DIAMOND - An Architecture for Persistent Space Platforms

Julian Breidenthal[1]
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109

Thomas George[2]
SaraniaSat Corp., Arcadia, California 91007

and

Marco Villa[3] and Ehson Mosleh[4]
Tyvak Nano-Satellite Systems Inc., Irvine, California 92618

We define DIAMOND, an architecture for generalized, persistent platforms in space, providing support infrastructure for multiple payloads with diverse missions, and able to accept the integration of payloads delivered to the platform after it is established in space. Such platforms would create a new space ecosystem with opportunities for much larger platforms than currently exist, for adaptation to changing technological and market conditions over long periods of time, and for tenants of the platform to launch only their unique payloads without having to carry all the equipment needed to support them. The DIAMOND architecture uses a novel "Architectural Shearing Layer" approach combining long-lived but replaceable structural and support infrastructure components with shorter-lived, higher-value service and tenant facilities. The structural aspect of the proposed architecture is a regular lattice constructed of tetrahedral cells, constructed of only a few types of simple structural components, patterned according to the cubic lattice of natural diamond crystals. The cubic lattice is arranged on larger scales to be fractal sponge, providing a disproportionately large number of surface attachment points while maintaining overall low mass of the entire structure. Generalized architectural shearing layers are also provided that permit easy separation between structural, power, thermal, propulsion/attitude control, pointing/vibration control, computing/data storage, and communication, and various operational aspects of the architecture. The combined result ensures longevity by enabling space platforms to undergo many cycles of change with little peril and at low cost, changing any part of the platform at different times and rates while leaving the remaining parts of the platform undisturbed.

I. Introduction

Enduring issues in space mission design include the inevitable wearing out of some types of spacecraft components, depletion of necessary spacecraft resources, and obsolescence of spacecraft technology. At the present time most spacecraft are designed as highly integrated systems, combining structural, infrastructure, and payload components into a whole that inevitably will become useless as a result of wear out, depletion, or obsolescence of a few of their components. This is a very undesirable situation considering the expense of placing a spacecraft at its intended location of service, setting limits to returns on investment due to limited life. However, after a spacecraft has exceeded its useful life, many of its components may still be useful, if the un-useful components could be replaced, or if the spacecraft could be disassembled, and either repurposed, or recycled and reformed for a different mission. Typically, it is not practical to replace most components in orbit due to

---

[1] Systems Engineer, Communications Architectures Research Section, Mail Stop 238-420, 4800 Oak Grove Drive, Pasadena, CA 91109, Senior Member.

[2] Chief Executive Officer, SaraniaSat Corporation, 1000 Fairview Avenue, #10, Arcadia, CA 91007.

[3] President and Chief Operating Officer, 15265 Alton Parkway, Suite 200, Irvine, CA 92618, Senior Member.

[4] Vice President of System & Mission Assurance, 15265 Alton Parkway, Suite 200, Irvine, CA 92618.

entanglements between them, especially interior components, although there has been much work on in-orbit servicing.[1,2]

It would be a great advantage to be able to construct spacecraft in such a way that they could be practically maintained over long periods of time, repaired, recycled, and repurposed, becoming in effect persistent platforms that can used for long periods of time in the way that real estate is used on Earth. It would also be an advantage for some missions to be able to construct larger spacecraft than can be launched from the Earth, notably in the areas of communication, remote sensing, and human occupation. In this paper, we define DIAMOND, an architecture for generalized, persistent platforms in space, providing support infrastructure for multiple payloads with diverse missions, and able to accept the integration of payloads delivered to the platform after it is established in space. Also, the DIAMOND architecture is amenable to on-orbit construction from its smallest components, providing a route to constructing larger structures suitable for microgravity-only environments. Such platforms could create a new space ecosystem with opportunities for much larger platforms than currently exist, for adaptation to changing technological and market conditions over long periods of time, and for tenants of the platform to launch only their unique payloads without having to carry all the equipment needed to support them.

II. Architectural Shearing Layer Concept

The concept of mechanical shear/slip planes is well known in materials science, and is depicted in Figure 1. Essentially, mechanical shearing layers allow materials to deform plastically without catastrophic damage to the entire crystal structure. This property alone can be useful for a persistent platform from a safety standpoint, but also, and more importantly, from a long-term adaptability standpoint. That is, mechanical shearing layers can enable separation, reattachment, and reconfiguration with limited disruption to most of the structure. More recently, generalized architectural shearing layers have been identified in building architectures[3] and information systems[4] as depicted in Figure 2. It has been found that those buildings which permit easy separation between the layers of site, structure, skin, services, space plan, and stuff are able to persist for long periods of time, even though the demands on the building change frequently. Usually the stuff and space plan layers evolve the most rapidly, but there are buildings, mobile homes and ships for example, for which the site shearing layer is the most active and is designed to be easily separable. Buildings that do not possess easily-separable shearing layers, that is, that entangle layers, are often destroyed and rebuilt when necessary changes in one of their layers lead to either great cost or great peril associated with the change, usually resulting from consequent changes forced in an entangled layer.

Frank Duffy, a former president of the Royal Institute of British Architects, is quoted in Reference 3 as arguing "…there isn't such a thing as a building. A building properly conceived is several layers of longevity of built components." We apply that argument here to the problem of creating persistent space platforms. That is, there really isn't such a thing as a persistent space platform. Rather, a persistent space platform, properly conceived, is several layers of longevity of things. We abstract "built components" to mean "things" in the most general sense, to permit us to consider separation and characteristic rates of change for hardware, software, protocols, information stores, operational concepts, etc. Well-designed shearing layers should enable tenants of a persistent platform to change connections, either mechanical or generalized connections in other domains, to suit differing rates of change dictated by the underlying technologies, free of excessive entanglement with other connections. Avoiding excessive entanglement avoids excessive disruption of the remainder of the platform when changes are made.

III. Summary of the DIAMOND Architecture

The DIAMOND architecture consists of the following architectural shearing layers:

- Structure, a pattern of constructing arbitrarily-shaped structures in a microgravity environment,
- Site Attachment, a pattern of attaching assemblies to the structure,
- Power provision, a pattern of generating, storing, and distributing electrical energy to attached assemblies,
- Thermal Control, a pattern of removing or providing heat to attached assemblies,
- Propulsion and Attitude Control, a pattern of providing propulsion and attitude control for the platform,
- Pointing and Vibration Control, a pattern of providing pointing and vibration control between the structure and attached assemblies,
- Communication, a pattern of providing communication between attached assemblies, and between assemblies and locations off of the platform, and
- Computing, a pattern of providing computing services to platform tenants.

Each of these layers is designed to be easily separable from the other layers, permitting reconfiguration, repurposing, and recycling with minimal disturbance of other layers. The ability to easily separate these layers is key to ensuring that parts of a persistent platform constructed using the DIAMOND architecture can change at different times and rates, at low cost, while leaving the remaining parts of the system undisturbed. This is a crucial characteristic for longevity of platforms constructed according to the DIAMOND architecture, enabling the platforms to undergo many cycles of change with little peril and at low cost.

The layers of the DIAMOND architecture are described in more detail in the following sections.

A. Structure

The structure shearing layer is a regular pattern constructed of repeated cells, constructed of only a few types of simple structural components, patterned according to the cubic structure of natural diamond crystals. Natural diamond crystals comprise assemblies of unit cells governed by the shape of the sp3-bonded carbon tetrahedron[5] as shown in Figure 3. The tetrahedron is unique in nature for its inherent regularity, stability, stiffness, economy, and ability to form (and re-form) complex structures. When combined in particular repeating arrangements, tetrahedral cells can form linear, planar, spherical, cubic, and more general structures.[6] For the DIAMOND architecture, the tetrahedra would be formed mechanically with a combination of uniform nodes (capable of forming tetrahedral junctions) and uniform beams (capable of attaching to the nodes). We do not claim to know the best shapes for the nodes and beams, as there are myriad possibilities, but for concreteness in this article we note that tetrahedral nodes could be formed from four identical flat plates capable of attaching to sides and ends of beams as shown in Figure 4. Thus we believe there could be as few as two types of components plus fasteners needed to create large complex structures. In this particular case, the two types of components would have very good packing characteristics, which is important for transporting the components in space.

Diamond cubic structures are exceptionally strong and rigid, making them an excellent "building block" for the incremental construction of very large and robust space structures. This opens up the possibility of using the tetrahedral habit of construction, which has less preference for the rectilinear directions seen in gravity-dominated architectures on Earth, and is more suited for construction in a weightless environment. Our intent here is that the structure would be assembled in space, and would therefore only need to be designed for microgravity loads, not terrestrial or launch loads.

Again, the diamond cubic is inherently a very strong structural pattern, and includes interior material that entails launched mass, and work for construction. In some applications the interior material may be important because it provides redundancy of attachments and load paths, making the structure tolerant of damage. In other applications,

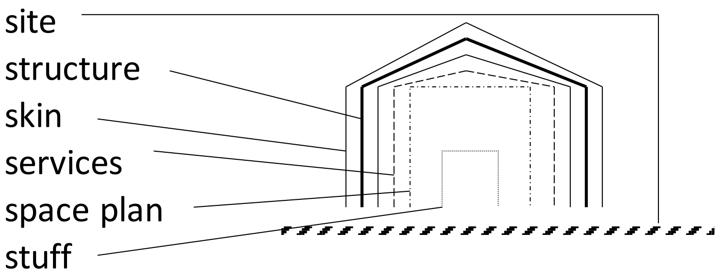


Figure 2. Shearing Layers of Change. *Structures that stand the test of time tend to show a common organization into separable layers matched to the characteristic rates of change associated with different concerns. The site tends to change the slowest, followed by structure, skin, services, space plan, and stuff which tend to change at progressively shorter time scales. Buildings which make it easy to separate layers can be adapted to new uses, while those that entangle layers often have to be torn down because of the difficulty of making necessary changes.*

---

[5] https://en.wikipedia.org/wiki/Diamond_cubic .

[6] http://www.jrgreer.caltech.edu/home.php .

perhaps most, redundancy beyond a certain level may add little value, and the interior mass represents an undesirable burden. We propose here a means to lighten the structure while compromising its strength or damage tolerance only slightly. Specifically, we propose removing portions of the diamond cubic in a three-dimensional fractal manner, either regular or random, applied recursively on many levels of scale. Prototypes of such objects are the Menger sponge and the Sierpinski pyramid, which correspond to rectangular and triangular material removal patterns, as shown in Figure 5. Fractal sponges are interesting because they have the properties of filling a finite space, and in the limit of large size (or small division) converge to having infinite surface area to mass, and volume to mass, ratios. Thus, they are very efficient at providing large surface areas and volumes with as little supporting mass as possible, which is a very desirable scaling characteristic. Menger sponges and Sierpinski pyramids, and perhaps other fractal structures, have the property of providing voids that start at a large scale and progress to smaller and smaller voids the deeper one moves into the structure. This property ensures that there will be easy access channels to every part of their interior volumes, which is important for construction of the structure, and replacement of attached assemblies. If chosen properly, the fractal characteristics can insure that access channels exist that are free of size restrictions commensurate with the smallest assembly contemplated for placement in the structure. The diamond cubic that would form the lowest level in the fractal sponge also is known to provide large interstitial channels, for example in the <100>, <110> and <111> crystallographic directions. These would provide a great variety of attachment sites, and permit maneuvering of objects within the smallest levels of the structure.

The general fractal sponge concept can be applied to form other linear, planar, spherical, or general structures with high surface area and low mass. Of course, infinitely small mass will not be achieved because practical realizations will not divide the sponge structure infinitesimally, and they will be limited by requirements for structural stability, for payload installation, and provision of various platform services.

B. Site Attachment

The Site Attachment shearing layer consists of arrays of beam locations in the diamond cubic to which any other assembly can attach, using matching arrays of clamps. For concreteness, a useful clamp could be a hinged split-ring bracelet clamp, similar to a common scaffolding clamp. However, we do not claim to know the best clamp arrangement at this time.

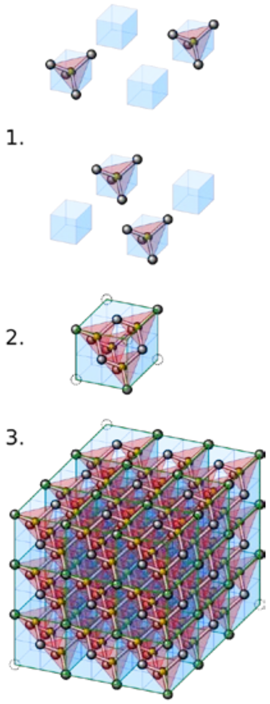


Figure 3. Diamond Cubic Structure. *Natural diamond is a regular crystal composed of tetrahedral cells oriented to be aligned to the corners of a cube (Figure 1), and empty cells, in a particular pattern than forms larger uniform cubical cells (Figure 2). These are stacked to form arbitrarily large structures (Figure 3). (Image source: https://en.wikipedia.org/wiki/File:Visualisation_diamond_cubic.svg. Used under a Creative Commons license)*

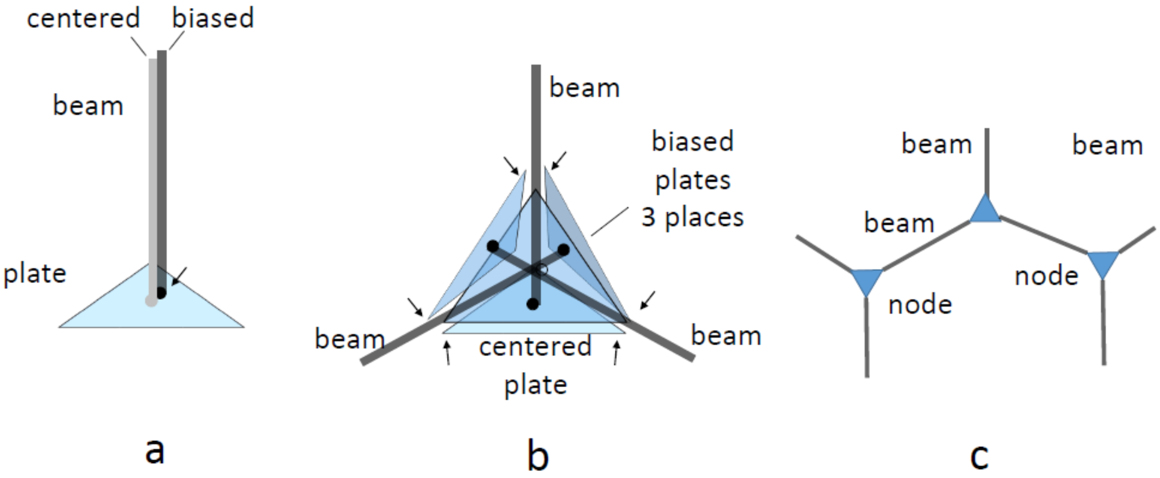
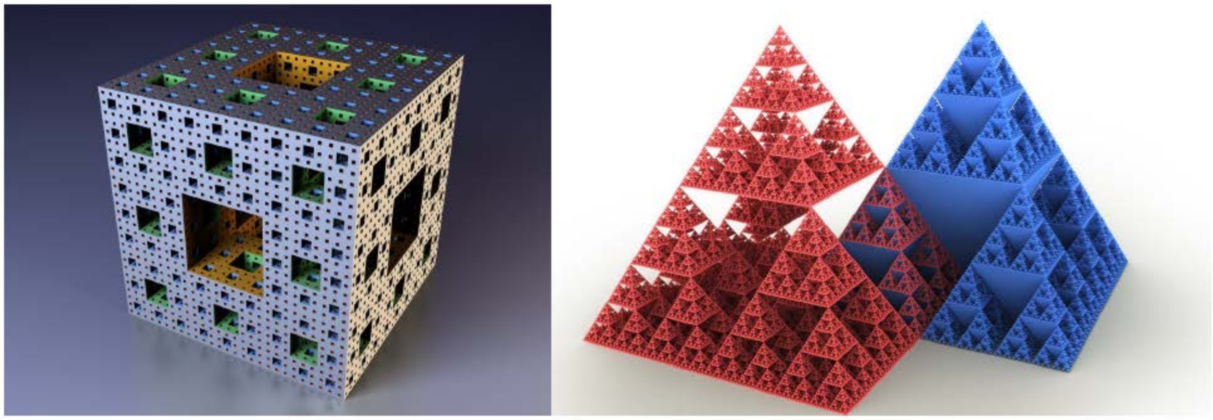


Figure 4. Nodes and Beams of the DIAMOND structure. *One possible arrangement of beams and nodes of the DIAMOND structure made of flat equilateral triangular plates and straight beams is depicted. Construction proceeds in (a) by attaching one beam to each of four plates in one of two positions near to the center of each plate as discussed in the text. Four beam-and-plate assemblies are oriented as shown in (b) and attached at the points indicated by arrows to form a node. In (b), one beam is pointing directly away from the reader; the beam end-offsets introduced in (a) are used to resolve interference between the beams at the center of the tetrahedron formed by the plates. The construction process continues by forming a network of beams and nodes conforming to the diamond cubic pattern, as shown in (c).*



(a) (b)

Figure 5. Examples of Fractal Sponges. *A Menger sponge of order four (a) and a square Sierpinski pyramid (b, red) and its inverse (b, blue) are shown. These are examples of three-dimensional fractal sponges that can be applied to reduce mass of a persistent platform based on the diamond cubic structure, while increasing the ratio of surface area to mass.*
(Image source: https://en.wikipedia.org/wiki/Menger_sponge https://en.wikipedia.org/wiki/Sierpinski_triangle . Used under a Creative Commons license.)

C. Power provision

The Power provision shearing layer consists of an assortment of standard terrestrial plug/socket and cable designs for different voltage/current ratings, but using space-qualified materials.

D. Thermal Control

The Thermal Control shearing layer consists of flat-plate connections for heat transfer, as well as sliding, clamped cylindrical connections for heat pipes. It is worth noting that space-qualified, flexible heat pipes capable of transferring heat over distances in excess of 20 meters are commercially available.

E. Propulsion and Attitude Control

The Propulsion and Attitude Control shearing layer consists of different sizes of attitude control or propulsion packages in any available technology. These would clamp onto the structure the same as any other payload. Sensors would clamp onto the structure near points for which control is referenced, and communicate with attitude control packages elsewhere, to collaborate in overall platform control.

F. Pointing and Vibration Control

The Pointing and Vibration Control shearing layer would be provided on a payload-by-payload basis using an intermediate payload between the structure (which provides gross orientation stability), and the sensitive payload. The intermediate payload would provide fine positioning, and if necessary also vibration isolation. Large-scale structural vibration quieting may also entail an internally layered architecture as described by Laskin in Reference 5, possibly requiring active components at strategic physical locations in the structure. This could conceivably create undesirable entanglements between DIAMOND architectural shearing layers. Whether the entanglement between layers is troublesome is not clear in the abstract; it may be possible to keep the entanglement low in particular designs by maintaining the services-as-a-payload concept for the active components.

G. Communication

The Communication shearing layer would be provided using the same communications shearing layers used on Earth: Bluetooth, Wi-Fi, Ethernet, Fiber, Internetworking Protocols, etc. for local communication. For off-platform communication, NASA, DOD, NOAA, NRO, and Commercial interface standards for orbital communication can be applied.

H. Computing and Data Storage

The Computing and Data Storage shearing layer would be provided using commodity cloud computing interfaces, similar to many commercial cloud services provided here on Earth.

IV. Operations Concepts

The availability of a rich set of architectural shearing layers opens up the possibility of creating a new, complex, and vibrant space technology “ecosystem”. Persistent platforms created with the DIAMOND architecture would enable both commercial and government customers to send only payloads for integration with the platform, and would enable a wide range of entrepreneurial business ventures to coexist. New operations concepts would be needed to realize the potential benefits of the architecture. Our preliminary view of operations concepts include Initial Construction, Services as a Payload, Recycling and Reuse, Platform Factories, Independent Service Provision, temporary and permanent Occupancy, temporary and permanent Ownership, the Real Estate Governance Model, and Demand-driven Pricing. However, we believe it is likely that many other operations concepts will eventually be developed.

A. Initial Construction

Initial construction proceeds in three overlapping cycles: transport of materials, node formation, and structural evolution.

Transport of materials starts from the site where the materials are manufactured, which may be on Earth, some other body, or eventually on the platform itself. Structural components (plates, beams, and fasteners) are packed into a space vehicle and carried to the site of the platform. Carriers are unloaded, parts are stored in a bundled fashion, and the carriers either return to the manufacturing site for continued deliveries, or are discarded. The store of parts itself will be a space object which requires station keeping, that may be provided by a spacecraft for that purpose, or after the initial platform, by the platform factory concept below.

Node formation proceeds according to the process depicted in Figure 4. As mentioned previously, one possible arrangement of beams and nodes could be based on flat equilateral triangular plates and straight beams. Construction proceeds by attaching plates to beam ends as shown in ubfigure 4(a). One beam is attached to each of four plates in one of two positions near to the center of each plate. The reason for having two attachment positions, one directly on center, and one biased toward one edge by somewhat more than a beam diameter, is to allow the beams to cross without interference at the center of the tetrahedron eventually formed by the plates. Four beam-and-plate assemblies are oriented as shown in Figure 4(b) and attached at the points indicated by arrows to form a node. The on-center plate provides an axis of rotational symmetry for the tetrahedron, and three biased plates are placed about the beam of the on-center plate to form a tetrahedrosn. If the biased plates are all arranged so that the bias is parallel to the on-center plate, in the same sense of rotation, the biases of the beam attachment points both prevent beam collision and introduce only a rotation of the sp3 bond directions about the beam of the on-center plate; the relative directions are preserved, though slightly rotated from the tetrahedron normals.

Structural evolution continues by repeating the node formation process at the free beam ends of previously-formed nodes, as shown in Figure 4(c). The first result of structural evolution is to form the cubic cell of Figure 3 (b), which is then repeated and interspersed with empty cubical cells to form the the diamond cubic pattern. Cubic cells are omitted wherever dictated by the fractal sponge pattern selected. Structural de-evolution can also be effected by disassembling nodes and carrying the parts away.

B. Services as a Payload

The availability of site attachment, power, thermal, and communications shearing layers, etc., make it possible for infrastructure services to be provided as though they are payloads. That is, power can be provided by one or many assemblies that reside at the persistent platform, arrive and are attached to the structure, and provide power to users through the power provision shearing layer. If the power-generating payload fails or becomes outmoded, it can be detached and a new payload brought in to replace it.

Similarly, any other infrastructure service can be provided as though it is a payload, and in the event of failure or obsolescence can be replaced. For example, a broken or depleted propulsion assembly could be removed and replaced with a full one, which is a simpler and in some cases safer approach than refueling or repair.

Attachment of payloads would proceed by carrying them to the platform, maneuvering the payload to the desired location on the platform, orienting the payload and attaching it to the structure using site attachment clamps, and connecting services associated with the DIAMOND shearing layers.

C. Recycling and Reuse

Assemblies which are no longer wanted to perform their original function can be detached from the structure at the site attachment layer, and then scavenged for the entire assembly (as might happen when one project is done but the assembly still has useful life), for smaller useful parts, or possibly returned to a manufacturing facility (not necessarily terrestrial) for repair.

The structure itself can be recycled by disassembling nodes. Entire sections can be separated by disassembling a set of nodes that constitute a detachment surface, or moved incrementally by disassembling nodes and reassembling them with different-length beams along a slip plane as depicted in Figure 1. Fractal sponges as proposed here possess many regions where disassembly and reattachment can be made without disturbing most of the structure, which may make this approach economical compared to building new structures.

Over time the recycling and reuse activity may lead to a materials market in space that avoids the costs associated with transport out of or into Earth’s gravity well.

D. Platform Factories

The existence of a persistent space platform with the DIAMOND architecture would also enable reuse of fragments of the platform, by disconnecting them from the main platform at convenient locations. For example, a corner of a platform constructed as a Menger sponge could be disconnected by removing beams along the smaller planes connecting to the remainder of the platform. The separated corner would itself be a smaller Menger sponge, which if equipped with its own propulsion assemblies could be moved to a new location. Later, the empty corner of parent platform could be filled in again, and the process repeated, essentially becoming an in-space factory for smaller platforms.

The factory process can also work in reverse: smaller platforms could be formed separately, then be attached to existing larger platforms, or be joined together to form larger platforms from smaller units.

DIAMOND's structural approach is inherently evolvable, robust, and diverse, with generous upper limits on capacity compared to terrestrially-constructed spacecraft that must be designed to survive terrestrial and launch loads. A decentralized approach to adding capacity and technological evolution can be used ensure that the GEO platform can support long-term growth, and in its ultimate state can accommodate both a large number and large variety of payloads.

E. Independent Service Provision

The ability to separate services at architectural shearing layers opens up the possibility of third-party utility services providers operating as they do on Earth, providing services at market-driven prices and even competing for business on the platform. If the service payloads are owned by the vendor, it should be able to provide its customers with services enabled by their own latest, high-capability and most efficient technology service-providing payloads.

F. Occupancy

The site attachment shearing layer (primarily), and the availability of other shearing layers for attachments other than to the structure, open up the possibility of payloads having temporary occupancy on the platform. In this case any of the three models commonly used in terrestrial real estate situations may be applicable: rent, lease, or buy. That is when a mission ends, the mission owner may end the rental or leasing arrangement, or may sell their real estate to another mission.

G. Ownership

If occupancy becomes temporary, so can ownership. This would make it reasonable to sell and buy real estate on the platform, possibly including attachment sites, the structure itself (including portions of the structure that might be detached and operated independently, or reattached to another platform), and payloads. The ownership may also be managed in rental, lease, and buy/sell situations.

H. Real Estate Governance Model

The persistence of a platform constructed with the DIAMOND architecture makes it possible to reapply centuries of legal precedent surrounding the successful, terrestrial, real-estate model, involving owners, lessors, renters, and businesses contracting between themselves to manage property use and exchange. Following conventional rules of terrestrial real estate, it should be possible for tenants to have a right to "peaceful enjoyment" of their site, limiting interference between activities on neighboring sites, while still enabling collaboration among neighbors as they choose. This may be particularly important for tenants that need separate infrastructure for safety, reliability, or confidentiality reasons.

Decisions to change the platform, its utilities, or its payload should be made from time to time. For most platforms we envision, at the level of a village in terms of complexity, the model of a homeowner's association can be applied. For larger scale enterprises, it may be necessary to institute full government apparatus comparable to a nation state.

I. Demand-driven Pricing

For many customers, surface real estate will be their preferred location, and may therefore have the highest payload leasing market value. For some other customers, lower pricing associated with interior payload attachment site may be attractive. For instance, interior locations may still be useful for, e.g. computational resource providers, some kinds of power generation, storage, and distribution, thermal management, local communication resources, activities requiring large volume or stronger structures, and any customer that can benefit (or experience no detriment) from being shaded from outside sources. From a leasing perspective, however, interior sites could be expected to have lower market value if there are a reduced number of potential customers needing interior spaces. We expect that interior payload attachment locations, will have lower prices, but this is not an absolute; we expect that the market would eventually determine the best prices for surface or interior real estate.

V. Conclusion

The DIAMOND architecture offers a combination of an efficient, a highly adaptable structural shearing layer, additional architectural shearing layers for all kinds of utilities, and new operating concepts. These are summarized in Table 1. Figure 6 shows a sample schematic of the relations between different kinds of payloads on a hypothetical platform using the DIAMOND Architecture.

The ramifications of the DIAMOND architecture are manifold. It can support multiple, diverse payloads on space platforms much larger than those that are in use today. The payloads, and the platforms, can be renewed continuously for long periods of time, making it possible to have persistent platforms and greatly improving the return on investment for assets placed in space. Payloads can be sent to a platform without a self-supporting spacecraft housing them, with the expectation of being able to obtain infrastructure services already in place, greatly reducing the cost of placing payloads in space, as well as decreasing the programmatic entanglements between payloads. This would dispense with repetitive launching of spacecraft buses, and mission lifetimes that are shortened by a long list of potential failure points.

Additionally, the size of investment in the platform and its infrastructure is easily adjustable as new customers emerge, and at a pace that can be adjusted to changes in programmatic plans, or to supply-and-demand in the commercial marketplace. The persistence of assets makes it reasonable to apply a terrestrial real estate paradigm to enable tenants to build, buy, or lease sites on the platform for payload attachment, with pricing based on the size and desirability of the site. Following rules of terrestrial real estate, a platform using the DIAMOND architecture can be designed to permit tenants “peaceful enjoyment” of their site, limiting interference between activities on neighboring sites, while still enabling collaboration among neighbors as they choose.

We note that there is nothing excessively challenging, or even new, about any of the technologies involved in providing the architectural shearing layers. Indeed, everything is already done here on Earth. What is new however, is the arrangement of shearing layers to permit persistent platforms to successfully pass through many cycles of change, including many kinds of unforeseeable change at the technological level, and to be constructed in a way that is natural for microgravity environments rather than being constrained by terrestrial or launch loads.

Ultimately, the DIAMOND architecture may enable the creation of a new space technology “ecosystem” supported by entrepreneurs, tenants, owners, service providers, manufacturers, explorers, and the like. The architecture would enable much larger platforms than those available today, with drastically altered economics of space applications. That is, it should be possible for missions to rent, lease, or buy the support infrastructure services that they need, in space, provided by third-party vendors, and to expect long durations for return on investment.

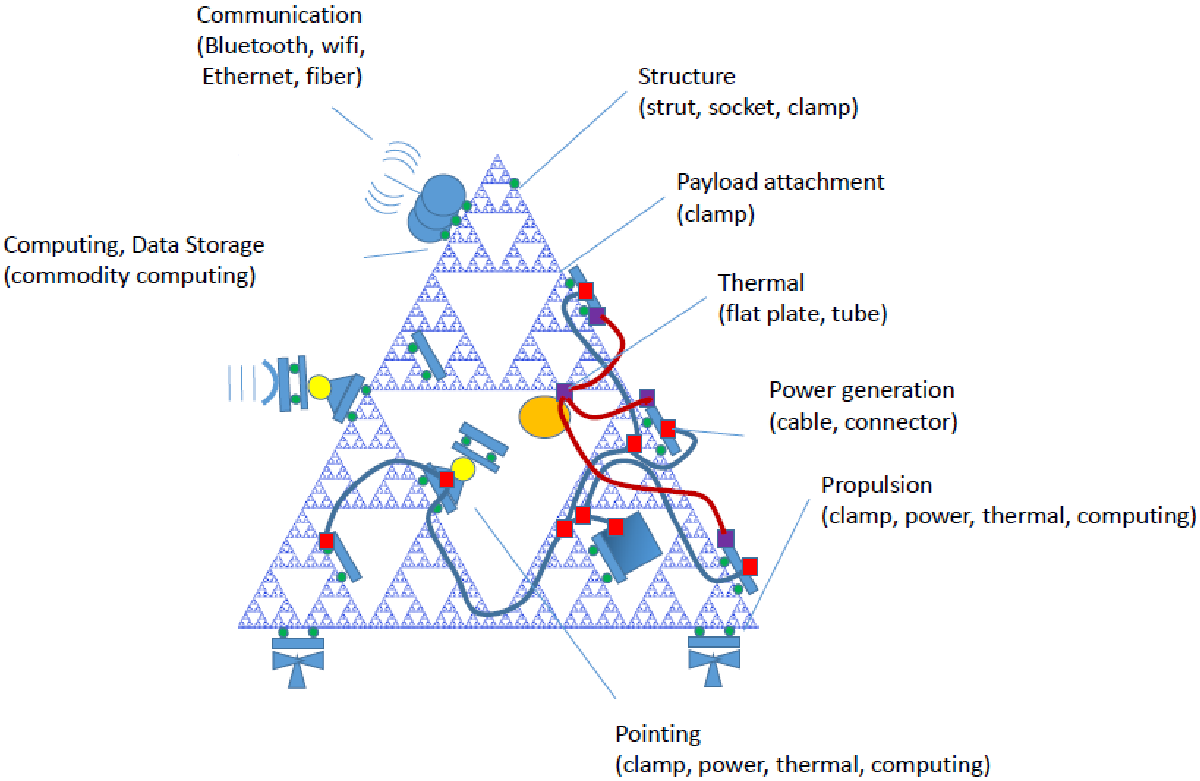


Figure 6. Schematic of a Persistent Platform with DIAMOND Architecture. *The structure in this case consists of a diamond cubic perforated in the pattern of an equilateral triangle Sierpinski pyramid (pale blue triangle pattern). Site attachment clamps (green dots) connect tenant assemblies to the structure. Propulsion assemblies (narrow rectangle with three triangles) are attached to the structure by means of site attachment clamps, and control the location and attitude of the platform. Power generation assemblies (narrow rectangle) are attached to the structure with clamps, and to using tenants using power cables (blue lines) and power connectors (small red squares). A thermal control assembly (orange ellipse) is also connected to using tenants by means of thermal connectors (purple squares) and flexible or rigid heat pipes. Pointing is provided to a tenant assembly by an intermediate assembly attached to the structure (yellow circle), the same clamping arrangement being used between the tenant and the pointing assembly, and between the pointing assembly and the structure. Communication, computing, and data storage are supplied to the remainder of the platform using specialized tenant assemblies (large blue circles).*

Table 1. Summary of DIAMOND architectural shearing layers

Architectural Shearing Layer	Typical Interface	Low rate-of-change Platform Infrastructure	High rate-of-change Tenant payloads
Structure	Nodes and Beams	Persistent Platform	Construction projects, spawning/docking of other platforms
Site Attachment	Quick-Disconnect Clamp	Service-providing assemblies	Tenant assemblies
Power provision	Space-qualified Power Plugs	Power Cables, Power meters, generation facilities	Service entrances to tenant payloads
Thermal Control	Thermal contact plate, cylindrical clamp	Heat pipes, solid heat conductors	Thermal control services payloads
Propulsion and Attitude Control	Site Attachment, power, thermal, communication, computing	Platform maneuvering assemblies	Payload maneuvering assemblies
Pointing and Vibration Control	Site attachment, power, thermal, communication, computing	Observatory assemblies	Tenant payload pointing and isolation assemblies
Communication	Bluetooth, Wi-Fi, Ethernet, Fiber, Optical and RF off-platform	Local Area Network on Ethernet and optical fiber, Wi-Fi Access points	Off-platform communications payloads
Computing and Data Storage	Cloud computing service interface	Servers, data center	Tenant payload computing services

.

Acknowledgments

The work contributed by the Jet Propulsion Laboratory, California Institute of Technology, was performed under a contract with the National Aeronautics and Space Administration.

References

[1]Flores-Abad, A., Ma, O., Pham., K., Ulrich, S., "A review of space robotics technologies for on-orbit servicing," *Progress in Aerospace Sciences*, Vol. 68, July 2014, pp. 1–26.

[2]Ellery, A., Kreisel, J., Sommer, B., "The case for robotic on-orbit servicing of spacecraft: Spacecraft reliability is a myth," *Acta Astronautica*, Vol. 63, No. 5–6, Sep 2008, pp. 632–648

[3]Brand, S., *How Buildings Learn*, Penguin Books, 1995, pp. 12-13.

[4]Simonds, I., and Ing, D., "A Shearing Layers Approach to Information Systems Development," IBM Research Report, RC 21694 (97736), 20 Mar 2000.

[5]Laskin, R. A., "Technololgy for Space Optical Interferometry," AIAA 95-0825, AIAA 33rd Aerospace Sciences Meeting and Exhibit, 9 January 1995.