes structurally differentiated and at the same time coupled to itself (Fig. 8). When it has developed the necessary feedback mechanisms to sustain itself as a body, Ocean may be cultured under the controlled bombardment of further asteroids [14].

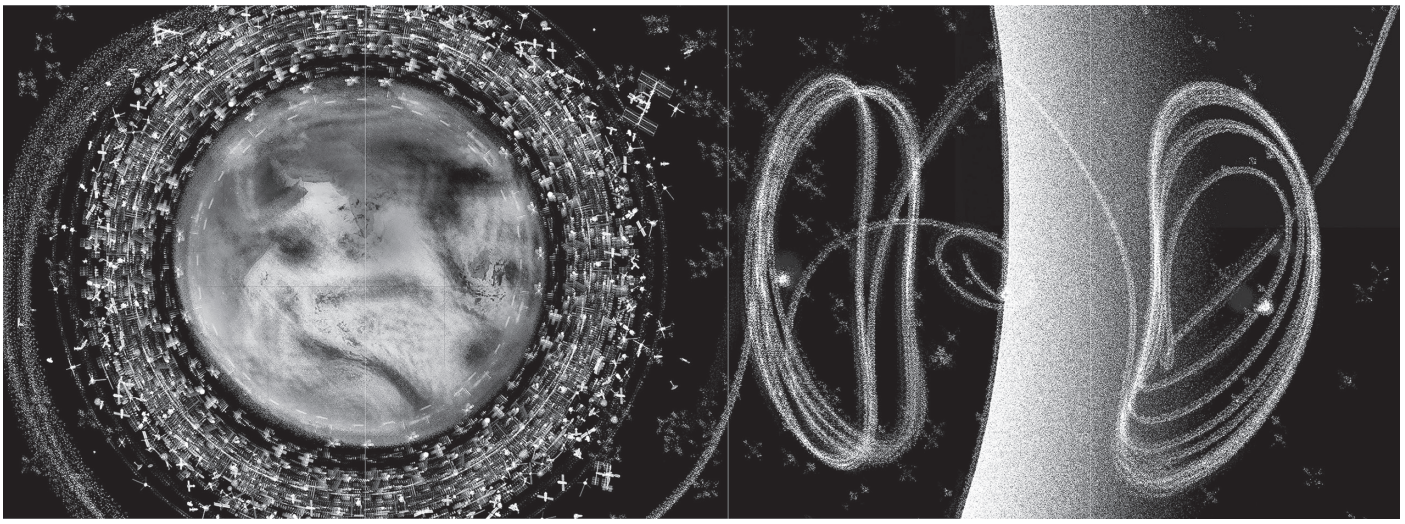

Fig. 4 An early attempt to 'paint' space. In the absence of 'ground' the project called for the conceiving of Lagrangian Points as datum, along with the development of representational strategies appropriate to their depiction. Before we can engage (as designers) with space, the fundamental dialects of architecture need to be re-purposed; the first being the distinction between inside and outside. If we take 'exterior' to signify the space *outside* of what is built, then in the case of the Ocean, 'interior' must necessarily be *inside a planet*.
(Francis Field)

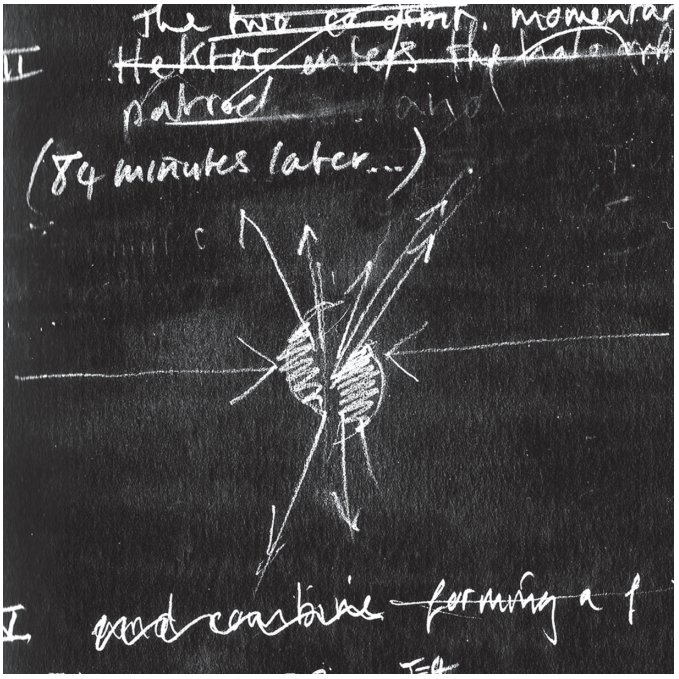

Fig. 5 Diagram depicting a key moment in Ocean's development: the collision staged at the Translunar Lagrange Point.
(Francis Field)

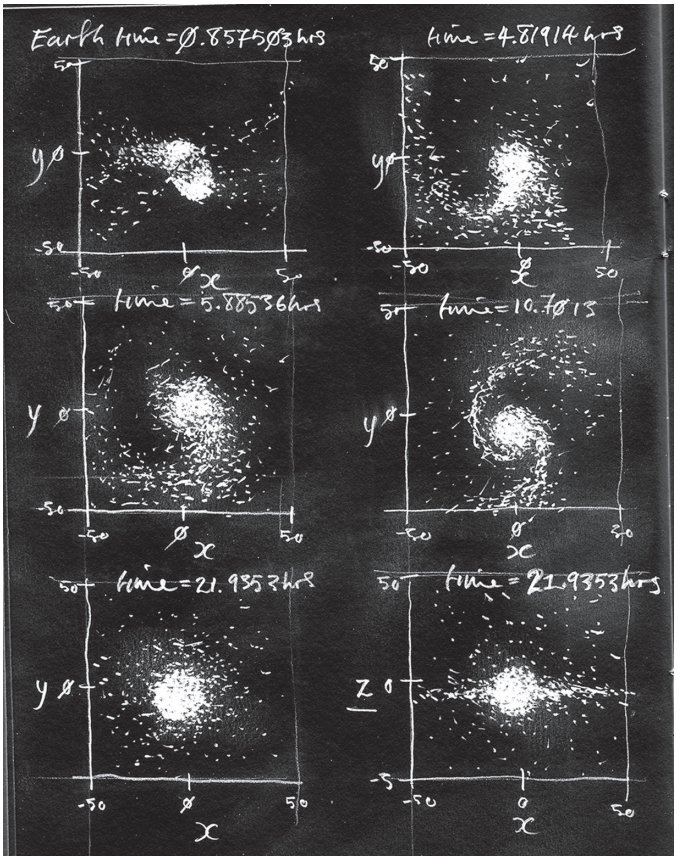

Fig. 6 Diagram depicting the force of gravity acting upon Ocean during the conclusion of construction phase I. This period is characterised by the subjugation of a myriad dynamic and ephemeral bodies to the realisatiion of a greater emerging whole.
(Francis Field)

The final phase is initiated when Ocean reaches a diameter of more than 400 km. In this state Ocean has sufficient mass to form a regular sphere under the influence of its own gravity. Ocean's frozen surface will have a high albedo, making it easily visible from Earth (Fig. 9) as it starts to collect layers of dust that begin to differentiate its surface. The eccentricity of Oceans orbit will cause flexure and internal heating of its rocky core which, combined with the friction between ice plates at its surface, will cause tidal heating necessary for a sustained hydrological cycle. Energy captured from these geothermal processes, along with solar energy, could be used to fuel water purification processes for the production of drinkable water. It is assumed that eventually Ocean may resemble other watery moons in the Solar System, such as Saturn's moon, *Enceladus* [15]. Due to its size it may then be necessary to move Ocean into an orbit alongside the Moon - by which time the Earth itself may have succumbed to rising sea levels!

Throughout all phases – from a nebulous cloud, to a hardened sphere – Ocean should most properly be described as a *body of water*. Because Ocean's essential material composition remains largely constant through out the formative process, so the different states of that process are only clearly distinguishable in Ocean's form.

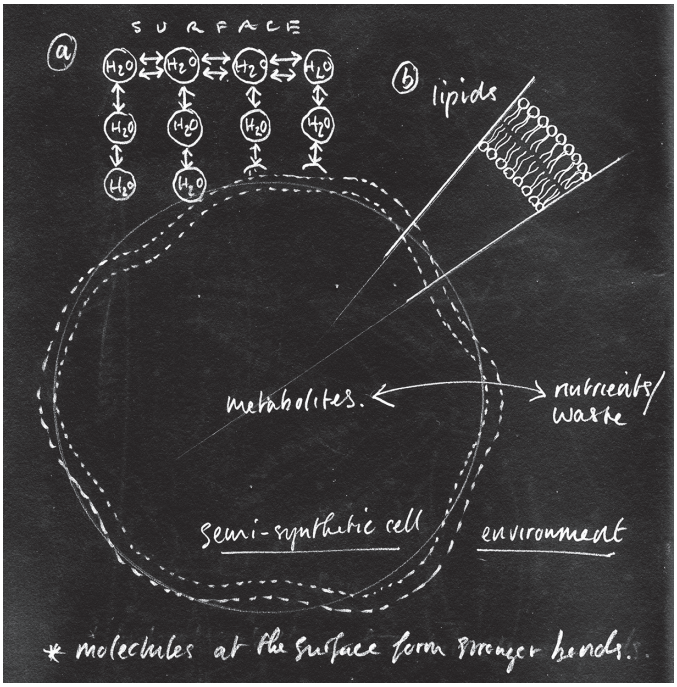

Fig. 7 Diagram depicting the separation of the waters from the waters during phase II of Ocean's development. (Francis Field)

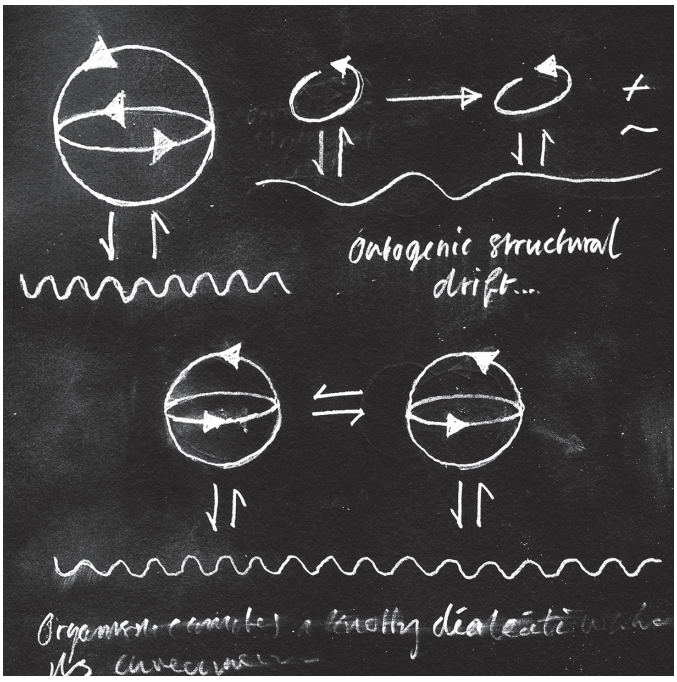

Fig. 8 Diagram depicting the structural coupling of Ocean with its environment, whence its autonomy is derived. (Francis Field)

If Ocean were to be constructed it would undoubtedly rank among the most challenging and complex projects ever undertaken by human civilisation, which is not to say that it can't be done. Within the species relatively brief duration on planet Earth, humans have repeatedly demonstrated an exceptional ability to manipulate the environment towards ends of a comparable magnitude to that of the Ocean project: Stonehenge, the pyramids, and more recently the 1969 Moon landing, are but a few examples. Once a *common goal* is identified, its realisation has only ever been a matter of *time*. The question now is whether, without some unifying religious belief or political ideology, popular consciousness can again be aligned towards such an ambitious goal?

In absence such strong currents in our society today, the construction of Ocean will need to follow an alternative channel, drawn from our present economic paradigm: a model best exemplified by the 'grand scientific experiments' that use increasingly large instruments to observe ever smaller and more elusive quantities of matter. One such project is the *International Thermonuclear Experimental Reactor* (ITER), whose purpose is to investigate the possibilities of making energy through nuclear fusion. ITER entails no less than the harnessing of powerful atomic storms at the centre of stars for use as a clean, unbounded energy source on Earth, and aside from the strange morphological resonance between this 'Sun in a bottle' and 'Ocean in space' there are other aspects worthy of comparison here. Currently ITER is funded through an international consortium of 35 nations. The project is so large it has invented its own unit of currency, the ITER Unit of Account, in order to control finances over extended periods of time. If Ocean is initially treated as a scientific experiment of this order we imagine its funding structure would be of a similar nature to ITER. As such, the success or failure of the ITER project could prefigure the feasibility of Ocean.

For both 'Sun in a bottle' and 'Ocean in space' use-value to humans lies in the provision of a clean, easily accessible, and abundant supply of *fuel* – the only difference is that one serves *Earth,* and the other *outer space*. Since on the whole, humans still inhabit Earth, it is relatively easy to justify spending on ITER, but hard to find funding for Ocean: this will continue to be the case for some time. Until this point the processes necessary to Ocean's construction ('ballistic asteroid capture' and the relationship between microgravity and biological systems etc.) will inevitably begin to be explored by private companies towards commercial ends. Having expanded across the surface of this planet, capitalism is looking to capture new frontiers [16], both above (in space) and bellow (on the sea floor), to sustain its growth. The project presented here has been conceived within this ineffable process of commodification: the space-time of Ocean begins here, with the capitalist model - but this is not to say that the two will remain in sync. As we have seen, the *theatre* of space is already underway and its actors cast, however, as mathematician George Spencer-Brown once suggested, *"...there is really nothing to prevent us rewriting the stage-directions."* [17].

Until its realisation, Ocean will exist as a book containing 14 diagrams, 22 orthographic drawings, 2 perspectives, 8 plates (a selection of which are reproduced here (Figs. 10 & 11)) and a body of narrative text. These are the modes and number of representational strategies necessary for Ocean to be inferred in the mind of the reader. One problem with the imagery of space inhabitation that we have today is that science fiction already does it better than architects ever could, so for architecture to contribute positively to the adventure into space it needs to discover, within its own discipline, a new means of drawing. The representation of Ocean entails the use of orthographic drawings, deploying the architectural conventions of *plan, section and elevation*, rendered at international ISO standard, A5. Although the size of the paper remains the same, the objects depicted do not. To represent the restless flows of energy and matter that embody Ocean it is necessary to depict Ocean through shifting changes in *scale* (stepping in powers of ten), rather than through the implied movement of the viewing subject - as is so often the case when human activities are depicted in space.

Fig. 9 Even long before Ocean forms a frozen surface it should be visible from Earth as an aura around the Moon: various optical effects will be produced by the refractive properties of Ocean, these may include complete rainbows, without horizon. (Francis Field)

In all Ocean's drawings, the pages of the book *are* space-time, and the ink Ocean's *boundaries* or *distinctions*. If the author had been solely concerned with a more complete *representation* of the space-time of Ocean, he would have included many more pages and simply left most of them blank (Figs. 11 & 12): in the interest of communication however, some marks were made to divide up the pages into readable signs. The focus of this project then, is with the question of how to represent the medium of space-time in a manner that is conducive to the human creature's being able to project its own potential actions into that medium, i.e. to involve itself in the space-time of Ocean.

3. CONCLUSIONS

The human passage into space is inevitable, but the *form* it will take is not. One thing we are certain of, the human body is in no way capable of life in the vacuum of space, just as it is useless underwater or in the air (Fig. 13). Despite the problematic of the human body, human agents successfully managed to visit all of these places even before they had the technological means to do so. This ancient tradition, having always been essential to the human condition, could now be described as *'going into space without a rocket'*. It is a procedure that all artists are aware of because it is their task to forge the way and to help others to get there too – a work of art being a carefully constructed *space vehicle* of sorts.

In October 1960 Yves Klein leapt into the void (Fig. 14) and claimed to have performed lunar travel. The following month he published this statement:

> *"Today anyone who paints space must actually go into space to paint, but he must go there without any faking, and neither in an aeroplane, a parachute, or a rocket: he must go there by his own means, by an autonomous, individual force."* [18]

Figs. 10 Ocean was exhibited at the Royal College of Art in June 2014. Pages from the book 'Space ~ Time & Architecture' were enlarged to ISO A3 and displayed alongside video extracts from DSI's 'promo' video, and Martin Lo in interview with Werner Herzog (for the film *'Wild Blue Yonder'* [2006]). Lo uses the analogy of the labyrinth to describe the Solar System as we understand it today. He describes the leap in our understanding - from the Copernican model (with discrete isolated orbits), to the dynamic relational system we understand today - as revolutionary. (Jack Hems)

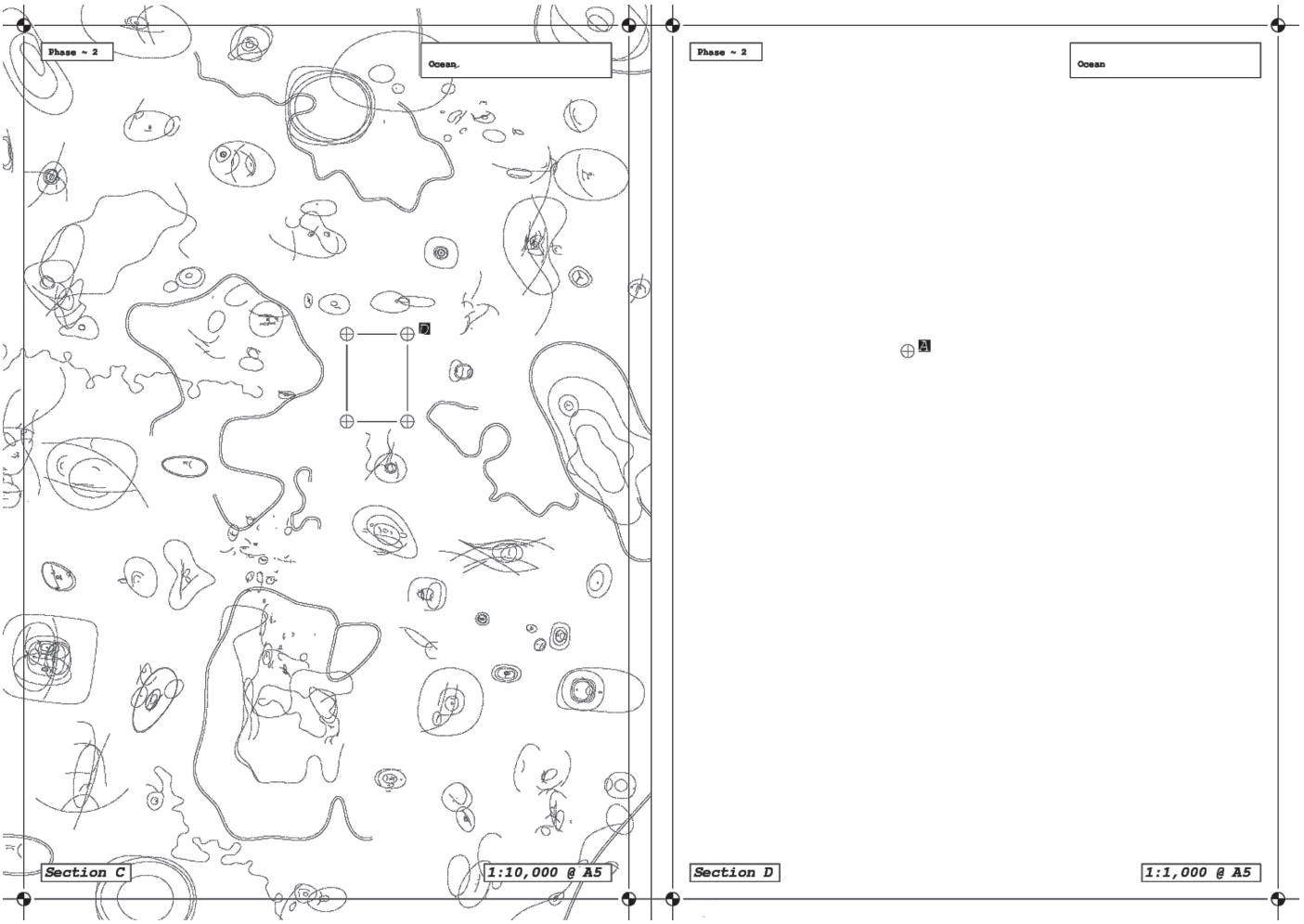

Fig. 11 Two sections at differing scales depicting Ocean; one shows 'animal' like forms, the other intentionally left blank in acknowledgement of Heisenburg's Uncertainty Principle. Of course the page above is not itself completely blank, for it bares the necessary marks (registration marks, key and scale bars) to frame 'blankness' within the self-referential network of the drawing series - much like the final page of an exam paper that bares the mark, [this page has been intentionally left blank]. From these examples we can infer the formal limit to *all* modes of representation. To recognise any thing is to distinguish it from its environment, whereby it is at once perceived as a separate but constituent part of the world, i.e. it is seen to be *less than whole*. A blank page too is always less than whole by virtue of the mark (whether we take the mark to be a word, a frame, or simply the edges of the page) that distinguishes the page as blank to an observer. It is the *form* of representation which ensures that the true nature of the world is always veiled from an external observer - a phenomenon perhaps to which William Blake was alluding when he wrote, "Tho' obscured, this is the form of the Angelic land". What is remarkable, however, is that the dividing line of the mark (section, frame, or otherwise) can be drawn in any place we choose, and although the fabric of reality comprises a gause too fine to perceive, the topology of its veiling structure is resolutely manifest as the inverse of our potential actions in the world. Here Heisenburg attempts at describing something similar: "The dividing line between the system to be observed and the measuring apparatus is immediately defined by the nature of the problem but it obviously signifies no discontinuity of the physical process. For this reason there must, within limits, exist complete freedom in choosing the position of the dividing line". (Francis Field)

Fig. 12 The Ouroboros archetype first surfaced in Ancient Egypt as a figure symbolic of space-time. Ouroboros or 'tail eater' is depicted in a state of constant growth and destruction. It is not static (as is drawn), but a representation of the process of perpetual motion. Its injunctive mode is like that of a blank page, or an Yves Klein monochrome painting. As such, it is an example of a very early space vehicle. (Theodoros Pelecanos)

Fig. 13 An Apollo 16 astronaut falls on the Moon, 1972. (NASA)

Both Klein and Neil Armstrong have visited the Moon, the key distinction between them however, is that they set off in *opposite directions*. Klein was always going to get there first because, where Armstrong had some 384,400 km to travel *outwards*, Klein found that he had only to travel *inwards* into the space that he already occupied. Of course both men were beaten by Newton (and numerous others before him), who without even taking *one small step* in space, was able to *divine* the laws of motion from mathematical principles, which themselves, by definition, have no physical existence. This is difficult to accept, so hard in-fact that we usually tell ourselves that it was an apple that did it!

Fig. 14 Le Saut dans le Vide (Leap into the Void), 1960. (http://www.metmuseum.org)

As far as this project has aligned itself with the market logic of advanced capitalism in its radical trajectory, it equally has its roots in Klein's space of *pure sensuous perception*. Both orders of space have been equally valuable to this body of design-based research. In conclusion then, it should be said that in allowing one order of space to dominate another always comes at a *cost*. The dominance of inner space, as Klein discovered, leads necessarily to the dissolution of the individuated self (If we examine Klein's utopia carefully we find that in the end, it contained no individuals). Allowing outer (or physical) space to dominate quite naturally leads to the type of world we usually describe as *Western civilisation*. Neither forms a complete picture, and if we are really to escape the trappings of Earth, both sides must be addressed, equally.

> *"In celebrating these great journeys into outer space, we tend to overlook the colossal and equally heroic journeys* in the opposite direction *undertaken, for the occasion, by men such as Isaac Newton. Without the extremely difficult, disciplined, and equally dangerous journeys into inner space, no journey into outer space could ever succeed."* [19].

REFERENCES

1. The *Department of Ontological Theatre* (DOT) was founded by Jon Goodbun and Victoria Watson in 2012 as a design research and teaching studio at the *Royal College of Art* in London. We took the term 'Ontological Theatre' from the historian and theorist Andrew Pickering, who coined the term to describe a radical nomadic tendency within cybernetics (see A. Pickering, "The Cybernetic Brain – Sketches of Another Future", University of Chicago Press, Chicago and London, 2010.[Book]). DOT confronts the contradictions of the present – ecological, economic, social, political, cultural, technological – through a strategic re-engagement with specific moments in the history of architecture. Rather than starting from surface level phenomena in the present, we will adopt a dialectical approach, tracing those contradictions back in time, identifying earlier dynamics. From here we stage Ontological Theatre: architectural experiments into the nature of order, planning, design and technology, and speculate about how we might think of matter, mind, social collectivity, and ecological systems in the future.
2. Latin: 'qualis' – *of what kind, of such a kind.*
3. M. Cohen, *et al*, "Water Walls Architecture: Massively Redundant and Highly Reliable Life Support for Long Duration Exploration Missions", *Citeseer,* 2012.
4. The only project known to the authors that is in some way comparable to Ocean, is the '*Blue Star Human-Dolphin Space Colony*' proposed by Doug Michels in 1978. Blue Star is a toroidal spacecraft with a glass sphere at the centre containing a body of water. The water sphere is inhabited by dolphins who use sonar to operate the on-board super computer. The human-dolphin community aboard the craft are tasked with making strategic and political decisions concerning life on Earth (based on the premise that they would have better ideas when liberated from the influence of gravity). In Michels' proposal, water is treated as a life support system for the dolphins rather than as an end in itself. The ultimate purpose of Blue Star was to build a relationship with dolphins, who at the time were thought (based on the work of John Lilly) to be of comparable or higher intelligence to the human species. Ocean is not a spacecraft and has no supporting infrastructure (at least not of the mechanistic type), it is a *site,* and should be seen within the tradition of *world building*. It is imagined that Ocean will support life and provide a resource for the human colonisation of space, however, Ocean is always discussed as a life form, in and of itself.
5. Here *value* is taken to mean the material or monetary worth.
6. http://deepspaceindustries.com/media/announcements. (Last Accessed 22th July 2014)
7. The Rosetta spacecraft was launched by the European Space Agency in 2004 to study the comet 67P/Churyumov-Gerasimenko. A probe will

be sent from the robotic craft and is expected to land on the comet in November 2014.

8. Planetary Resources is a rival asteroid mining company established in 2010, see: http://www.planetaryresources.com. (Last Accessed 27 November 2014)
9. http://deepspaceindustries.com. (Last Accessed 22th July 2014)
10. The Interplanetary Superhighway (also referred to as the Interplanetary Transport Network, ITN) was conceived as a practical application of the work of 19th century mathematician Jules-Henri Poincaré. The power and efficiency of this new infrastructure was most elegantly demonstrated by the manoeuvres performed by the ARTEMIS-P1 spacecraft during the THEMIS mission (2010), as it transferred between the Lagrange Points either side of the Moon.
11. For a recent proposal for L1 & L2, see the *Exploration Gateway Platform* project developed by Boeing in 2011.
12. The halo orbit performed by the ARTEMIS-P1 spacecraft can be seen at: http://www.nasa.gov/mission_pages/artemis/news/lunar-orbit.html#.U850oPldWSo. (Last Accessed 22th July 2014)
13. The mean diameters stated here should serve only as an rough indication of the scale of these asteroids. The irregular nature of asteroids in general, combined with the limited data that has so far been collected means that their precise form and composition is, one the whole, still largely speculative. 617 Patroclus is in-fact a binary system composed of two bodies, the smaller body, known as Menoetius, gives rise to the official designation *(617) Patroclus I Menoetius*. 624 Hektor is suspected to be a 'contact binary' (formed of two bodies, once distinct, that have partially merged) and is now known to support a small moon.
14. This process may be assisted by the 'ballistic capture' of comets should the opportunity arise. For a detailed case-study of this emerging technique see Garcia Yarnoz, D. *et al*, "Easily Retrievable Objects Among the NEO Population", *Celestial Mechanics and Dynamical Astronomy*, **116**, pp.367-388, 2014.
15. The diameter of Enceladus is estimated to be 500 km. Due to its relatively low density and high albedo (the capacity to reflect the Sun's light) it is suspected to contain a large volume of water. Recent photographs taken by *Cassini-Huygens* spacecraft clearly show plumes of vapour erupting from Enceladus' surface, which may indicate that sandwiched between a rock core and frozen crust, is a liquid ocean.
16. See David Harvey's concept of 'spatial fix' and the role of the frontier in D. Harvey, "*Spaces of Capital – Towards a Critical Geography*", Routledge, New York, 2001.
17. J.Keys, "*Only Two Can Play This Game*". Julian Press, First Edition, pp.14, 1972.
18. Y.Klein, "*Dimanche - Le Journal d'un Seul Jour*", 1960.
19. J. Keys, "*Only Two Can Play This Game*". Julian Press, First Edition, pp.136, 1972.

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