OFF-SITE / OFF-WORLD: PREFABRICATION FOR EXTREME CONDITIONS AND UNPREDICTABILITY

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OFF-SITE

Prefabrication is most often used in the construction industry for economic reasons, employing mass production and standardization to ease assembly, reduce waste, and to hopefully improve quality. The pitfall to this way of thinking is that architects can be blinded to the specificities of a site by using the same construction methods and materials for any given site condition, producing objects capable of landing in any environment. On the other side of this equation are conditions that are so extreme that we are forced into designing through prefabrication due to the inaccessibility of working in the intense environmental conditions of a difficult site.

A project, constructed off-site, must ultimately adapt to real world conditions through physical assembly completed on site, and then through use over time. Specific site conditions can be neglected while designing the assembly process, but for extreme sites every conceivable condition must be thought through during design. These "buildings," however, are almost never built with the notion of transformation over time.

In their book, *On Weathering: The Life of Buildings in Time*, Mostafavi and Leatherbarrow argue:

> Architecture made up of a 'kit of parts' changed the relationship between a building and its potential site… to a great degree independent of its local environment and climatic conditions - which paradoxically makes it siteless. The variations in the weather and hence in weathering, which can be anticipated in any location, cannot be reconciled with this manner of practice. [1]

Architects using prefabrication often minimize site considerations, because they focus on the construction and assembly process. Site considerations are reduced to generic variables, inoculating a building from what a site may offer. How do we as architects begin using prefabrication without losing sight of one of the most critical aspects of any piece of architecture?

Are there lessons to be learned from extreme off-site prefabrication? What are the implications for how we consider and define site? Can we strive for modifications or a series of attachments that insure a site and building interface over time? Architecture is defined by a relationship to site through time. This paper will examine how extreme site conditions have created opportunities for future adaptation of architecture suited for these environments.

Formidable Sites And Cities

Architects have a history of tackling inaccessible, often formidable site conditions. Since prehistory, we've built on swamps, islands, cliffs, deltas, riverbanks, sand, water, granite, etc. The decision to "dwell" in these extreme environments is usually pragmatic, despite the risks.

Architects hail cities like Paris, Rome or New York as perfected urban conditions where site and building ebb and flow into an experiential whole. These cities accomplish this through hundreds of years of modification and through the altering of complex relationships between site, climate, structure and space. We view these and other ideal forms of site-specific architecture like the Anasazi cliff dwellings in Mesa Verde or Canyon de Chelly, long after their inaugural moves have been made and remade – modification over time is a key to their success as architecture anchored to a site.

Traces of the geologic and topographic layers are but a few in the strata of any city. Thousands of minute decisions, adaptations, constructions and transformations embed any city with a kind of slow learning that can mask the extreme nature of a city's origins. This slower, adaptive learning can then respond to abrupt alteration and allow for the re-configuring of new site relationships. The Haussmann Plan for Paris is an example of this concept, where an existing city was sliced through and subsequently re-clad.

Kenneth Frampton, writing in *Towards a Critical Regionalism: Six Points for an Architecture of Resistance* refers to this slower adaptive learning:

> …inscription, which arises out of 'in-laying' the building into the site, has many levels of significance, for it has a capacity to embody, in built form, the prehistory of the place, its archeological past and its subsequent cultivation and transformation across time. Through this layering into the site the idiosyncrasies of place find their expression without falling into sentimentality.[2]

For Frampton, it was significant to illustrate the difference between a building that is "in-laid" in the site and a building that is simply set on the ground because an acknowledgment of time is essential to expression. The building itself did not need to age, but the process of "in-laying" would allow the building to embody the site's history. Off-site construction is then irrelevant when considering where architecture gains its expression.

Home in a Box

What architects define as "architecture" has an insistent relationship to site through time. This is inevitable, because architecture is built within a context, regardless of its construction method. Architecture, prior to construction, is arguably always "off-site." It is done in a designer's head and is translated onto a drawing board or computer before it is ever physically on site. In other words, designing off-site is not an emergent concept.

Off-site construction is significant, because it requires a prolonging of the off-site stages of design. The translation process, like the design process itself, is removed yet again from the site. The translation is not through construction on the ground – it is only upon assembly in-situ that adaptation can occur. This means that the process of assembly and the potential adaptation on the ground through construction must also be designed and designed in such a way that it can react or respond to future site conditions.

Discussing mass production as a byproduct of the Industrial Revolution in, *Modern Architecture: A Critical History*, Kenneth Frampton writes:

> The Crystal Palace was not so much a particular form as it was a building process made manifest as a total system, from its initial inception, fabrication and trans-shipment, to its final erection and dismantling.... Its realization, which took barely four months, was a simple matter of mass production and systematic assembly.[3]

Much later Frampton furthers this analysis in *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*, describing the difficulty of prefabrication as it meets both site and building program, leaving the user to wander throughout the resultant architecture in search of the entry or other programmatic features due to the labyrinthine attributes of prefabricated structural systems:

> Expressive inadequacy is already evident in the Crystal Palace of 1851, and a similar limitation will arise much later in the technocratic proposals of Fuller and Wachsmann, in which productive and geometrical means rather than institutional ends will be the prime movers of form.[4]

Frampton outlines a critical deficiency in off-site construction – it ignores the site, but it also ignores the way we internally perceive it. In the 1970s there was an interest in "kit homes" similar to the earlier Sears and Roebuck homes that were delivered by rail. One particular brand, the Wausau home, was shipped by truck and could be erected by a family or local contractor on a preformed foundation. Wausau homes were modeled on standard housing typologies – many were simply split-level homes built with stressed skin floor and wall systems that sped up on-site assembly. Similar to normative suburban conditions, owners begin modifying these homes with add-ons and landscape elements. Many of these modifications were derived as a reaction to climate (sun shading, landscape planting requirements, and topography) or from an owner's desire to utilize their entire site. Over time these prefabricated homes become less an isolated readymade and more a condition of exchange between object and site.

What is worth learning from these homes is that while they were partially prefabricated, they were conventional enough in terms of materials and methods of assembly that they were easy to modify. Their generic nature and assembly makes them ideal for future modification and adaptation to site conditions, effectively tackling the dilemmas laid out by Frampton.

In the 1950s, the automotive industry developed a strain of prefabrication that afforded synthetic variation. This design strategy allowed various body styles and even different makes of cars (Chevrolet, Buick, Oldsmobile) to take advantage of similar materials, tooling and subassemblies, such as frames or running gear, while continuing to offer customers a sense of the personal - cars became customizable at the dealership by individual order. The result is a hierarchy of mass-customization through parts-assembly, "features," and aesthetics. This kind of customization produces skin-deep variation, but the principle of a structural skin with "soft spots" for customizable features is not unlike the Wausau home, although carefully designing the weak spots in the overall structure where variation could occur.

Performance

Cities may grow out of extreme sites, but the auto industry uses extreme environments as direct locations for the refinement of prefabricated components and subassemblies. By understanding how components fail in these environments, automotive designers improve safety, fuel economy and the handling qualities of vehicles. The grueling 24 hours of the Le Mans, the Paris to Dakkar Rally, and 0-60 acceleration rankings all testify to the rugged conditions of the competition venue as a means of assuring performance. Intriguingly, manufacturers do not necessarily rely on in-house models to test these environments but also distribute models to smaller independent teams who use brand bodies to radically experiment. Many manufacturers use these modifications to produce "concept cars" that provide trickle-down technology transfers to production vehicles. In the 1980s Porsche produced the 959 – a concept car that pioneered the use of variable all-wheel drive, anti-lock braking, and ground effects. More importantly, the 959 allowed Porsche to synthesize all that they had learned in competition events in a car that would guide their designs for the next decade.

This kind of performance testing through failure and customization is not unlike what Stewart Brand, in his book *How Buildings Learn*, describes as the six "S's".

> The 6-S sequence [Site, Structure, Skin, Services, Space Plan, and Stuff] is precisely followed in both design and construction. As the architect proceeds from drawing to drawing – layer after layer of tracing paper, 'What stays fixed in the drawings will stay fixed in the building over time,' says architect Peter Calthorpe.[5]

Brand, like Leatherbarrow and Mostafavi, is looking for a way of understanding buildings over time. Intriguingly, performance testing through failure culminating in the "concept car" borrows the same strategy. While the "car" itself is continuously remade, the parts that stick, that work, remain fixed and unaltered. Both automotive performance testing and the architectural design process work iteratively and through failure to achieve greater performance, but in terms of the absolutes of competition, the auto industry divorces itself from aesthetics and maximizes the opportunities of engineering – this typically results in competition cars that are stitched or joined together out of various models.

The Landscape of Space

The Space Program adopted prefabrication to cope with the physical displacement from site, such as the distance to the moon. This required an assumption of what constitutes site. Unlike the controlled conditions of performance testing, and incremental modification over time, the Space Program adopted a more radical approach using empirical experimentation combined with precise scientific models to produce a series of prototypes that are continuously used today. The prototype, in essence, has never been de-commissioned to give way to the type itself.

Writing on the "vernacular" that has developed in Space Architecture, Space Architect Kriss Kennedy describes three categories of "architecture": "…*launch vehicles* to put materiel into space, *pressure vessels* (modules) to contain breathable air and provide habitable conditions, and *support infrastructure*."[6] Because whole buildings cannot be launched into space, only pieces can be launched at a time. Like building cranes and delivery trucks, the tools to assemble and deliver a project to a site are themselves an integrated piece of the overall design. The Space Shuttle (or "launch vehicle") is not only a product of engineering prototyping, but also a rather clunky appropriation of the technology itself. While the vernacular may be considered a launch vehicle, the space shuttle is essentially a jet plane strapped to a prototypical rocket.

Regarding site and performative response, in *Complexity and Contradiction*, Venturi writes:

> The tradition 'either-or' has characterized orthodox modern architecture: a sun screen is probably nothing else; a support is seldom an enclosure; a wall is not violated by window penetrations but is totally interrupted by glass; program functions are exaggeratedly articulated into wings or segregated separate pavilions…. Such manifestations of articulation and clarity are foreign to an architecture of complexity and contradiction, which tends to include 'both-and' rather than exclude 'either-or'. If the source of the both-and phenomenon is contradiction, its basis is hierarchy, which yields several levels of meanings among elements with varying values. It can include elements that are both good and awkward, big and little, closed and open, continuous and articulated, round and square, structural and spatial. An architecture which includes varying levels of meaning breeds ambiguity and tension.'[7]

The Space Shuttle is a both-and phenomenon. This is in part because the "site" of space is so extreme performance testing is prohibitive. Engineers rely on the performance testing and iterative learning in other technologies and incorporate these technologies into the design with more radical hypothetically tested technologies.

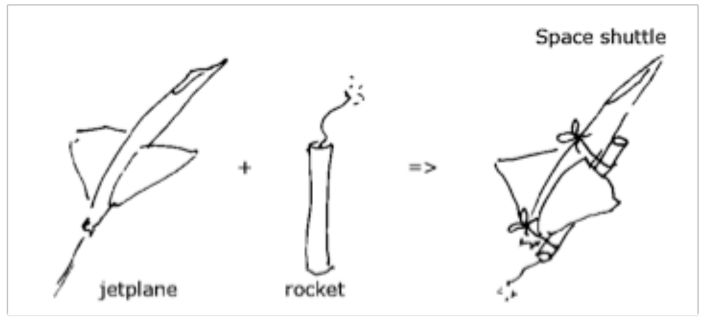

Figure 1. Clunky hybridity.

Physicist Richard Feynman, when investigating the shuttle *Challenger* crash on the Rogers Commission, noted that, "Most airplanes are designed 'from the bottom up,' with parts that have already been extensively tested. The shuttle, however, was designed 'from the top down' – to save time. But whenever a problem was discovered, a lot of redesigning was required in order to fix it."[8] Feynman hit on a key feature of space architecture that is perhaps the most valuable and the most risky aspect of its design: launch vehicles are a hybrid of extensively tested parts and entirely hypothetically tested parts. Underestimating the potential risk led directly to the *Challenger* disaster.

But the clunky hybridity of launch vehicles is also the area of greatest potential for the purposes of this paper. Existing models serve as the basis for direct mimicry, but the various kinds of vernacular developing in Space Architecture do not replicate our traditional understanding of structures on earth. They create ambiguity and tension in their meaning, conveying their clunky hybridity. Through empirical testing, the experimental components limits are reached producing modification in the hybrid assemblies.

Space travel demands engineered products that exceed design expectations due to the safety issues required by extreme temperatures, projectile movement, intense acceleration/deceleration and rotation. Intriguingly, rather than focusing on minimal criteria that correlates to life cycle cost, there exists in the extreme conditions of Space Design a type of thinking that considers the excessive and unique first rather than the standard and conventional.

Ultimately, not only are the engineered strengths of materials critical, but more importantly, the expansion and contraction of various connections and assemblies are vital. Prefabrication is necessary in the assembly and design of cost effective repetitive units, but it also produces the need for connecting multiple units. This also manifests a series of moments that might ultimately allow for adaptation through connection and add-ons, developing site relationships over time. The potential for add-ons might literally build on connective moments at the joints themselves. Similar to the Wausau house, site relationships are built through time. But unlike the Wausau house's normative construction, these opportunities are brought about through the unconventional tectonic nature of the hybrid and piecemeal assembly required for the landscape of Space.

The Mudskipper

The new Amundsen-Scott South Pole Station also builds on both iterative learning and a kind of clunky hybridity. As a base that has been continuously inhabited since 1957, it has had to cope not only with extreme conditions but also with the unpredictable nature of durability and economy building in full-scale prototypes.

The first base constructed at the South Pole established the lifespan of a structure built in-situ: it was crushed by ice sheets, buried under snowdrifts, and ultimately demolished. The station was originally thrown up in a month using basic military camp construction methods, not conceived to last longer than a couple of years.[9] The second base constructed in 1975, is summarized by the architects of the newest base, Ferraro Choi:

> The habitat at the previous 1975 Amundsen-Scott South Pole Station was constructed inside a 50-meter diameter geodesic dome that became mostly buried each austral winter by constant snowdrifts. Every year, bulldozer crews spent several days excavating the dome out from its winter snow accumulation. However, to avoid a "bowl effect" of snow buildup in the nearby surrounding area, the crews also had to push the snow nearly a mile away, a continual process that expended precious fuel. The dome began to show signs of structural fatigue from years of excessive and unevenly distributed snow loading and no longer had sufficient capacity for the increasing population of operations personnel and visiting scientists. [10]

Like the iterations in Space Shuttle development, the three bases have in essence always been experimental prototypes that build on the lessons learned from initial construction, but these do not seek to build on existing technologies.

The latest base, completed in 2008, is at a peculiar evolutionary moment. Employing a different kind of clunky hybridity than the space program, the station builds on design principles employed in other technologies, without borrowing the technology wholesale, as the space industry does. Because the structure is combatting permanently building snowdrifts, the building was designed on stilts. The foundation is permanent, and hydraulic jacks will be used to lift the building in components a full story higher, inserting new sections of column underneath the building. Because the building may settle locally as it is built on an ice flow, the linkages between the main components of the building are designed to expand .25 meters (both the skin and the systems linking these components), and the hydraulic jacks can also be used to level the building.[11] The base itself also has one large chamfer running along the longest edge, which is facing into the prominent winds. A clumsier rendition of an airplane wing, it nevertheless more effectively channels wind under and over the building, helping push snow away from the building.

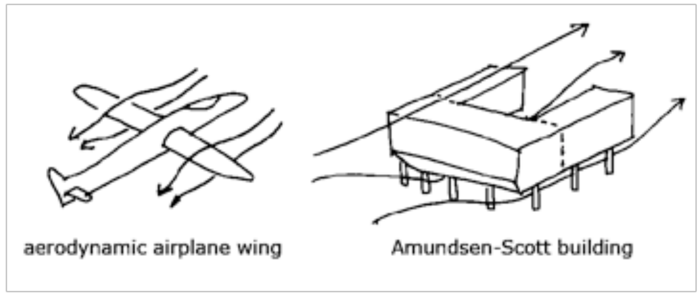

Figure 2. Borrowing design principles

The base is not meant to last forever. But its design is meant to carefully prolong its lifespan. Its durability is learned from the failures and lessons of its predecessors. Distinct from the evolving clunky hybridity of the space shuttle, the South Pole station is bizarrely metamorphic. It bears no resemblance to its predecessors, but it is built from the lessons learned from previous versions (which seem more about what not to do). Like the caterpillar, this building seems, of the examples given, most conscious of its lifespan, how time will affect it. All of its joints are exposed, and these are some of the most interesting aspects of the design, as they must tolerate so much change over a long period of time. Perhaps the best evolutionary comparison is the mudskipper – half fish, half not, and really pretty ugly. Like the mudskipper, the station has not quite shed its flippers or gills but has managed to grow feet.

CONCLUSIONS

Extreme sites demand that buildings utilize prefabrication, and like concept cars, extreme conditions produce tectonics that serve as performance criteria for future models. What is potentially peculiar to building for extreme site conditions is the "top-down" approach Feynman noted when investigating the shuttle Challenger - opportunities (and risks) are brought about through the unconventional tectonic nature of the hybrid and piecemeal assembly required. The prototyping used for these environments is often discontinuous and persistently experimental.

However, the lessons to be learned from this kind of construction reveal a new potential for "in-laying" a building on a site, especially when considering that the expression, or meaning, is brought about by embodying the site over time.

Marco Frascari, when writing on the significance of the detail as generative to architecture, wrote:

> Architecture is an art because it is interested not only in the original need for shelter but also in putting together, spaces and materials, in a meaningful manner. This occurs through formal and actual joints. The joint, that is the fertile detail, is the place where both the construction and the construing of architecture take place.[12]

The appropriation of existing technologies at normative grafting points seen in the clunky hybridity of Space Shuttle design offers the possibility for ongoing modification similar to the Wausau home. In this manner, designers can create modification by designing attachment accessories that could insure site, building and human interface over time, eliminating the "expressive inadequacy" Frampton found in the Crystal Palace. This "both-and" approach to design (merging appropriation and experimentation) allows for a shifting sense in meaning, opening the door to the possibility of embodying the site itself.

In 1953 Louis I. Kahn stated:

> I believe that in architecture, as in all art, the artist instinctively keeps the marks which reveal how a thing was done. The feeling that our present day architecture needs embellishment stems in part from our tendency to fair joints out of sight, to conceal how parts are put together.... If we were to train ourselves to draw as we build, from the bottom up, when we do, stopping our pencil to make a mark at the joints of pouring or erecting, ornament would grow out of our love for the expression of method.[13]

Could the manner in which Kahn describes and honors an ornament that is tied to tectonic expression be seen as a means for off-site prefabrication to be reconciled with tangible site conditions? The joint between both larger and normative prefab components could in this manner find a dialog with site as a form of ornament that could grow toward site in a manner that is more spatial than visual. Turning Brand's six "S's" inside out, tenuous joints become the most fixed, operating in conjunction with the site itself. This can be seen in performance testing through the patchwork of subassemblies revealing the methods the auto industry uses to generate new form.

In *Anchoring*, Steven Holl writes: "Architecture does not so much intrude on a landscape as it serves to explain it."[14] Perhaps off-site prefabrication when viewed in light of Holl's statement work to "explain" site by way of a celebration of the porosity of an object/building by way of its joints that are required for off-site prefabrication itself? Likewise the establishment of a "clumsy" aesthetic that learns principles rather than appropriates from adjacent technologies (i.e. the new South Pole station) offers the opportunity to return to a truly site-specific design. These notions might produce precisely controlled site specificity that could become a powerful tool for sites that require buildings erected in an immediate fashion, while simultaneously producing the variation and individualization that are critical to the way we carve out our own space over time.

Mostafavi and Leatherbarrow write:

> Mass production, and the ensuing changes in methods of assembly determined by this new aesthetic, were, nevertheless, to be the source of a great degree of unpredictability.... The increase in the number of parts went hand in hand with the increase in the number of joints, or points of connection between elements.... This resulted in an increased number of places in the building exposed to the influence of the elements.[15]

A careful rereading of this passage displays an opportunistic potential, where Mostafavi and Leatherbarrow's 'extra' joints, become important moments for design driven environmental inquiry, further opening the door to the possibility of consolidating Frampton's notion of "in-laying" a building into a site. In the end however, for the future of prefabrication in architecture, time (and the occasional inconsistent experimental leap) is key to establishing more intricate site relationships with the potential for adaptation, ultimately producing a kind of performance based evolutionary variation and a careful articulation of joinery may come to serve as an accelerator to this preferential outcome.

ENDNOTES

1. Moshen Mostafavi and David Leatherbarrow, *On Weathering: The Life of Buildings in Time,* (Cambridge, MA: The MIT Press, 1993), 29.
2. Kenneth Frampton, "Towards a Critical Regionalism: Six Points for an Architecture of Resistance," in *The Anti-Aesthetic: Essays in Postmodern Culture*, ed. Hal Foster, (New York: The New Press, 1983), 26.
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13. Louis I. Kahn, "Toward a Plan for Midtown Philadelphia," in *Perspecta: The Yale Architectural Journal*, v. 2, (Cambridge, MA: The MIT Press, 1953), 23.
14. Steven Holl, *Anchoring*, (New York: The Princeton Architectural Press, 1989), 9.hh
15. Moshen Mostafavi and David Leatherbarrow, *On Weathering: The Life of Buildings in Time*, (Cambridge. MA: The MIT Press, 1993), 17-21.