KEYNOTE ADDRESS:
Innovation and Tradition in Human Spaceflight Architecture

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Abstract

In most societies today, people balance their lives between tradition and modernity. Modernity often relates closely to innovation, or at least to a positive view of it. Similarly, tradition and innovation engage in a dialectical process in which the new transforms the old. This essay presents a view of these dynamics from the perspective of a career as an architect in the (NASA) Human Spaceflight program and its unique genesis of Space Architecture as a discipline.

Keywords: Space Architecture, airlock, Colqhoun, Suitport, ISS, Space Station, modernity, Vitruvius, Palladio, spacecraft, space habitat, misuses, Maimonides, Rambam.

Nomenclature

AIAA:	American Institute of Aeronautics and Astronautics
AX-5:	(NASA) Ames experimental space suit 5
BDA:	Big dumb airlock
EMU:	Extravehicular Mobility Unit, the Space Shuttle era spacesuit, still used by NASA on the ISS
ESA:	European Space Station
EVA:	Extravehicular Activity, to egress to the vacuum of space in a spacesuit
FoM:	Figure of Merit, from System Engineering
HSF:	Human Spaceflight
ISS:	International Space Station
LEV:	Lunar Electric Vehicle
MBA:	Space Station Multiple Berthing Adapter (cylindrical tunnel)
MDA:	Skylab Multiple Docking Adapter
NASA:	National Aeronautics and Space Administration
NewSpace:	Commercial, entrepreneurial, and private space launch and exploration companies and activities
PLoC:	Probability of Loss of Crew
PLoM:	Probability of Loss of Mission
PLSS:	Portable Life Support System for a space suit
Rambam;	Rabbi Moses ben Maimonides
SSF:	Space Station Freedom
TRL:	Technology Readiness Level

1. Introduction

When Prof. Maria Joao Durao (University of Lisbon Faculty of Architecture) invited me to give a keynote address on the theme of Innovation and tradition, I was intrigued, but I warned her that speaking on this topic might risk exposing the audience to how strange my mind is. She said that would be OK, but I wonder if she knew to what she was agreeing.

I hope this essay will add up to more than a simplistic mashup of art, design, engineering, and philosophy. It is difficult to approach this topic as a detached academic polemic. I can make sense of this topic only from personal experiences and insights seasoned by unsystematic reading and analysis in multiple disciplines. For this reason—the personal angle—it is not practicable to provide reference citations for some of my key assertions. However, I try at least to frame this narrative within the "traditional" benchmarks for rational discourse and philosophy.[1] Here I present examples mainly from my earlier work because it is better for discerning the salient aspects of innovation, tradition, and modernity.

To start, the perspective that I bring to the discourse on tradition versus innovation derives from my career spent in Aerospace and Architecture, specifically in the US human spaceflight (HSF) program. This HSF endeavor identifies most closely with NASA, where I worked for over a quarter-century. However, in the nascent era of NewSpace, consisting of commercial, entrepreneurial, and private space ventures, it is

[1] This paper embodies a largely philosophical essay, which is somewhat rare for the architectural design literature. The advantage of a philosophical essay is that one can ask questions, but need not answer them.

becoming the province of many startup companies. I come to innovation from the NASA *tradition* that the team takes priority over the individual contributor. I carried this approach—this attitude—into my post-NASA career for Northrop Grumman, my own (former) business Astrotecture®, and in my current participation in Space Cooperative. *It's not about me.* My contributions consist primarily of "getting out in front" of major programs to focus on identifying which innovations the human space program will need. Next comes formulating the concepts and proof of those concepts to demonstrate their feasibility and advantages.

1.1 Buckminster Fuller and his Dymaxion Principle

Buckminster Fuller was my earliest mentor. I attended many of his lectures from 1970 to 1982 and listened to the ones I could not attend. I have read nearly all his books. If I could encapsulate all that I learned from Bucky in one thought, it would be a recitation of his Dymaxion Principle. The Dymaxion Principle derives from methodological roots, which Fuller recounts in a conversation with Dr. Jonas Salk in the mid-1950s, soon after the global, life-changing success of his polio vaccine.

> Dr. Salk said, "I've always felt that those dymaxion gadgets—cars, houses, maps, etc.—were only incidental to what you really are interested in. Could you tell me what your work is?"
>
> I said, "Yes, I've been thinking about that definition for a long time. I've been engaged in what I call comprehensive anticipatory design science."
>
> And Dr. Salk said, "That's very interesting, because that's a description of my work too" (Original emphasis. Fuller, 1965, p. 63).

In terms of practical application, Michael Hays, Prof. of Architecture at Harvard, said,

> We didn't talk about sustainability in Fuller's day. . . . But he was trying to develop ways of living that would benefit the largest number of people with the fewest possible resources. (McKeogh, 2008).

This overarching objective of Operating Spaceship Earth (Fuller, 1969), to make a fair and sufficient allocation of resources for all people was a constant theme in Fuller's work. So, Fuller's approach to the *Dymaxion Principle* stands on these three dynamics:

Comprehensiveness—seeing the big picture, the integrated system within all it entails,

Anticipation—foreseeing what the building, the house, the invention, the operation, the system will need in its full development, and

Design as Science—the idea that not only should there be a rational and empirical basis for design decisions, but that it should derive from a testable, empirical, and "provable" basis.

This last point is especially relevant to Space Architecture today. The act and the art of designing are fun. Yet, unless there is an empirical, evidence-based foundation for a design in Space Architecture, it is no better than any ego-driven artistic design or any unself-conscious engineering scheme that fails to consider its human impact and consequences.

1.2 Design Science?

Fuller's notion of Design Science stands on the argument that a design solution should be *testable* and *provable*. However, Fuller does not go as far as his 20th-century contemporary philosophers of science did.

These contemporaries (e.g., Feyerabend, 2010, pp. 16, 146; Kuhn, 1975; Popper, 2002, pp. 18-20) addressed this argument and principle in the scientific method. To sustain a scientific theory or hypothesis, it must be *falsifiable.* It would not suffice, not solely that the hypothesis, theory, or—in this case—design should be *provable*. Provability depends largely on observation and analysis. *Proof* and *falsification* do not necessarily cancel each other out, but they must remain separate and distinct. For falsification, the test is always: Can you reject the *old paradigm* (Kuhn, 1975, p. 95) or reject the *alternate hypothesis?* Does the *null hypothesis/old paradigm* prevail?

It may seem strange to couch a design problem and its solution in this language of science, but how can it constitute a true Design Science while eschewing the true language of science? In my view, falsifiability pertains first to the design problem definition, to verifying the elements that comprise the problem. Are the requirements the correct ones? Second, falsifiability applies to validation of the design solution. Does the solution address all the elements of the design problem definition? Does it meet the requirements? Does it "solve" the design problem?

1.3 Robert E. Machol and System Engineering

Another mentor I met when I started working at the NASA Space Station Concept Development Group in Washington, DC (1983-84) is Robert Machol, the founder of *System Engineering*. Subsequently, Machol engaged in several consulting contracts at NASA Ames Research Center, where we held frequent discussions. Machol was a Fuller contemporary who surpassed Fuller in the Comprehensiveness dimension of the Dymaxion Principle. Robert Machol and Harry Goode's seminal book System Engineering (1956) presents innovative, systematic, and quantitative approaches to analyze and solve complex design problems. This first version of what became his System Engineering Handbook presents a revelatory and revolutionary way to approach and analyze technical problems. Like Fuller, Machol emphasizes looking at the total context, the big picture, the comprehensive design problem space. From Machol, I learned to ask always: What are they not seeing? What are they not considering? Not taking into account? What happens if you calculate that? . . .

1.4 In the Space Community

What I found early in my NASA career—and throughout my work in HSF—was that when dealing with architects, engineers, or scientists, there were always many things that they did not consider in the problem definition and design of an HSF project. Those blind spots would afford the basis of a dissertation, but essentially here are the patterns of omission that I found:

- Architects look at the big picture, but their grand concept as a design solution tends toward the egotistical and overlooks key practical issues in design of an HSF habitat.
- Engineers wish to believe that everything is reducible to a quantitative problem for which there must somehow exist a quantitative optimization, if not a deterministic solution.
- Scientists want the best possible accommodation for their experiment, instrument, or payload but tend to be reluctant to see or to embrace the larger design problem and solution.

Of course, there are important exceptions to these observations which would afford another dissertation, so let us leave it there.

2. The Guide for the Perplexed

This section addresses the conditions and circumstances that promote and stimulate the deep insights that lead to genuine creativity in design. The framework for this discussion is knowledge of *absolute* or *necessary* truth versus the knowledge of good and evil.

2.1. Maimonides

One model for design problem conceptualization that I found and have used for more than 40 years to think about this conundrum comes from Rabbi Moses ben Maimon (רבי משה בן מימון) or Maimonides, also Rambam (רמב״ם). His Guide for the Perplexed, written in the 12th century, presents a model that postulates the concept of truth and falsehood as separate and opposed or unconnected to the concept of good and evil.

Although there are enormous numbers of commentaries on this work and interpretations of it, I found my own interpretation of a key part of it. Discussing *Bereshis*, the Book of Genesis, Rambam explicates the incident of Adam and Eve disobeying God's first command and eating from the fruit of the tree of *knowledge of good and evil* (Maimonides, 1190, pp. 96-97). To set the stage:

God tells Adam (Genesis 2:16-17):

2:16
וַיְצַו֙ יְהוָ֣ה אֱלֹהִ֔ים עַל־הָֽאָדָ֖ם לֵאמֹ֑ר
מִכֹּ֥ל עֵֽץ־הַגָּ֖ן אָכֹ֥ל תֹּאכֵֽל׃
2:17
וּמֵעֵ֗ץ הַדַּ֙עַת֙ ט֣וֹב וָרָ֔ע לֹ֥א תֹאכַ֖ל מִמֶּ֑נּוּ כִּ֗י
בְּי֛וֹם אֲכָלְךָ֥ מִמֶּ֖נּוּ מ֥וֹת תָּמֽוּ׃

2:16: " And the LORD God commanded the man, saying, "Of every tree of the garden you are free to eat;

2:17: but as for the tree of knowledge of good and evil, you must not eat of it; for as soon as you eat of it, you shall die."[2] (translation, Sefira, 2011).

Here is how Rambam explains the story.

> ". . . the intellect which was granted to man as the highest endowment, was bestowed on him before his disobedience. With reference to this gift the Bible states that "man was created in the form and likeness of God." On account of this gift of intellect man was addressed by God, and received His commandments, as it is said:
>
> וַיְצַו֙ יְהוָ֣ה אֱלֹהִ֔ים עַל־הָֽאָדָ֖ם,
>
> 'And the Lord God commanded Adam' (Gen. ii. 16)--for no commandments are given to the brute creation or to those who are devoid of understanding.
>
> Through the intellect, man distinguishes between the true and the false. This faculty Adam [and Eve] possessed perfectly and completely. The right and the wrong are terms employed in the science of apparent truths (morals), not in that of necessary truths, as, e.g., it is not correct to say, in reference to the proposition "the heavens are spherical," it is "good"

[2] The Talmud states in Sanhedrin 56 that these two verses do double duty in conveying to Adam a symbolic or metaphorical mnemonic for the seven Noachic laws.

> or to declare the assertion that "the earth is flat" to be "bad": but we say of the one it is true, of the other it is false. Similarly, our language expresses the idea of true and false by the terms אמת [emet, truth] and שקר [sheker, falsehood], of the morally right and the morally wrong, by טו,[tob or tov, good] and רע [ra', bad or evil]. Thus, it is the function of the intellect to discriminate between the true and the false--a distinction which is applicable to all objects of intellectual perception.

Before they violated Her command and broke what was *de facto* the first covenant between humans and the God of the Torah, presumably Adam and Eve lived in a kind of perfect state of bliss. In this state, they enjoyed a direct knowledge of their *Creator* and her Creation. In this knowledge, they could know absolute truth and recognize its opposite—falsehood—in all its degrees from absolute to commonplace.

Note that Rambam calls this insight ***necessary truth***. Imagine necessary truth existing on an axis of data that is orthogonal to the axis of knowledge of good and evil. That is the knowledge of the profane, the everyday, workaday knowledge of getting by, of just surviving. Like cartesian coordinates, these axes intersect only at *0,0 knowledge.*

So, when Adam and Eve ate of the fruit of the tree of knowledge of good and evil, God's **punishment** for them ***was to give them that knowledge of good and evil.*** Although Adam and Eve retained their intellectual faculties, the experience of acquiring the knowledge of good and evil effectively wiped out their ability to know truth, to know ***necessary truth***. By inference, they lost most or all of their ability to distinguish between truth and falsehood. Being thus afflicted with the knowledge of good and evil, Adam and Eve were constantly asking, "Is this thing better than that thing?" Or, to keep to the horticultural metaphor of *Paradise Lost*[3], the vanished Garden of Eden, "Is this berry better to eat than that berry? Is this flower better to sniff than that flower?"

So how does this half-baked theologizing relate to tradition and innovation? The way I conceive it, tradition is rooted invariably in the knowledge of good and evil. We have always done x this way, therefore it is right. Those people over there do x differently, so that is wrong. What is more, sometimes, they do y instead of x, which is even worse. Tradition has little to do with necessary truth.

Still, tradition is not automatically synonymous with tribalism, ethnonationalism, doctrine, or adherence to any particular stylistic mindset. However, there are overlaps. None of these observations imply that tradition itself, *per se*, is evil or good. Most traditions simply are, simply exist, carried on by the family, the clan, the tribe, the state, the nation—indeed—the people—who inherited.

2.2. The Analytical Framework of Necessary Truth

Following Rambam's set up (or my interpretation of it), if tradition sits on the axis of the knowledge of good and evil, the way to innovate (insofar as I experience it) is to learn the necessary truth about the design problem space. In that moment of *knowing*, the flash of insight occurs—that blazing photon of truth—that tells the architect, the artist, the designer, the engineer, or the inventor that another way is possible. To apply Rambam's terminology, does the status quo way reflect a ***necessary truth?*** Why not do it another way that could be different? Not good, not better—just POSSIBLE! The claim that a different way is *better* or *worse* on the axis of good and evil can come only after a great deal of hard work, testing, and usually many failures by the creator (the small "c" creator).

That is the flash of insight I have been very fortunate to experience a few times. Sometimes it proves successful, more often not. But the point is that this glimmer of necessary truth is the font of profound insight that leads to true originality.

Life in much of engineering—especially System Engineering—as practiced today operates within the multitudinous gray scales of good and evil. Is widget A a little better than widget B? Does item c give a measurably better performance than item d? Is that small difference statistically significant? Having lived their entire professional careers in the fog of shades and tints of gray, some people may become so neurologically or neurotically inhibited from seeing truth and falsehood that they oppose innovation, period.

Money affords the ultimate gray scale. Does X cost less? Does Y return more profit? More return on investment? Thinking this way would be anathema to all forms of creative innovation in art, design, and engineering. Yet it comprises the calculus that drives so much of human activity.

2.3. Necessary Truth and the Suitport

My patent that best reflects the analytical

[3] Apologies to John Milton.

framework of the axis of necessary truth versus the axis of good and evil is the Suitport Extravehicular Activity (EVA) Access Facility. The model of these axes represents an analytical approach of inquiry to anticipate and comprehend the design problem space and hopefully find a transformational solution. It is not a prescriptive design solution-seeking method.

The Suitport constitutes a kind of "airlockless" airlock for spacesuits, or to put it into NASAspeak, for an EMU[4]. which is an early case of an acronym within an acronym: an EVA Mobility Unit. Before the International Space Station (ISS) Program, the paradigm of an EVA airlock was simple. It consisted basically of a big hermetically sealable container that the crew could depressurize when they wanted to "go EVA," that is egress the spacecraft. After ingressing back into the airlock, the crew would seal the outer hatch, repressurize the airlock, and be able to doff their EMUs and breathe the air.

The problem with this traditional method of using the big dumb airlock (or BDA, even detractors can make up acronyms) was that it required sacrificing the volume of air in the airlock. For a future airlock of 6 to 8 m^3 (212 to 283 ft^3), that amounts to a significant and painful loss. Even If one wanted to save (most) of the air in the airlock, it takes crew time while transiting the BDA, electrical power, and pump cooling to pump down the air into a separate storage container under higher pressure. Also, in the conventional schemes such as the Voshkhod inflatable airlock, the Skylab airlock, and the airlock on the Salyut stations (and later on Mir), the only place to stow the suits when not in use was in the BDA. For the ISS, which anticipated many frequent and "routine" EVAs, this scheme could not succeed.

Also, I was very concerned about the Skylab precedent of the airlock segment situated between the Orbital Workshop where the crew lived and the Multiple Docking Adapter (MDA) where the Apollo CSM docked. When a buddy pair went out EVA, leaving the airlock depressurized, the third crew member was required to retreat to the MDA lest he be cut off from escape in an emergency. Placing the entrance to the Space Station between modules that it must isolate and separate when the entrance was in use seemed self-defeating at best. There was also the issue of the several hours required for the crew to prepare the suits for the EVA and the additional hour required to conserve the atmosphere in the airlock by pumping about 90 percent of it down into a tank.

I was thinking that the Space Station would need a kind of formal—not just functional or, rather partially dysfunctional—entrance. I was thinking about the *Propylaea*, the ceremonial entrance to the Acropolis in Athens, wondering, "Does the Space Station need a Propylaea?" I was in one of the Ames EVA Branch spacesuit labs looking at the AX-5 rear-entry hard suit mounted on an unpressurized donning fixture shown in FIGURE 0. A whisper chanted in the back of my mind, orbiting in ellipses:

- Anticipatory, comprehensive, *falsifiable*?
- What are they *not considering*?
- What is the *necessary truth*?

FIGURE 0. AX-5 "Hard" Spacesuit, mounted on the unpressurized donning fixture. The astronaut is evoking Da Vinci's *Vitruvian Man* with his arms and legs. Designed by Hubert C. "Vic" Vykukal, Ames Research Center. NASA Photo.

The flash of ***absolute truth*** that hit me was: *Why pump down at all?* Is pumping down the airlock a necessary truth? *Why not just seal the rear-entry port to the pressure bulkhead?* Sacrifice only the small interstitial volume of air between the suit hatch and the station hatch. FIGURE 1 shows the Suitport assembly. Note where the Portable Life Support System (PLSS) backpack seals against the pressure bulkhead, leaving the interstitial volume No. *92* as the only volume that needs to be sacrificed to vacuum. Save the mass of the pumpdown compressor and tank. FIGURE 2 presents a longitudinal section through an EVA Access Module, with the Suitport installed in the internal bulkhead.

[4] EMU is an early instance of a NASA acronym within and acronym, standing for EVA Mobility Unit.

Some colleagues to whom I have told this story brush it off, “You just had a *prepared mind.”* Certainly, possessing a “prepared mind” may help, but it does not explain the sharp departure from status quo.

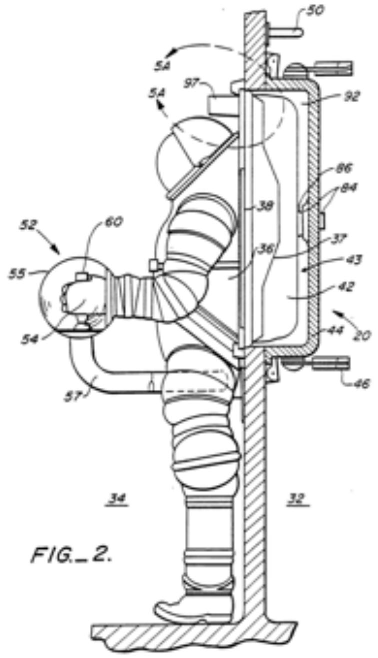

FIGURE 1. Cross-section of an AX-5 hard space suit attached and sealed to a Suitport. (Cohen, 1989).

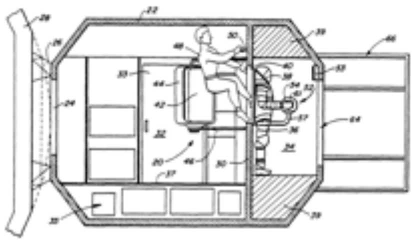

FIGURE 2. Longitudinal cross-section of a Suitport installed in a cylindrical EVA Access Module. The crewmember is donning an AX-5 space suit. (Cohen, 1989).

With this design solution, the Suitport offers order of magnitude savings in atmosphere conservation, power, pump cooling, and crew time. It also has attracted support from the space community for its potential to control and mitigate Lunar or Martian dust from entering the space habitat living environment. The astronaut Michael Gernhardt built a full-scale, pressurizable working prototype of two Suitports into the NASA Lunar Electric Vehicle (LEV). He drove it as the NASA “float” in President Obama’s first inaugural parade in 2009. FIGURE 3 shows the LEV.

FIGURE 3. Lunar Electric Rover on Parade. Courtesy of NASA.

3. Modernity and Tradition

When I first considered this theme, *Innovation and Tradition,* my mind went quickly to the dialectic of Tradition and Modernity, which describes the balancing act that is part of my life. For some people choosing tradition or choosing modernity is an easy decision, not even really an actual choice in many cases. I always feel that I am balancing between traditional aspects of life and more modern aspects. I think of all the balancing I do about the multiple axes: tradition and modernity, the unity of knowledge and the fragmentation of knowledge, the continuity of Einsteinian time, and the discontinuity of how I experience it.

3.1. Classicism and Modernism

Within terrestrial architectural circles, there has been a robust dialogue for decades about the potential connections of Modern Architecture to its predecessor, Classical Architecture, and its integration with engineering. Modern Architecture was in its essence, a reaction against the over-decorated and stylized 19th-century forms of Gothic revival, Romanesque imitation, and other romantic departures. Multiple authors and architectural historians have written on this theme for or against, but mainly in favor of the connection. Among these historians, Alan Colqhoun, a British architect and professor at Princeton, stands out as a leading proponent (Colqhoun, 1991). Colqhoun directs his attention particularly to the Swiss modernist Le Corbusier. Colqhoun writes about what he calls Le Corbusier’s paradox of reason—actually, there is a multitude of paradoxes (Colqhoun, 1989, pp. 98-99):

> Le Corbusier was evidently still acutely aware of the conflict between an aesthetic idealism leaning toward the classical and an avant-gardism that wished to embrace the most modern tendencies.
>
> . . . By committing himself to the general principles of modern engineering, the architect will rediscover the sources of his own discipline. To demonstrate this, Le

> Corbusier must first distinguish between engineering and architecture. The aim of the engineer is to provide what is useful. The aim of the architect is to arouse emotion. . . . In this theory, the difference between the architect and the engineer seems to lie in the degree of intentionality. Engineers make architecture, as it were, unintentionally. They make us feel harmony, but it is in the intentional manipulation of his feeling of harmony that the work of the architect lies. Thus, if in one sense, the engineer and the architect start from the same foundation, in another sense architecture has its own basis, which lies in its ability to strike our senses by means of clear, simple forms. The engineer, proceeding by the route of knowledge, merely shows us the path of truth, whereas the architect makes this truth palpable.

Colqhoun is attempting to balance or rebalance the 19th-century schism between architecture and engineering in his interpretation of Le Corbusier. Because the engineer calculates the design according to the laws of physics, engineering follows a set of "universal laws." The architect designs for the formal experience of the environment and all it can evoke emotionally, thereby following another—and presumably different—set of "universal laws." Colqhoun thus attempts to reconcile the classicist claim to an architecture rooted in nature (and natural law) and the modernist vision of an architecture based on engineering and technology.

The place Colqhoun's effort breaks down is where he ascribes "the path of truth" to physics- and math-based engineering. That relegates the architect to "making this truth palpable," by which he seems to mean to give it form, volume, and a visual perception. This notion of truth in design is far more pedestrian than Rambam's ***necessary truth.*** Ultimately it does not reunify architecture and engineering but rather merely asserts their division of labor.

3.2. The Unity of Knowledge (or the lack thereof)

Colqhoun demonstrates the ongoing struggles in architectural design, history, ideology, practice, and theory. Taken together, they make quite an academic rabbit hole. However, the conflict lies primarily in the time-honored art of making fine distinctions.

For me, the reason for these struggles may be that I always see connections much more strongly than I see separations. When I first started junior high school (middle school) going to classes in different subjects with different teachers somehow *did not make sense.* In a fundamental way, I could not see the subjects as isolated and distinct from one another. Without physics, mathematics had no purpose. Social Studies (history) and literature had no separate existence. Without the chemistry of paint, clay, and glaze, art could not happen.

3.3. Dis-Continuum of Time?

Often, I feel a similar way about time, that the connections across the years, centuries, and millennia are stronger than the passage. According to Steven Hawking, time is not a social construct (1988). Rather, it exists independently of human perception and psychology. How we perceive time may evoke a cultural, psychological, or social response. In this respect, I feel like I am on a sort of temporal slide that allows me to slide forward and back through temporal space, or as Einstein would have it, the space-time continuum. After all, *what good does this time continuum do us if we are always stuck in the present?*

3.4. Dis-Unity of Architecture and Engineering

A parallel phenomenon overtook the entwined development of architecture and engineering. Until the late Renaissance, there was no breakdown between architecture and engineering. Gradually civil and structural engineering began to emerge as their own disciplines. By the early 19th century, when J. N. P. Durand founded the École Polytechnique in Paris, the split became complete. Since that time, engineering and the sciences have split many times into a vast multiplicity of different specialties. The practice of Architecture too began to fragment along the lines of specialized building types. In the 1980s, clients in the USA began to complain that increasingly architecture firms were no longer "full service." Instead of doing the complete design themselves, architecture firms began contracting-out for civil, electrical, mechanical (plumbing, heating, ventilating, and air conditioning), and structural engineering.

Meanwhile, I have not ceased to see the unity of Architecture, Art, Engineering, and Science through the connections among them. In this respect, I plead guilty to being a traditionalist—perhaps a paleo-traditionalist, just like I am a paleo-modernist. Insofar as the modern world demands the fragmentation of knowledge and creative design effort, it encourages the stovepipes between small groups of hyper-focused professionals who may be barely educated about anything else. This is a situation that I have encountered many times in the aerospace design field. When I was working on the integration of the "System of Systems" for the Northrop Grumman/Boeing proposal for the Orion Crew Exploration Vehicle, I discovered that there were 16 separate engineering stovepipes. None of them talked to the others. But for my work, I needed to talk to all of them. Often it was difficult just to introduce myself because some of them could not imagine why they should want to talk to me or anyone outside their stovepipe on this project. When I introduced concepts about how the crew would operate the Orion for a vast array of tasks, one of the Boeing operations managers contradicted me, "If you're not burning propellant, it's not an 'operation.'"

But it's the CREW exploration vehicle," I retorted. "When the crew does anything for the mission inside or outside the spacecraft, it is an operation."

This manager could not accept my statement. Is this what modernity has bought us — this ever-fracturing of design and design knowledge? The steady proliferation of narrowly-focused journals, each one wanting its own "manual of style" and peculiar system of reference citation?

3.5. Using Historical Methods

The way I see these long-deceased theorists and their buildings is that they speak to me. The same experience and meaning that the architect intended for her client is what I experience or at least want to experience. It does not concern me that this work may have influenced others or benefited from someone else's influence.

The methodological and theoretical books communicate to me even more strongly. When I read Vitruvius, Alberti, Palladio, Serlio, or Gropius, I do not hear them as speaking only to their contemporaries (much less only to Art Historians). I experience them as speaking directly to me across the centuries and millennia.

In contrast, most architecture students are taught a very watered-down Marcus Vitruvius Pollio, 1st Century BCE. through these two mantras:

1. Firmitas, Commoditas, Venusitas (Firmness, Commodity, and Delight; or Strength, Usefulness, and Beauty) and,
2. The column is the principal ornament of architecture.

So, what is the principal ornament of *Space* Architecture? I would argue from what little we have to go on so far, it is the handrail, both interior and exterior. THAT would be a different essay.

3.6. Vitruvius and Privacy

For a counter-example to these recitations that offer something timeless—and transcends gravity regimes—I look to Vitruvius. In his Ten Books on Architecture, Vitruvius gave the first known definition of privacy in architecture and contrasts it to public spaces (Vitruvius, 1st Century BCE, Section 6.5.1):

> The private rooms are those into which nobody has the right to enter without an invitation, such as bedrooms, dining rooms, bathrooms, and all others used for the like purposes. The common are those which any of the people have a perfect right to enter, even without an invitation: that is, entrance courts, *cavaedia,* peristyles, and all intended for the like purpose.

However, the ancient Romans threw a twist into what we today would consider private or a private function. In modern times, the bedroom and the bathroom or water closet are the most private rooms. But for the Romans, the dining room was the most private while the toilet room was more public, a place of invited conversation among friends or family sitting side by side. A bedroom was possibly less private than the dining room since the bedroom "guests" did not need to be of the same economic or social class. However, to break bread with someone from a lower class was more of a taboo, hence the ultimate private nature of the dining room. '

There are only limited examples of "private spaces" in space habitats. The Skylab Crew Quarters Deck included the first private sleep compartments. FIGURE 4 shows a sketch of the three sleep compartments. Raymond Loewy, the industrial designer, laid out the plan so that the floor area of each would be a different shape to give each one a separate identity. The mission patch for the Skylab II mission (the second crew rotation) displays Leonardo Da Vinci's drawing of Vitruvian Man, a most appropriate emblem, shown in FIGURE 5.

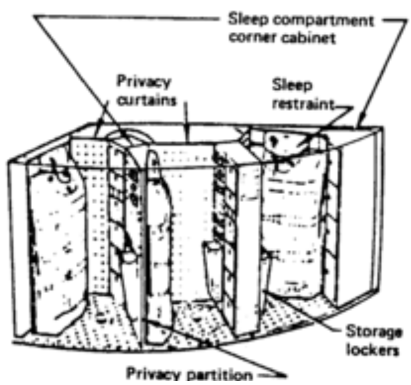

FIGURE 4. Skylab Crew Quarters sleep compartments (total floor area 6.5m^2 (70 ft^2). NASA Man-System Integration Standard, NASA STD-3000.

FIGURE 5. Skylab II mission patch, displaying Leonardo's Vitruvian Man.

3.7. Palladio and Space Station

Andrea Palladio was possibly the most influential architect ever in the Western world. Architects have copied his style and borrowed his elements all over Europe, North and South America. In The Four Books on Architecture (1570, p. 28). Palladio offers three formulae to calculate the proper ceiling height of a room based upon its proportions and size. When I was designing the space habitat module for the Space Station Proximity Operations Simulator, it was necessary to determine this ceiling height for a module "room" with a longitudinal vaulted ceiling.

FIGURE 6. Oblique view of the Space Station Proximity Operations Simulator. NASA photo**.**

In practice, this exercise meant determining the physical floor height within the horizontal cylinder. This floor height would then indirectly define the ceiling height. I tried all three of Palladio's formulae, all of which are based on his proportional method of *the sesquialteral.* None of these methods worked perfectly, but once I understood their deep structure, I was able to adjust them to solve the problem. That exercise set the floor height at 0.73 m (2.4 ft) above the bottom of the horizontal module cylinder. So, the floor to ceiling height came out at 3.55 m (11.6 ft). FIGURE 6 shows the width and height of the simulator window bulkhead with its controls and displays.

More recently, I referred to Palladio's method of connecting rooms and assigning functions to them in a paper on the configuration of lunar lander habitable modules. I made specific reference to Palladio's drawings of the *Villa Emo* to apply his method of connecting rooms by function within a mathematically derived grid (Cohen, 2010, p. 6).

So, here I am, working on the human spaceflight program for NASA, and later Northrop Grumman, and then for my own former company, Astrotecture®, but making use of these long-past *traditional* architectural precepts and design methods. This apparent difference in direction often causes cognitive dissonance for people who hope to understand Space Architecture and how I do it. The idea that there is no expiration date on a good idea runs contrary to our "modern" throwaway society disposable-everything consumer culture. In the wonderful film, *Hidden Figures,* Katherine G. Johnson (Taraji P. Henson) says they can use Euler's method to calculate John Glenn's reentry trajectory and landing point.

A young engineer complains, "But that's so old!"

"But it works" replies Katherine Johnson calmly.

3.8. Academia

Academia is not immune to such trends and fads. In many universities today, most professors give at least lip service to being "interdisciplinary." What that means in practice is that once a year, an engineering professor has lunch with a literature professor, and they talk about their children. I have run into this situation myself at about a dozen universities. In one way or another, they all make the same objection, "You do so many different things; you work in Architecture, life support, EVA airlocks, habitability, human factors, and structures, etc. How can you work in so many different disciplines? We would not know in what department to put you! You would not fit anywhere!" And all the while, I think I'm doing just one thing: Architecture.

Here is the rub. Academia can tolerate people from different fields working together in a multidisciplinary way. Unfortunately, Academia cannot seem to handle people who work in multiple fields simultaneously or make connections between them. To paraphrase *Ghostbusters*, "Important safety tip: Don't cross the beams."

4. Modernity and Innovation

Innovation is often considered synonymous with modernity, but it is not. Granted, the only constant in our lives is the ever-increasing pace of change[5] that tends to define modernity. But are these changes all innovative? If they truly are innovative, will they be welcomed? If it is truly innovative, is it necessarily fast-paced?

4.1. The Triangular-Tetrahedral Space Station

In Continuum of Space Architecture (2012), I trace the evolution of understanding of the Platonic Solids from Earth to orbit. In The Dialogue of Timaeus, Plato describes the five solids that have a single polygonal face, and he ordered them according to the number of faces: Tetrahedron, cube (or hexahedron), octahedron, dodecahedron, and icosahedron.

Leonardo da Vinci drew the Solids with an emphasis upon the edges or struts. From a modern computer-aided design perspective, he drew them as wireframe models that dissolve the faces.

Buckminster Fuller took the Solids to a higher level entirely in Ideas and Integrities (1963). He placed the emphasis on the vertices and reordered them by the number of vertices: tetrahedron, octahedron, cube, icosahedron, dodecahedron. I took Fuller's stress upon the importance of the vertices or nodes and applied it to a configuration for a space station (Cohen, 1988).

The previous NASA and contractor concepts presented Space Station configurations composed entirely of cylindrical modules and cylindrical tunnels called multiple berthing adapters (MBA) connected together in an awkward and largely unworkable rectangle. Making these right-angle connections to form rectangles of modules would impose potentially large bending moment forces that the structure must resist across the width of the docking port.

Adding spherical nodes would provide the additional and hopefully sufficient berthing ports for other pressurized modules or cargo carriers and docking ports for spacecraft such as the Soyuz or Space Shuttle Orbiter. Therefore, it would be advantageous to maximize the number of nodes relative to the modules. The polyhedron that gives the highest ratio of nodes to struts — in this embodiment as pressurized cylindrical modules — is the tetrahedron with four nodes to six modules.

This year, the shortage of docking ports on the ISS proved the Triangular-Tetrahedral geometry prophetic. On at least two occasions, the lack of an open docking port, compelled either a delay of a launch (Howell, 2021) or the relocation of a spacecraft already docked to the ISS (Matthewson, 2021).

The triangular/tetrahedral geometry imparts a structural advantage as well. The predecessor rectangular configurations (plus the cube and dodecahedron) are not self-rigidizing. They achieve structural stability only through the stiffness of their joints. Where that joint involves a berthing hatch connection, the attached pressurized module can impart a large bending moment that exerts a force on the berthing hatch frame. The frame must resist this force with a resisting moment arm across the diameter of the berthing hatch.

A triangular-faced polyhedron does not present this structural shortcoming. Because the triangles act like the pin-jointed truss members, there is no bending moment to resist at the joints. Their berthing port need not provide a moment-resisting arm across its diameter.

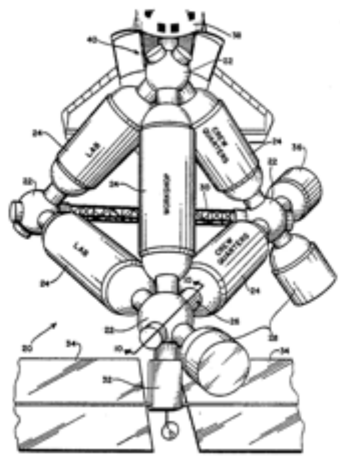

FIGURE 7. Triangular/Tetrahedral Space Station, US Patent 4,728,060. 1988.

4.2. Space Station Nodes

In this patent, the baseline configuration is the tetrahedron with spherical nodes at the vertices. This patent introduced the spherical nodes into the NASA *Space Station Freedom* in the October 1985 Requirements Update Review 2. Subsequently, NASA "rationalized" the nodes to short cylinders to make the hardware consistent with the "common

[5] Prof. Richard Duke at the College of Architecture and Urban Planning at the University of Michigan—Ann Arbor coined this expression.

module," particularly the frusta-conical end domes. The nodes persisted in the ISS.

4.3. Space Station Cupola

The 1988 Space Station Architecture patent incorporated the cupola as a domed window assembly attached to a radial berthing port. The idea for the cupola and the radial ports in combination stemmed in part from Filippo Brunelleschi's Duomo in Florence. Shown in FIGURE 8, the Duomo's cupola on top looks out in all directions. The rondel windows around the base of the dome form a radial band of openings (that allow for thermal expansion).

FIGURE 9 shows how the Cupola mounts on a hemispherical segment derived from a structural node. This arrangement introduced the cupola concept that now flies on the ISS, attached to an Earth-pointing radial docking port on a node.

FIGURE 10 shows the spherical nodes and cupola as introduced into the SSF configuration in lieu of connecting tunnels and MBAs.

FIGURE 11 illustrates the Cupola that the European Space Agency (ESA) built to NASA specifications, mounted on a radial port of the *Tranquility* Node 3.

FIGURE 12 shows a closeup exterior view of the ISS Cupola, with a Progress freighter spacecraft docked to the Russian segment in the background and a Soyuz spacecraft to the left.

FIGURE 13 shows an astronaut at the robotic control workstation inside the ISS cupola, with the blue Earth below.

FIGURE 8. Brunelleschi's Duomo of the cathedral in Florence, with the horizontal band of radial rondel windows and the cupola.

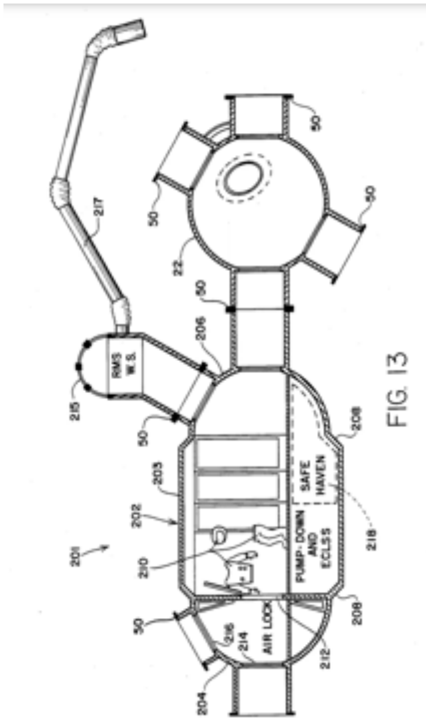

FIGURE 9. Longitudinal Section through a spherical node, space station module, and cupola (No. 215) attached to a berthing port. US Patent 4,728,060. 1988**.**

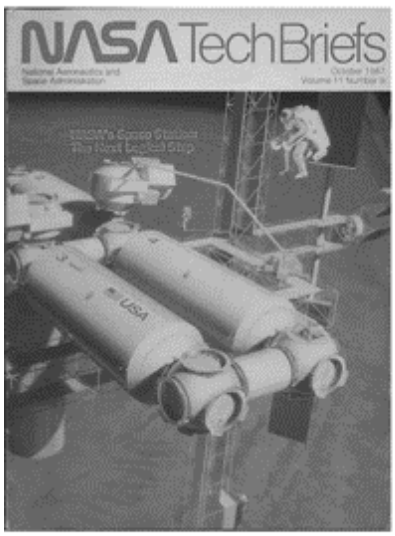

FIGURE 10. Space Station Freedom configuration with spherical nodes and the Cupola mounted to a berthing port on the spherical node on the right. October 1985**.**

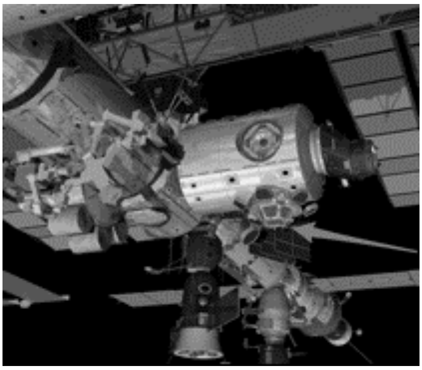

FIGURE 11. ISS Cupola mounted on a radial berthing port of Node 3, *Tranquility*. Artist Credit: Jessica Orwig/NASA.

FIGURE 12. Closeup exterior view of the Cupola, looking towards the Russian segment. NASA photo.

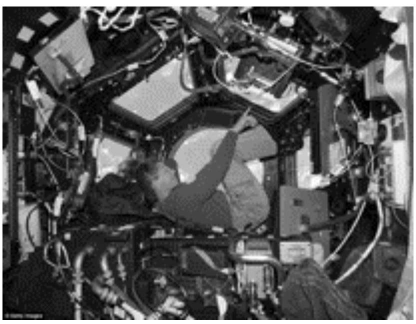

FIGURE 13. Interior view of the ISS Cupola, with astronaut Karen Nyberg. NASA photo**.**

5. Innovation and Tradition

Here we come full cycle back to the starting theme: *Innovation and Tradition*. At this point, it becomes felicitous to inquire further into innovation, or more precisely, into modes, styles, or types of innovation.

Many people balance their lives to some extent between tradition and modernity. But that is quite different from the dialectic between tradition and innovation.

Sometimes my path teeters across a landscape of unraveling tradition in the sense of extended family that my children don't know and may never care to know. I may be the last one to know that immigrant generation, who heard first-hand their stories of struggle and travail to leave the old country and come to the new. Modernity often means a universe of new opportunities. Some of these opportunities inherently involve innovation of various kinds with concomitant letting go of traditions. Most commonly, modernity and its innovations give the opportunity to improve the standard of living far above what the family in the old country could even begin to imagine.

5.1. The Consumerist Fallacy

One way the dialectic between *Innovation* and *Tradition* manifests itself is that many people believe that what they consume – what they buy – defines who they are. These patterns of consumption mediate between tradition and modernity for these citizens in some fundamental, meaningful way. In this narrative/scenario, the clothes you wear, the car you drive, the style of furniture you select, and the media to which you addict yourself all shape your identity, cultural inheritance, and social status.

In modern society, far too many people define themselves primarily by what they consume. This consumption stems from the myriad flood of promotions and imagery that deluge—what's the word? — *consumers*. Even though some of the "influencers" of consumption may acquire wealth in the $billions, the belief system, indeed ***the tradition***, they promulgate conveys the same fallacy.

In my jaundiced view, this overwhelming emphasis on conspicuous consumption is an indelible outgrowth of *the tradition of industrialized society.* But what is more important, this tradition of consumption as the existential expression of one's identity demonstrates entrapment on the axis of the knowledge of good and evil. The more one believes that if she could buy only the next model Jimmy Choo shoes or if he could buy the next upgrade to the iPhone XXX, that all will be well with the world.

On the contrary, this compulsive consumerism is part of what poses an existential threat to the survival of the human species and indeed to most life on our planet. Think of all the plastic waste pollution, much of which comes from packaging unnecessary consumer goods. The energy to produce all these superfluous products converts ultimately to heat and carbon dioxide that drives climate change. These traditions of consumption may add up to a slow-motion suicide for our species, *homo consumians.*

5.2. Glass box Methods versus Blackbox Methods

We move from the consumption side to the production side when we begin to talk about designing. This section offers a much-simplified excursion into design methodology. These methods under discussion are: Glass Box, Black Box, Persuasion, and Participatory Design.

Glass box methods are systems of rationality that seek to establish progressive gateways to check for errors and safety hazards before allowing a design or project to pass through to the next step. System Engineering is the preeminent glass box method. Robert Machol almost single-handedly founded System Engineering in the 1950s and developed his Handbook as what Kuhn calls a standard text (Kuhn, 1970). NASA adopted, accelerated, and developed System Engineering further as the major enabling discipline for the Apollo Program and subsequent programs (e.g., Shuttle, Space Station, Orion, Artemis, etc.). The methodology of System Engineering is to make every aspect of a project explicit, knowable, and measurable, checkable and checked, testable and tested, so the people engaging in it can ensure a successful outcome.

Black-box methods largely comprise the processes inside the individual brain, when the creative juices flow, mixing with intuition, informed guesses, leaps of faith, and risk-taking. There is a whole academic sub-discipline devoted to studying and trying to understand black-box methods. They publish in journals such as *Design Studies.* These studies can be very valuable for understanding how a particular designer or population of designers worked on a design problem and found a solution. While these investigations may be informative in the neuro-cognitive realm, they do not appear to offer much in the way of prescriptive tools for the designer. In sum, they tend not to be generalizable from one designer to another, much less the whole community of architects or Space Architects. The way I understand Black Box Methods is that they are largely unknowable. As for myself, I do not have a start button to begin working creatively.

What happens for me is that I encounter a traditional way of perceiving or conceptualizing something, but I read the data or the evidence differently. Arthur Conan Doyle describes exactly this phenomenon in "The Noble Bachelor"(Doyle, 1892, p. 127). After the bride disappears from the wedding breakfast, a clue is found. It is a piece of paper torn from a hotel bill with a note written on the back.

Inspector Lestrade hands it to Sherlock Holmes, who turns it over and reads the bill.

> "This is indeed important," said he. . . .
>
> Lestrade rose in his triumph and bent his head to look. "Why," he shrieked, "you're looking at the wrong side!"
>
> "On the contrary, this is the right side."
>
> "The right side? You're mad! Here is the note written in pencil over here."
>
> "And over here is what appears to be the fragment of a hotel bill, which interests me deeply."

Then, by tracing the prices of the items on the bill to the hotel whence it came, Holmes finds the runaway bride and her original husband, whom she believed had died years earlier.

That experience of seeing the facts on the opposite side from what everyone else sees is a recurring and critical facet of my innovative process. I can't help it. In part, it relates to Robert Machol's "What are they not considering?" What is more important is that people tend to develop assumptions and unsubstantiated expectations for many things. Then they find what they expect to see. At the risk of being often surprised or nonplussed, I try to avoid unsupported assumptions and instead endeavor to be open to new ideas, options, and possibilities.

5.3. Participatory Methods

Beyond Glass Box and Black Box methods arise the so-called "second-generation" methods, which are mainly participatory design methods. A "third-generation" perhaps is emerging in cyberspace with new collaborative tools. Despite the power of the internet and the slew of collaborative tools, agile and nimble scrums that accelerate the design process, a true generational change in design methods has yet to appear in a truly dispositive way.

As the name suggests, participatory design methods apply to bringing a diverse group of people together—often including stakeholders with conflicting interests—to work together on creating or finding a mutually tolerable design solution. Note that I do not say "mutually satisfactory."

At their foundation of participatory methods are rooted in the *Symmetry of Ignorance.* Each participant brings her or his expertise and local knowledge to the table. However, what each participant does not know about all the others' personal experience and insights renders everyone equally ignorant of those others' reality. Appreciating the *Symmetry of Ignorance* is a first step to equality in the participatory design process.

In participatory design projects, a winning solution may be simply one that does not anger any of the stakeholders who go through the process—or does not anger them *too much*. In the larger context of participatory design, the key step—perhaps more than in other processes—is to agree upon a design problem definition. Whereas a traditional engineering design problem definition may anchor in the bedrock of quantitative performance requirements, the design problem definition in a participatory design process depends upon a far more subjective set of determinants. A participatory design problem definition exists only insofar as there is cultural, economic, political, and social agreement among the stakeholders and, by extension, among the design professionals who may facilitate the design process for these clients.

Participatory design has become *de rigeur* among many community development, urban design, and urban planning initiatives. This transition from top-down planning à la Baron Haussmann in the 1850s and 60s in Paris or the urban renewal (aka removal) projects a century later in the United States represents an important innovation at a societal scale. However, that does not mean that every person whom the project will affect casts an equal "vote" or can exercise equal influence in the process.

5.4. Systems of Persuasion

Such flashes of insight as reading the "evidence on the opposite side" may enable starting an innovation, but it is far from enough. The designer, the architect, the Space Architect must formulate the concept, document it, and find ways to persuade other people to "buy-into" it.

Take the example of a recent trend (not rising to the level of a 'movement') of "Deconstruction." The Deconstructivist mantra is Jacques Derrida's insight that ***at basis, all systems of rationality are systems of persuasion***. And that is true, well, and good. However, Derrida failed to grasp that *Persuasion is extremely difficult,* especially with architects' clients. Persuading people to accept an innovation is often much harder than creating the innovation itself. Advancing a space project through all the gates and checkpoints against error requires excellent powers of persuasion. In the case of many aerospace innovations, an inventor or principal investigator can fight her entire life to put just one exploration mission, one space science experiment, one technology development across the goal line.

5.5. Technology Readiness Levels (TRLs)

The two notions I employed earlier, concept formulation and proof of concept, are NASAspeak for stages in the innovation development process. Each has a NASA code word for Technology Readiness Level (TRL). Concept formulation and proof of concept are TRL-2 and TRL-3, respectively. That's right, NASA and other US government agencies have developed a scale to quantify the progress of conceiving, developing, and testing new innovations. In this culture, this tradition, nothing can really exist or truly stand on its own unless there is some way to measure its progress.

5.6. Preventative Methods

However, thinking about innovation as just another rationalizable process that institutions can quantify tells us nothing about the innovation inspiration or process itself. Comprehending the underlying creativity and creative process demands an entirely different conversation. This conversation revolves around design methodology. All methodologies are to some degree preventative — to prevent error — and so are "prophylactic in their essence." It is in this vein we see the specific manifestation of System Engineering, insofar as it has evolved today.

5.7. Figures of Merit (FoM)

In current practice, System Engineering analyses stand on foundation stones known as Figures of Merit (FoM). A project may write its FoMs in two different but parallel ways. The colloquial way is to express the purpose. The technical and even legalistic way is to express the performance metric associated with the FoM. TABLE 1 shows the FoMs that the Northrop Grumman Team pursued for NASA's Constellation Program Altair Lander (2006-2010).

5.8. Disruption

Disruption is a popular theme in the world in Silicon Valley, where I live while writing this essay. There, disruption is considered a *good thing.* The idea is that by introducing a technology, it is possible and desirable to upset the status quo, drive economic, cultural, and social change, and even put the old-line companies out of business. And, of course, the successful entrepreneur is supposed to rake in $billions for her disruption.

What is missing from this conceit is that these new technologies are not just disrupters, they may also become powerful enablers of new forms and activities not hitherto possible or even imagined.

To take one example, the telephone. Alexander Graham Bell first demonstrated the telephone publicly in 1876 at the Centennial Exposition in Philadelphia. The reception it received was positive, favorable, and impressed, but the potential of it, of placing it in every office, then every home, and much later in every pocket, was far from anyone's consciousness.

TABLE 1. Figures of Merit for the Constellation Altair Lunar Lander

Colloquial FoM	Technical FoM	FoM Metric for Reliability
Safety	Probability of Loss of Crew (PLoC)	1/1000 = 0.999
Mission Success	Probability of Loss of Mission (PLoM)	1/500 = 0.995
Affordability	Cost per Mission	$ USD determined by model
Mass	Landed Payload Enabled	Kg of payload on lunar surface from the tyranny of the Rocket Equation
Crew Productivity	Crew Productivity (CP)	(Cohen, Houk, 2010)

What made the telephone economically and commercially viable was the development of the skyscraper. All of a sudden, there were hundreds, even thousands of people working for large business concerns, all within one building. Talking to other people meant traveling vertically in the building. Certainly, there were elevators, but they were slow and often temperamental. The Skyscraper office building constituted the first ready-made market for instantaneous telephonic communication.

Thomas Edison developed the electrical power generating plant, which he considered his most important invention because it enabled so many hundreds of other electrical devices.[1] The Edison-type power plant made it possible to operate electric lighting, electric motors, and telephones without the weak, unreliable batteries that powered the precursor telegraph systems.

Communication technologies probably demonstrate the most consistent disruptive effect and the most dramatic impact over the longest period of time of any "disruptive technology." Consider the societal changes and improvements that arose from each of these innovations in accuracy, audience size, fidelity, and speed:

- National postal system, including post roads and stamps (circa 1789 in the USA),
- Telegraph (1848),
- Telephone (1876),
- Radio (~1900)
- Television (1936)
- Internet (1968)
- Macintosh Computer (1984)
- Cellular phones (~1990)
- Smart phones (~2005)

The greatest scientific controversy about Thomas Edison's work concerned his claim to "divide electricity" by inventing the parallel circuit. His contemporaries simply could not believe that it was possible for the parallel circuit to operate as Edison claimed. Today, the parallel circuit is the cardiovascular system of nearly every artifact that uses electricity.

6. Discussion

To conclude, we look at the pros and cons, advantages and disadvantages of tradition and innovation. None of these assessments are dispositive or final. They fall more along the lines of "the preponderance of evidence." Here are some quick examples.

6.1. The Misuses and Uses of Tradition

It is too easy to be glib about Tradition in this context. The misuses can be anything any of us have wanted to get away from. The uses connect to all kinds of nostalgic and sentimental memories and the feelings associated with them.

Misuses

The quintessential misuses of tradition are:

- To oppose an innovation because of old habits without regard to performance improvements.
- "That will never work because we've always done it *this* way."
- Because of reasons unrelated to the

[1] You can see a complete Edison power plant intact at the Henry Ford Museum/Greenfield Village in Dearborn, Michigan.

innovation itself:

- The cardinals supposedly telling Galileo they would not look through his telescope at the moons of Jupiter because if what he claimed was true, they would be "committing blasphemy."
- Antisemitism, burning witches, racism, atavistic nationalism, and other abhorrent ideologies and practices.

Uses of Tradition

- Ethics and rule of law in regulating space transportation—commercial, governmental, or private.
- The historic architectural theorists speak directly to us now. (e.g. Vitruvius, Palladio, etc.)
- Understanding the cultural, economic, environmental, political, social context of a building site and setting.

Benefits of Tradition

- Maintain one's comfort zone.
- Afford certainty (whether deserved or not) about the nature of reality.
- Transmit cultural, ethical, and social values to the next generation.
- Sustain and operate within well-understood engineering analysis, design methods, means of production, and standards for reliability and safety.

6.2. The Misuses and Uses of Innovation

Our generation (i.e., mine), the "Baby Boom" generation, is the first to have its existence—or at least birth cohort—bounded by two major technological events: the atomic bomb at Hiroshima and Nagasaki and the Apollo landings on the Moon. These events constitute the nadir and the apex of human innovation and accomplishment.

Misuses of Innovation

- Twitter: Can one prove that anyone who posts to Twitter is not a total idiot?
- Nuclear weapons: We are still living with an existential threat for our species and ecosystem that is far more immediate than the threat of climate change.
- Climate Change caused by human action.

Uses of Innovation

- Almost everything we take for granted today—or at almost any moment in our too-busy lives.
- Medicine: the control of infection.
- Computerization: A smartphone has more computational power than existed in the entire world when I was born and probably than when I graduated from college.
- Instantaneous communications

6.3. The Costs and Risks of Innovating

Everything new comes at a cost. Even if something does not go horribly wrong (e.g., Bhopal, Challenger, Chernobyl, thalidomide), there are costs and risks.

- Risk of Failure and its cost both financially and to mental health.
- Risk of liability for unanticipated consequences.
- Risk of putting people out of work who cannot then find jobs with their existing skills.

6.4. Benefits of Innovation

- Make the world a better place, etc.
- Acquire wealth and power.
- Protect public health & safety – Definition of a Licensed Architect or Professional Engineer
- Reduce wasteful consumption
- Protect the environment
- Improve efficiency in many areas of process
- Enhance communication
- Resolve disputes without violence or war.

7. Conclusion

This essay presents one architect's understanding of how innovation and tradition interact in Space Architecture. From an ontological perspective, unless one knows and comprehends the design precedents and the traditions they embody, one cannot ***anticipate*** or ***comprehend*** what constitutes a ***true innovation*** or if such is needed. I say ontological instead of epistemological or phenomenological perspective because architecture, design, and engineering consist of so much more than *knowledge*, *per se*. Space Architecture goes to the study of being—and surviving—in space. It is the study, theory, and practice of design for space living and working environments. These environments can and will support crews, bases, settlements, towns, and cities in orbital microgravity and in partial gravity on the Moon, Mars, and beyond.

There is an unfortunate but perhaps natural tendency among people who contemplate the practice of Space Architecture to assume that because they are entering a "new" field that whatever they do must — as if by default — be "innovative." If one falls into this fallacy, one could not be further from knowing the ***necessary truth.*** Unless one knows thoroughly the precedents and ***tradition***, one cannot know what ***innovation*** is or what it needs to become.

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