White Paper Submitted To:

Technology Innovation Program

NATIONAL INSTITUTE OF STANDARDS AND MEASURES

A Critical National Need Idea

PERFORMANCE BUILDING

Transforming Construction from the Industrial to the Performance Era

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Key Words:

- Standards and Measures
- Function-based Modeling and Computing
- Cloud Innovation
- High Performance Building

PERFORMANCEBUILDINGINSTITUTE

Providing construction industry research and technology development
guided by systems-thinking, computational sciences and market realities

PERFORMANCE BUILDING — Transforming Construction from an Industrial to a Performance Era

By Mark S. Sands, PE ~ November 6, 2009

INTRODUCTION AND ABSTRACT

The construction industry has been in trouble for decades. Although it has been challenged to innovate and optimize, construction remains the industry with the poorest productivity record[1]. Yet over this past decade another challenge has been presented to the industry; to produce **high performance buildings**.

At issue are two converging needs; the **societal challenge** to conserve and the industry's need to improve its performance. The construction industry doesn't operate in a vacuum. Because of its massive size, the industry's poor performance creates repercussions on a national scale. Our **nation's well being**, as it relates to the **environment**, **energy independence** and **national security**, is at stake when construction performs poorly. Ironically, until construction's productivity improves, the societal challenge to conserve, i.e., produce high performance buildings, will require increased expenditures of natural and human resources.

Society's challenge to a poorly performing industry has revealed a **critical national need**. The construction industry must develop **transformational research** to address its poor performance. Left un-addressed, the industry may produce high performance buildings, but will do so by expending exorbitant amounts of human and natural resources in the process.

There are at least three reasons why the **federal government** plays a **critical role** in this issue: (1) transformantional change will occur when the large owners demand it, and the federal government is the nation's largest real estate owner; (2) it is integrally involved in the development and adminstration of **building codes and procurement policies.** It is these codes and policies that either hinder or assist productivity and innovation. (3) it is taking a leading role in attracting and funding transformational improvement through **research and technology development**.

Serious **government attention is justified** to address this **critical national need** for three reasons: The first relates to the magnitude and societal reach of a massive but stagnant construction industry; second is mounting societal challenges not being addressed within the industry, particularly relating to energy and environmental concerns; and third is that of the billions in government research and technology funding, the least amount is going to the industry with the greatest need — construction.

This is one of three white papers presenting the idea of shifting the construction industry from its current **industrial-style structures and practices** to a **performance paradigm**. The **transformative result**: the construction industry becoming a catalytic, rather than a debilitating, force in the **new energy-ecology economy**. This tranformation will be achievable as interested parties gather from all corners of society to address this dilemma. As has been the case in other industries, a key factor in construction overcoming its failings, is the application of **systems-thinking** and **computational sciences**.

GOAL: A lean and powerful construction industry producing innovative, cost-effective, high performance buildings.

Essentially, the performance paradigm shift is made up of **five transitions**, with the first being the practice of systemic **standards and measures**. Because of construction's complexity, the practice of standards and measures needs a new technology that is referred to as **function-based modeling** or computing — the second transition. Together, these will allow the management of building projects to focus away from services, documents and performance in accordance with documents. Instead, this third transition will enable the management focus to center on the **completed operating and functioning building**.

Innovation is effectively prohibited under the current industrial-era structures and practices. Transitions one, two and three are needed to reorganize the industry around building performance. Once that reorganization is effective then **integrated innovation** not only can happen, but will happen more or less naturally. Finally, as a renewed and reshaped construction industry begins to adopt innovative structures, processes, designs, products and systems then transition five is possible — **integrated optimization.** While the current industry is trying to optimize a fragmented and non-innovative industry, the new performance paradigm will enable an integrated and innovative industry to be optimized. It doesn't make sense to optimize the record player if the iPod is in the works and needs optimization. Everyone expects innovation and optimization from Apple and Google, digital era industries that never had to deal with an industrial paradigm, but everyone *needs* innovation and optimization from construction, a foundational industry as old as civilization.

A series of **research and technology projects** will proceed out of this paper. These are outlined in the conclusion and will serve to meet the societal challenges, and overcome the construction industries failures to-date.

PERFORMANCE BUILDING

This is about construction's problems and possibilities. The problems concern economical and ecological demands for high performance "green" buildings. The possibilities concern movements in *systems thinking* and *computational science* that might be able to deliver such buildings.

It's as if construction were currently suspended between two paradigms: the old "industrial paradigm" characterized by fragmentation, commodity-based standards, and "bottom-up" logic, and an emerging "performance paradigm" in which systems thinking and computational science empower a lean and powerful industry that produces *innovative, cost-effective, high performance "green" buildings*.

Shifting to the performance paradigm is increasingly necessary as the tension develops between market demands and industry capacity. There is, for example, the *2030 Challenge*, which asks the building community to adopt measures for carbon-neutrality by 2030 (no fossil fuel GHG emitting energy used to operate buildings).[2] The 2030 Challenge is one among many goals, challenges, demands, petitions, and manifestos from the environmental movement to encourage or force construction to be green. Meanwhile, building owners listen to environmental demands, wonder nervously how much carbon-neutral buildings will cost, and submit their own demands to construction, "for operating cost efficiencies and a return on their investment for any extra costs that environmentally friendly design adds to the project."[3] Even the most innovative and productive industries would struggle to satisfy such demands.

However, construction is neither very productive nor very innovative. The U.S. Commerce Department determined that construction labor productivity *declined by nearly 20%* between 1964 and 2003, while all other non-farm industries *improved by more than 200%*.[4] Lacking more recent studies, this has continued to be the standard by which construction productivity is reported. In this paper's argument, the decline in productivity is linked to industrial-style structures and practices that owners and industry leaders must replace with performance structures and practices. For nearly forty years construction has been trying to inspire and stimulate productivity improvement and innovation, but will continue to fail under the industrial-era paradigm.

A CASE FOR TRANSFORMATIVE CHANGE

Because no other American industry impacts the national economy, ecology and national security like construction does, no other industry needs reform like construction does. From a macro perspective construction is massive, four times larger than the auto industry. From a micro perspective, each construction customer has to bear most of the economic burden of the industry's poor productivity and performance, which affects their ability to compete in the global marketplace. Possibly the greatest concern, however, is construction's impact on the environment, energy dependence and national security — which is three-fold:

- The actual building process is among the largest consumers of energy and natural resources.
- The operating building product consumes more energy and natural resources than any other market segment.
- Construction is critically connected to the nation's energy production capacity and distribution infrastructure.

Once shifted into the performance paradigm, construction will be positioned to help revitalize the economy and ecology, both by *being* a highly productive and innovative industry, and by *producing* buildings that do the same. This is the first argument for transformation. The second argument concerns the owners.

Owners must understand how much they stand to gain from the performance movement, but also how much the movement depends on them. Most owners will (or should) resist buying a building, no matter how green it is, if it is built and operated to their economic and the ecology's disadvantage. *Therefore, construction needs to give owners two things: (1) green buildings where the operational benefits will exceed the development resources capital costs, and (2) empirical evidence that the operational benefits will exceed the development resources and capital costs.* At this point, in the industrial paradigm, it would be difficult to do either: for a host of reasons discussed below, high performance buildings are not a natural product of the current system, and, even if they were, it would be impossible to give an owner proof of performance because there are neither performance standards nor ways to measure building performance against a standard.

The third argument for transformation is this: the industry has the means of changing. The first step toward any solution is identifying the problem, and construction's problems are very clear. Most of them derive from industrial-era structures and practices of compartmentalization and fragmentation, which must be replaced with practices of integration and consolidation. The multi-dimensional fragmentation inhibiting construction looks something like this:

1. The *discipline dimension* — site, structural, architectural, mechanical, electrical, and functional (equipment/furnishings) are the major disciplines with sub-disciplines (trades) within each.
2. The *production tier dimension* — design, engineering, management, manufacturing, distribution and assembly. Also referred to as the process tier.
3. The *project life-cycle dimension* — the building development, production, and delivery process; and the building itself — its function, operation and maintenance (building life).
4. The *team life-cycle dimension* — where firms and people are re-shuffled on a project-by-project basis, never reaching the optimization that the learning/experience-curve provides.

Each dimension, which should be an integrated, collaborating whole, is fragmented into incompatible pieces working to cross-purposes, inhibiting optimization and innovation. Beginning with management and information sharing practices, the industry needs to transition from compartmentalized and linear logic into computational-systemic thinking. This general paradigm shift will bring about the five specific transitions that will launch the high performance building era.

THE PERFORMANCE PARADIGM SHIFT

The proposed **performance paradigm shift** finds its origin in two late 20th-century movements. The first, **systems thinking**, comes to construction from the work of W. Edwards Deming (statistician who helped transform Japan's industry post WWII). Deming taught that the economy and psychology behind thinking in terms of a system lead to higher quality and productivity in a given industry. Systems thinking is not just thinking in terms of a system, but in terms of a *systems goal* toward which all individuals, sub-systems, structures, methods, procurement, standards and measures, etc. are organized. If the system-wide goal is **performance**, then all system parts must be re-oriented around that goal. Deming wrote extensively on the psychology of standards and measures, showing that if you train people to measure "things," they will keep pushing their own standard higher to beat themselves.[5] The implications of systems thinking are huge for a dysfunctional construction system, where every discipline, production tier, procurement practice, etc. is fragmented and needs to be integrated in terms of a system goal.

The second movement, **computational science**, is a more recent movement in information technology, and is transforming the way information is organized and used. The National Science Foundation defines computational thinking as the "computational concepts, methods, models, algorithms, and tools" that promise "a profound impact on the Nation's ability to generate and apply new knowledge."[6] For construction, computational thinking provides the technology capable of processing the complex data structures that make up the construction system. Without computational thinking, performance-based systems thinking would be impossible, because the complexity of the construction system surpasses the capacity of any manual calculus.

While construction substantially missed the first systems-thinking movement, it has tried to incorporate computation into some industry areas. However, because computational science presupposes an integrated system — a "network" — in the first place, any effort to use computational science in a fragmented system like construction will fail to achieve its purposes. For this reason, construction must integrate before it can compute.

FIVE TRANSITIONS TOWARD TRANSFORMATION

The **performance paradigm** rests on a shift toward **computational-systemic thinking.** The five specific transitions listed above serve as concrete goals as construction makes the shift. Let's consider each one.

Transition One — Performance Standards and Measures: from commodity-based to performance-based standards in areas where productivity and performance improvement are sought.

Performance standards and measures, particularly for the *building as a whole system*, are essential to overcoming construction's productivity and innovation failures. Analysts from many corners are beginning to agree that standards and measures are instrumental to the transformative change needed. Standards and measures are linked to innovation, productivity, sustainability, efficiency and global competitiveness in studies by organizations such as the National Research Council (in a study for the National Institute of Science and Technology)[7], National Institute of Building Sciences[8], US Department of Energy[9], US Green Building Council[10], and the National Science and Technology Council[11]. These serve to validate the veracity to the need for systemic standards and measures.

If this true, the discussion moves to the next significant problem. How can standards of measures be determined at the whole building (and major building system) level? Most projects are unique and complex creations, and no one has been able to establish a system where whole buildings can be submitted to *systemic standards* — whether the measure is the gross building area, the capital expense, the energy consumption, operating expense, or the many other metrics throughout the building process.

At issue is the chasm between the clear need for systemic performance standards and measures, and a construction industry that cannot produce or submit to such standards and measures. The performance paradigm thesis includes the theory, practice and technology that bridge the chasm.

Construction's inabilities to innovate, and its declining productivity, are caused by the way the industry competitively bids the products and services. It does so by establishing commodities from the point-of-production, up through the suppliers, sub-sub trades, sub-trades, and often the builder and designer as well. Most likely, the federal government as the largest owner will lead the correction of this practice.

In short, the phenomenon flows like this: when value is based on a commodity, not function (performance), all energy goes towards producing a given commodity at the lowest cost, instead of producing a given function or performance at the lowest cost. Two problematic consequences: (1) over time, focus on cost reduction instead of quality leads to decreased quality, defects and rework, decreased productivity, and, ultimately, increased costs, and (2) working within a commodity-based specification means that innovative alternatives outside the specification are neither procured nor produced.

Rather, when production and procurement revolve around the building system and performance (instead of component commodities), all purchases, designs, contracts, etc. are chosen for how well they contribute to the overall performance of the building system. The benefits of this practice are twofold: (1) over time, focus on performance leads to increased quality, which leads to increased productivity, which leads to higher value and reduced costs, and (2) working within a performance-based specification means that innovative alternatives are encouraged because whatever system or combinations of systems best perform that function wins. In this way, performance-based value opens up procurement and production to all sorts of innovations that commodity-based procurement discourages. So, wherever improvement is needed, commodity-based standards should be replaced with performance-based standards.

Because performance measures and standards will apply to all building tiers, it will be possible to measure a project or building's performance at any level. In tier one, the *Capital Expense Effectiveness Index* (CEI) and *Building Performance Index* (BPI) measure project and building performance at the most general level. There will be dozens of measures in at least three other tiers that measure cost and value effectiveness, and environmental and energy effectiveness. Perhaps the most important aspect of performance measures and standards is the use of historical data from actual projects used to produce comparables (comps) to establish market value.

The establishment of performance measures and standards is perfectly possible with the right technology and the right organization to collect and manage the performance data. A computational modeling system will be able to organize all the layers of data, and then process the data into usable standards and measures, and then apply the standards to make project predictions, and finally validate the actual work against the standard. Such a technology is under development and is detailed in Transition Two. The organization needed: a Standards and Measures Authority is needed to standardize and manage data collection, archiving and processing of historical data (cost, effort, energy, waste, etc.) for both the project process and the completed building operation.

Transition Two — Function-based Computational Modeling System: incorporating function-based computing and data modeling for planning, performance standards, and management

Although Building Information Modeling (BIM) technology has revitalized the construction industry, in its current state, it can't affect a project until after the feasibility, planning and budgeting has been completed. That is, BIM is principally an "object-based" modeling technology. This means that virtual models must be first created (manually) as geometric objects or imported as pre-designed forms. In effect, BIM works as a virtual representation of a physical space or system. There is an emerging generation of BIM that includes, in addition to object-based modeling, function-based modeling. Function-based BIM will advance the industry in three major ways: (1) comprehensive top-down project planning, (2) empowering the practice of systemic standards and measures: and (3) enabling virtual project development.

Advancement 1: Comprehensive Top-down Project Planning

Function-based BIM provides comprehensive planning early and accurately on a real-time basis. This lets the building team model a variety of project scenarios well before the design begins. That is, the team can virtually "try out" and examine any variety of scenarios for buildings and/or major systems to assess the best options. The result of function-based modeling is better informed decisions much earlier in the process. For each scenario, it will produce a spatial program, scope of work and quality, first and operating cost budgets, and milestone schedule.

This technology provides functional (non-geometrical or non-form) information modeling of a building, or master plan, or even an institutional, enterprise or business plan. It is based on pre-built composites of fixed and variable properties and values for program, scope, cost, schedule, etc.

Advancement 2: Breakthrough Technology Advancing Standards & Measures

Systemic performance standards and measures, as described above, are vital to the construction industry overcoming lack of innovation and declining productivity. The function-based modeling science will be instrumental for establishing productivity, performance and value measurement at the whole building level and also for major building systems. In fact, there is no other way proposed to establish such standards. Using accurate historical data from *varying* actual completed projects, a functional modeling system will be able to simulate such standards of measure as if there were many prior *near-identical* actual/control projects available as comparables.

The importance of establishing standards and measures cannot be overstated, and neither can the importance of function-based modeling system, the engine that powers performance standards and measures

Advancement 3: Virtual Project Development

Many already know that integrated **Virtual Design and Construction (VDC)** is the process and that BIM is the supporting technology. In the performance paradigm this process and technology will be expanded into **Virtual Project Development (VPD)** and it's supporting **BIM Family**, respectively. The BIM family members include:

- **Function-Based Modeling (fBIM)** – A sophisticated virtual planning technology that enables the owner and building production team to simulate multiple whole building (and major system) scenarios in real time by modeling the program, scope, quality levels, capital budget, operations budget and schedule.
- **Geometric-Based Modeling (gBIM)** – The technology currently understood as BIM which grew out of the 3-D object oriented and data centric CADD systems used in design and documentation at the whole project level as well as the material assembly levels.
- **Operations-Based Modeling (oBIM)** – The modeling technologies that simulate and automate the aspects of a project that aid in the forecasting, measurement, adjustment and overall operation and management of the completed facility, starting with energy modeling and ending with building automation and facility management systems.
- **Procedure-Based Modeling (pBIM)** – Currently recognized as project information management systems providing the interoperability applications that put project information on a global database readily available through a web-based portal.

The BIM Family becomes the *integrated holistic planning, design, procurement, construction, and facility operation technology* that many have envisioned.

Transition Three — Operating Building Focus: from a focus on the completion of services to a focus on the long-term performance of the completed building.

At present, a variety of independent designers, contractors and manufacturers are responsible for various fragments of the project, but no one is responsible for the total operating building performance. For example, architects and engineers function as consultants whose service pertains to the design and engineering fragment of the total operating building. If the design turns out an operating building that is inefficient or costly, the consultants have no "product performance warrantee" that the owner can hold them to. Similarly, contractors, subcontractors and manufacturers have responsibilities to build and supply according to the consultants' documents, but their particular services and products pertain only to some aspect of the physical structure of the building, not to its eventual performance. In the end, consultants, contractors, manufacturers, etc. are all evaluated according to their completion of one fragment of the total operating building, so that no one is actually responsible for the total building performance. This all changes under the performance paradigm.

Under this transition, it becomes possible for a single building producer (or production team) to focus its efforts toward *total building performance* (functional, operational, and environmental). In order to achieve a clear and congruent focus toward the total building performance four key practices should be instituted:

- **Performance Standards and Measures —** Performance data (from actual projects) has not been collected, in part, because building performance is affected by too many variables (climate, solar orientation, thermal building properties, people load, equipment load, etc.) and has been too complex for manual calculus. Technology will enable performance standards for operating buildings to be measured against the pre-determined performance objectives.
- **TruEx-based (or Life Cycle) Management—** The *True Expenditure* (TruEx) is the value that represents the total expenditure of the building life cycle, and which all optimization and innovation efforts are ultimately aimed at improving. Currently, projects are planned and measured according to a *Capital Expense* (CapEx)**,** which is *fundamentally incompatible* with sustainability and building performance objectives.
- **Preplanning Performance Objectives —** The establishment of functional, operational and environmental performance objectives should precede all other design and planning actions: not only for the conceptual design. Also, performance objectives should precede the site selection or the arrangement of buildings and other site improvements. This will prevent the typical loss of performance potential that occurs when the buildings and site surfaces are located and situated before an analysis of the climate, solar orientation, traffic and people patterns, etc. takes place.
- **Clarity of Roles & Responsibilities —** This transition clarifies the organization of roles and responsibilities in two stages: (1) restructuring that results in one organization responsible for disciplines (HVAC, electrical, site, etc.) within the overall building system; and (2) when it is realized that the building producers are more

qualified and equipped to manage and operate the completed building, building producers will take up the responsibility for building performance.

Transition Four — Integrated Innovation: from fragmented to integrated structures and practices that promote innovation for *total building performance.*

The primary obstacle to innovation is, per usual, fragmentation. Over the years, this multi-dimensional fragmentation has made an an unusually diffuse and "shallow" construction community. Even the larger firms represent a small fraction of the market share, and have not been able to achieve the scale, mass or capacity to gather together manufacturers, researchers and other resources to undertake applied research and development. Even if they were able to gather such resources, the industry’s institutionalized commodity-based procurement practices would inhibit the opportunities to apply such innovation.

As the first three transitions are adopted, innovation will follow more or less naturally. In this way, performance standards contain a built-in incentive for integrated innovation. If the construction community doesn't integrate and consolidate, it simply won't have the capacity to develop the total-building-performance solutions that the economy and environment demand.

There are at least five innovation categories that are already ready for development:

1. **Cyber Discovery Initiatives (CDI)** — *CDI* is the NSF's term for "revolutionary science and engineering research outcomes made possible by innovations and advances in computational thinking.”[12] *Building Information Modeling* (BIM) is the construction’s CDI hero, although BIM's potential is largely untested. For software developers with advanced computational skills, construction offers a vast and yet unexplored horizon.
2. **Prototype and Composite Development** — every building is a super-composite of prototypical materials and products. Building differentiation happens at the *point-of-prototype*. For a McDonalds or Wal-Mart, the point-of-prototype happens at the whole building level (i.e., there is little differentiation). For a school or hospital, the point-of-prototype could happen at various levels. There is great need for the development of prototypes and composites in both program spaces and construction systems and assemblies.
3. **Product, System and Pre-fabrication Development** — Once government procurement moves from commodity to performance-based practices, the demand for new manufactured products and systems will expand dramatically, especially for products that integrate architectural, mechanical and electrical systems, or that satisfy sustainability needs. Manufacturers will be teamed with other manufacturers as well as researchers, engineers, architects, construction managers, field foreman, etc. to design and manufacture new systems. For custom and semi-custom systems and assemblies that need to be specially fabricated to fit a particular building configuration or composite, there will be increased opportunities to develop systems that improve field productivity and building performance.
4. **Project-based Development** — At the level of an active project, there will be greater opportunity for architects, engineers, builders and subcontractors to innovate. In an integrated atmosphere, good improvised solutions will reach the broader marketplace through defragged channels.
5. **Applied Research and Development** — Universities and vocational research institutions are obvious centers of innovation that will be better integrated into the construction industry in the performance paradigm.

In order to meet performance standards, manufacturers and building producers (this term, “building producer” refers to the first tier of design and construction contract providers) will have to pursue serious *capacity building. Capacity*, in this case, has two essential parts: (1) a research and development team profoundly proficient in computational science and systemic, interdisciplinary thinking. These are the cognitive skill sets and training that researchers possess, and which competitive building producers and manufacturers must have access to and (2) the integration of research to include *all disciplines and production tiers* not typically available to any one construction organization in the current industrial paradigm. In short, true capacity building is a complicated, time-consuming and expensive venture that is probably out of the question for the majority of building producers and even manufacturers.

Capacity either exists, or could be developed, among many building products and systems producers, mega or large-specialty building producers, software developers and university-based research centers. The problem is that these organizations still constitute a small segment of the construction community. The question remains: where and how does innovation from the industry-at-large develop?

Borrowing the transformational concept of cloud computing from the computing science, **Cloud Innovation** is a strategy proposed in the performance paradigm. The intent is for cloud computing centers (consolidated and networked innovation organizations) to bring premium research and development services to the building community. Instead of expecting every architecture, engineering or construction company to come up with a state-of-the-art research and development team, **Cloud Innovation Centers** could be established to provide R&D services for the vast majority of the construction community. These centers would deploy innovative experts within various disciplines and production levels to serve the industry at large. By consolidating the R&D and spreading the results across hundreds of practitioners, the cost becomes nominal to its users.

Transition Five — Integrated Optimization

“Optimize human enjoyment in the act of production and you optimize production” — W. E. Deming

The high performance building is a holistic system that needs to be planned, contracted and produced as such (and then innovated for and **optimized** as such). Only at that point — will construction be ready for optimization at three levels: the organizational structure, the processes, and the building as a product.

Organization Structure Optimization

Working under industrial era practices and procedures, the building organizational structure has become increasingly fragmented or “specialized”. That is, the traditional master builder became the architect and builder — then the builder became the manager and subcontractors, etc. These organizational fragmentations led to several attempts at collaboration between the various parties (e.g., construction management, and then variations on the design-build and integrated project delivery practices).

In the traditional structure, there is *no one* person or organization responsible for performance of the completed building. The optimized structure brings clarity of roles and responsibility together with effective planning, design, construction, and operation of the building system. When the clarity of structure and responsibility in each major discipline (architectural, mechanical, etc.) is extended to the project as a whole, an optimized project team emerges.

This optimized team looks different than the current norm in many ways. One key optimization is referred to as integrated team-life. This too, is derived from W. Edwards Deming's work on productivity and optimization in management. Deming's emphasis on systems thinking and leadership is opposed to current construction norms, including the fragmentation of discipline and the practice of repeatedly reshuffling the project team over multiple projects. For the sake of industry optimization, disciplines must be integrated, and the practice of shuffling project teams must be replaced with a practice of *"standing relationships,"* in which a team collaborates over multiple projects.

Consolidation of the supply chain is another dimension of organizational optimization where project by project commodity-based procurement is replaced with stable, direct, long-standing relationships between the building producers and key manufacturers. By consolidation and integration, a team can direct more energy to improving quality, performance, cost reduction (first and life cycle), and speed to delivery.

Process Optimization

Once organizational structures are optimized, process optimization may naturally follow. Three key processes that will succeed: *Lean Building, Production Quality, and Process Integration and Automation.*

1. **Lean Building** — a lean building or lean principles is synonymous with optimized building performance and principles of performance optimization. Both pursue the production of value for customers, with the understanding that such a pursuit leads to waste reduction at all stages of the design, construction and delivery processes. This is accomplished through the constant examination of the value of a given task with respect to the total system goal. As Lean Building advocate Koskela has written, lean is a “way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value."[13]
2. **Production Quality** — in the 1990's, *Total Quality Management* (*TQM*) migrated from the manufacturing to the construction industry with the purpose of improving quality, but was ultimately incompatible with construction's fragmented organizational structure. Construction reverted to inspection-based quality control, a system that inherently assumes poor quality, which leads to reduced quality, increased rework, delay, decreased productivity, and so on. By contrast, true TQM focuses on quality at the point-of-production, which lower costs by reducing rework and delay, ultimately increasing productivity. True TQM therefore requires (a) the active integration and collaboration of tradesmen, foremen, material men, manufacturers, manager and designer, and (b) the replacement of inspection-based oversight with a measurement apparatus at the point-of-production; i.e., the replacement of inspection-based quality control with true computational TQM that is empowered by performance statistical samplings, measurement and process improvement techniques.
3. **Process Integration and Automation** — many of today’s processes and technology tools are a direct reflection of the high rate of variation (defects, errors, etc.) that occurs during the prosecution of the work. The performance paradigm shift naturally inclines all structures and practices towards integration and automation (computation), processes, procedures and technology tools to become more streamlined. The actual processes become significantly reduced or even eliminated, and therefore look much different than those being used today.

Operating Building Optimization

When building producers are equipped with performance standards and measures, and when they accept responsibility for total building performance, then buildings enter the performance paradigm. Before, it was impossible to talk concretely about building performance, because the standards and measures weren't based on performance, but on cost. For these reasons, high performance buildings don't merely "improve" industrial era buildings, but so far surpass them that a different system of measurement is necessary. The difference between performance and industrial era buildings would be similar to the difference between a record player and an iPod: it's absurd to say that the iPod "improved" the performance of a record player. With an iPod, performance had to be measured differently, and same will happen for buildings. To this end, organizations and processes will integrate and consolidate, and, in their finally optimized state, will finally be able to produce the high performance buildings the performance paradigm requires.

CONCLUSION AND NEXT STEPS

Shifting paradigms is not very easy, but it is very important. Attempts at improving the industry continue to be applied within the industrial paradigm, which is why construction is still struggling to produce cost effective high performance buildings. Future attempts at improving the industry must begin with a weaning away from industrial-era structures of fragmentation and commodity-based standards, and the adoption of performance-based standards and measures. This will be accomplished by a re-trained mind oriented toward systems thinking and computational science.

A series of **Research and development** projects will proceed from the ideas in this paper. One series of projects are outlined in the related “Standards and Measures” paper, and another series in the “Function-based BIM” paper. In addition, the following research and development projects flow from the performance paradigm:

- **Total True (Life Cycle) Expense Management Science** — Empirical and statistical methods of prediction and measurement that enables Deming’s philosophies and systems-thinking to be applied to the total expenses of a completed operating building. This science will be foundational to reshaping the structures and practices to contract, design, procure, construct, and operate buildings.

- **Technology Supporting True Expense Management** — Development the technologies supporting Total True Expense Management Science.
- **Technology Supporting Cost Segregation/Accelerated Depreciation** — A subset of the True Expense Management that automates the process of cost segregation according to depreciation schedules for the variety of systems that depreciate at varying rates according to tax codes.
- **Transformative Change in Responsibility for Building Performance** — Following the Total True Expense Management Science, this project will provide the framework and contractual agreements for the Building Producer (or Production Team) to be responsible for the operating performance and efficiency of the completed building and infrastructure.
- **Construction Cloud Innovation Science and Technology** — This research project will take the principles of Cloud Computing used in the technology industries, and apply it construction innovation.
- **Integrated and Consolidated Sustainability Science and Technology** — This project will effectively constitute the first wave of actual innovation, research and development that a Cloud Innovation apparatus would engage in. Its focus will be on the systemic performance and efficiency of the building process and product with added emphasis on energy consumption, storage and even production. It will also accommodate and bring cost effectiveness for ecological or environmental protection and preservation purposes.
- **Prefabrication Methodologies and Standards** — This project will expand the methodologies and standards that will enable innovative prefabricated (proprietary) systems and assemblies to be assimilated into the market place. This will require public and private procurement policies to be revised to enable such innovation to be adopted throughout the market at large.
- **Systemic Transformation of Building Codes and Conformance** — Development of the framework and process for developing new building codes and the administration of building codes, inspections and approvals wherever the industrial paradigm is in conflict with the performance paradigm, and inspection-based quality is in conflict production-based quality (TQM).
- **Integrating Functional Equipment and Built Environments** — This integrates the functional (technology, medical, educational, industrial, etc.) equipment and processes into the building systems and processes.
- **Geometric-based BIM Prototype, Composite and Disciple Integration and Technology Advancement** — Development of the standards for integrated design, budgeting, procurement, construction and commissioning for multi-disciplinary prototypical and composite assemblies. It would also create catalogs of common building assemblies from structural to building enclosure to interior architectural to mechanical and electrical systems. It would also develop whole room composites with integrated architectural, mechanical and electrical objects. It would be built totally around open geospatial standards so that generic and product specific objects could be pollinated into the various prototype and composite assemblies.
- **TQM Philosophy and Applied Science in Construction** — Development of a framework and process for adopting measures-oriented Total Quality Management, and for migrating away from inspection-based quality assurance internally and also by testing agencies and governing authorities.
- **Performance replacing Commodity-based Procurement** — Development of a framework and process for public construction projects to be procured outside of the traditional design-bid-build approaches. This will enable performance standards to drive efficiency and cost effectiveness.

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1 ENR, July 29 Productivity Report Calls For Integrated, Efficient Approach, by Bruce Buckley. "…a 2004 analysis by Dr. Paul Teicholz of Stanford University…suggested that construction labor productivity declined by nearly 20% between 1964 and 2003, while other non-farm industries improved by more than 200%."

2 See www.architecture2030.org (The 2030 Challenge)

3 ENR, July 01, 2009, "The recession has caused many owners to take a closer look at green's benefits," by Gary J. Tulacz The article begins, "The American economy is in recession, and owners are under pressure to deliver projects as cheaply and quickly as possible. This has caused some tension in the design sector, with owners seeking sustainable design that brings more to the finished project than simple recognition as a green building. They are looking for operating cost efficiencies and a return on their investment for any extra costs that environmentally friendly design adds to the project."

4 See endnote 1

5 Peter Capezio and Debra Morehouse. Taking the Mystery out of TQM. Career Press, 1993. page 68

6 NSF Website, 29 July 2009, National Science Foundation <http://www.nsf.gov/crssprgm/cdi/>.)

7 Advancing Competitiveness and Efficiency in the U.S. Construction Industry, National Research Council. From the National Academies Press (www.nap.edu)
8 The assessment by NIBS was in context of the U.S. Congress' Section 914 of the Energy Policy Act of 2005, "to address not just more energy efficient or "green" buildings but rather *high performance* buildings that combine the objectives of reducing resource energy consumption while improving the environmental impact, functionality, human comfort and productivity of the building."
9 Building Cost and Performance Measurement Data, Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy's (EERE) Kim M. Fowler, Pacific Northwest National Laboratory, Page1. http://www.wbdg.org/resources/measperfsustbldgs.php
10 USGBC Tackles Building Performance Head On (Press Release – Washington DC August 25, 2009) www.usgbc.org
11 Federal Research and Development Agenda for Net Zero Energy, High Performance Green Buildings, National Science and Technology Council – Report of the subcommittee on Building Technologies Research and Development, October 2008, Page 7
12 See endnote 5
13 Koskela et al. Design and Construction: Building in Value. Woburn, MA: Butterworth-Heinemann, 2002 (pg. 211).