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Standards and Measures — Whole-building Metrics Driving Innovation and High Performance

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Abstract

Purpose — Construction's coming age of innovation and high performance will naturally flow from the effective development of whole-building standards and measures.

Findings —Construction analysts correctly identify **performance-based standards and measures** as the missing link to overcoming poor performance throughout the industry. But neither the analysts, nor the industry, have identified the measurement science, technology or structures needed to establish and apply standards, starting with the whole-building *as a system*.

Limitations — While the proposed approach and technologies will readily adapt to horizontal (roadway), heavy and process oriented construction projects, the science and modelling presented in this paper has been limited to vertical (commercial) building project types.

Implications — The building process lacks standards beyond the commodity measure; i.e., at the point-of-production or trade level. Commodity-based standards and procurement practices necessarily prohibit innovation, leading to high cost and low performance. So, commodity-based standards must be replaced with performance-based standards and practices, wherever performance improvements are needed. The Implication of changing this basis in procurement and contracting will be transformational. Decades of pent up productivity decline will give way to a process that equips, empowers and rewards lean principles from the early planning through the completion of building projects.

Value for Practitioners — Two key indices will result from whole-building standards; the CEI (cost effectiveness index) and BPI (building performance index). Like safety's the Experience Modification Rate (EMR), these and many other indices will impact the building process and completed building performance. As a result, practitioners will be able to produce much greater value for their customers.

Key Terms — Performance Standards and Measures, Function-based BIM, Systems thinking, High Performance, Prediction, Validation and Calibration, Market Average Baseline, Benchmarking, Industry Target, Project Target, Performance-based, Commodity-based[2].

Paper Type — Forum Paper

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[2] "Commodity-based" is a term that reflects traditional supply chain practices that reduce products or services to a commodity in the sense that at least three (typically) suppliers can submit identical or "as-equal" products or services.

Introduction

"Measure everything that is measurable and reduce the things that do not admit to direct measurement to indirect measurement" ~ Galileo

"Train people to measure things and they will keep pushing their own standards higher to beat themselves." ~ W. Edwards Deming

The combination of construction's poor productivity[3] and inability to advance systemic innovation burdens building owners and fails to address the mounting demand for cost-effective, high performance buildings.

Among economic, political, academic and industrial analysts there is a call for *Standards and Measures* practices far beyond those practiced in today's construction industry. To appreciate how much energy is going into this matter, consider just a few of the following excerpts from various analysts:

- In a study for the National Institute of Standards and Technology, performed by the National Research Council entitled "*Advancing Competitiveness and Efficiency in the U.S. Construction Industry*," the establishment and practice of "effective performance measurement to drive efficiency and support innovation" is cited as one of five principle actions recommended for industry advancement.[i] "Performance measures," continues the report, "are enablers of innovation and of corrective actions throughout a project's life cycle."
- In the 2008, *"Assessment to the US Congress and US Department of Energy on High Performance Buildings"* by National Institute of Building Sciences, five of the eight recommendations relates to the establishment of performance metrics and verification methods for high performance attributes.[4]
- The US Green Building Council announced on August 25, 2009: a n*ew initiative for comprehensive data collection and analysis methodology development will be shared with LEED (Leadership in Energy and Environmental Design) building owners and project teams to help close performance prediction gaps.* This initiative complements the new requirement for ongoing performance data from buildings as part of their certification under the latest version of LEED.[5]
- In a report to the National Science and Technology Council on high performance green buildings, the first goal is to: "Develop the enabling measurement science to achieve net-zero energy, sustainable, high-performance building technologies."[6]

[3] ENR, July 29 *Productivity Report Calls For Integrated, Efficient Approach*, by Bruce Buckley. "Productivity has been a hot-button issue in recent years, particularly following a 2004 analysis by Dr. Paul Teicholz of Stanford University. It suggested that construction labor productivity declined by nearly 20% between 1964 and 2003, while other non-farm industries improved by more than 200%."

[4] 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."

[5] *USGBC Tackles Building Performance Head On* (Press Release – Washington DC August 25, 2009) www.usgbc.org

[6] *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

- A Department of Energy report states, "A key barrier to widespread adoption of sustainable design is the lack of actual, measurable performance information for sustainably designed and operated buildings."[7]
- The Pankow Foundation and Design-Build Institute of America commissioned a study on innovation and project delivery. An important concluding principle was, "Extensive academic study, however, is lacking regarding metrics that can be used to measure innovation performance. Additional research is needed to determine how innovation can be measured and the appropriate metrics to use for measurement…"[8ii]

The dilemma is this: there is a clear need for whole-building (systemic) standards and measures in order for high performance buildings to be built — but the construction industry, under its current practices, has not been able to produce nor apply them.

To address this dilemma, we must at least begin by defining "high performance building." The Energy Independence and Security Act (EISA) of 2007 (Title IV, Energy Savings in Buildings and Industry, Section 401, Definitions), defines a "**high performance building**" as follows:

> A building that integrates and optimizes on a life-cycle basis all major high-performance building attributes, including energy conservation, environment, safety, security, durability, cost-benefit, productivity (occupant), functionality and operational considerations.

This definition has merit because it includes "cost-benefit"; an attribute that is too easily sacrificed too often, including LEED projects. That is, building owners need proof — empirical evidence — that "high performance" buildings can be produced at their "cost-benefit." The EISA definition is still lacking though because it fails to establish a reference (measures against a standard); that is, it assumes that there exists such a thing as a "standard performance building." This assumption is erroneous, and needs correction.

These matters must be addressed so that building owners may both advocate for, and become active partners in, a better building process and product. The thesis of this paper is that performance standards and measures, of the *building as a whole system*, are vital to a high-performance building. Assuming this is true, determining standards of measure at the whole building (and major building system) level is imperative. Most projects are unique and complex creations, and *there exists no established methodology* whereby whole buildings can be submitted to *systemic standards* — whether the metric is gross building area, capital expense, embodied energy, or any number of other measures.

The one exception to this is the measure of energy consumption by the US Dept of Energy – Energy Information Administration (EIA). Energy consumption has been collected, compiled and reported in the 2003 (updated in 2007) Commercial Building Energy Consumption Survey (CBECS). From this data the US Environmental Protection Agency (EPA) has created the Energy Star rating program. This is a move in the right direction but falls short in the pursuit of the high performance building in two ways. The first goes back

[7] *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

[8] *Energizing Innovation in Integrated Project Delivery - Research Project* – By John Gambatese Oregon State University – for The Pankow Foundation and the Design Build Institute of America, December 2007 Page 89

to the EISA definition. The Energy Star program does not yet account for whether or not a qualifying building has been produced at a **cost-benefit**. The second way relates to the need for a more sophisticated measurement system and modeling technology that considers a more comprehensive range of functional attributes of a building. For example, a Family Practice physician office without a diagnostic imaging function would require significantly less energy than an OBGYN medical practice with x-ray, ultrasound and mammography imaging functions. But the CBECS and Energy Star data and analysis don't make this distinction. As such, building functions with a principle building activity with inherently low energy consumption functions could earn an Energy Star with nominal effort and investment, while those with inherently high energy consumption functions will struggle to gain the rating even with a significant investment in energy conservation.

Resolving these two important factors the pursuit of high performance building, including the energy consumption aspects, requires two integrated practices that are not currently operating in today's construction industry. W. Edwards Deming's contributions to *systems-thinking*, combined with *computational science*, are critical to a revitalized construction industry — through the science and psychology of measurement. Essentially, construction must shift from its current *industrial-style* structures and practices, to a building *performance paradigm*. This shift is made up of five transitions. Because of construction's complexity, the application of standards and measures requires a new technology that is referred to as *function-based modeling* (fBIM) or computing — the first transition. The second is the application of systemic *standards and measures*. Together, these will allow the management of building projects to shift their focus away from performance "in accordance with documents," which is essentially a temporary system. Instead, in this third transition the focus is on the actual performance of the *completed and operating building, which is the sustainable system*.

The first three transitions are needed to reorganize the industry around building performance. Once that takes place then the fourth transition, innovation, will not only happen, but will happen more or less naturally. This is because performance-based standards are able to replace commodity-based specifying and procurement practices. When these commodity-based practices are circumvented, the supply of innovative solutions will result as described below. As a reshaped construction industry adopts innovative structures, processes, designs, products and systems; then transition five, optimization, is possible. This illustration shows the relationship between the five transitions.

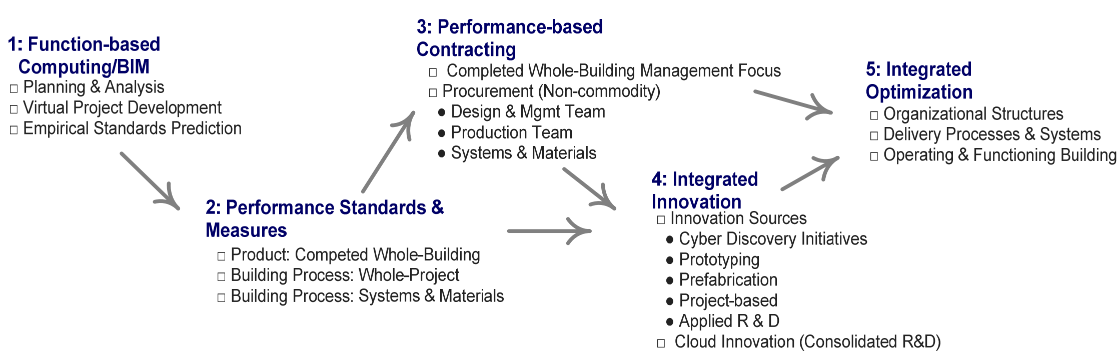

Figure 1: Schematic Flowchart of the Five Transitions to the Performance Paradigm Shift

Performance Standards Stimulate What Commodity Standards Inhibit - Innovation

Performance standards and measures are essential to solving the industry's dilemma. To implement this practice a deeper understanding of the problem is needed. This is necessary because the way that construction is currently specified and procured is in direct conflict with the proposed practice of performance standards and measures.

Statement of the Problem

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. As has been the case in less complex industries, construction must find a way to get out from underneath the commodity bidding practices.

In short, the phenomenon flows like this: when value is based on a commodity, not function (or performance), all energy goes toward producing a given commodity at the lowest cost, instead of producing a given function or performance at the lowest cost. So, if a document specifies a commodity, whatever supplier can provide the lowest-cost commodity within that specification will get the contract. Two problematic consequences: (1) over time, exclusive focus on cost reduction instead of quality leads to decreased quality. This leads to more defects and rework, which decreases productivity, and, ultimately, increases costs, and (2) working within a commodity-based specification means that innovative alternatives outside the specification are neither procured nor produced.

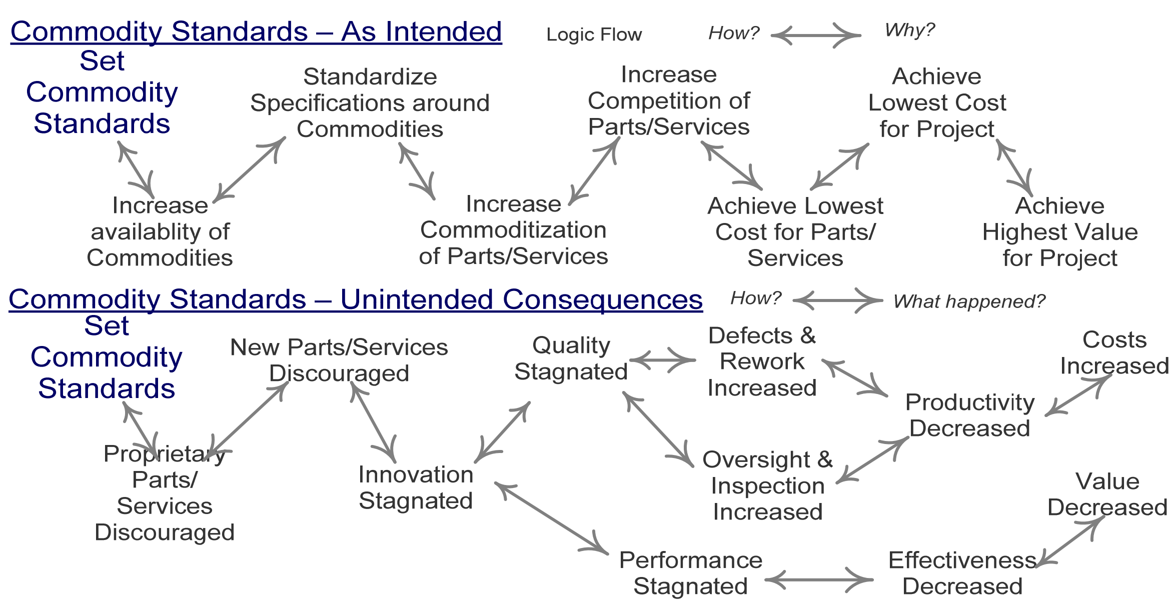

Figure 2: Logic Flow Chart of the Intention and Unintended Consequences of Commodity Standards

These two above charts show the logic of commodity-based value: the intentions and the consequences. The top chart shows Why (left to right) and *How (right to left)* commodity-based value was intended to produce value. The bottom chart shows *What Happened* (left to right) and *How* (right to left) typical commodity-based value created the opposite affect: reduced quality and performance that increases costs and decreases value.

Solution

When performance replaces commodity standards, the result will include empirical prediction and validation of performance metrics at the whole building level. The building team (design, production and supply chain) will have the needed standards to improve against. Also, a contracting system can be established so that compensation and business success is a function of the building performance. The building performance will include first cost and quality as well as operating efficiency and cost-effectiveness. This can begin with the first project, but produces its greatest results as building product manufacturers are able to work together with the production team to develop high performance integrated products and systems according to the *systemic* performance.

It works like this: when production and procurement revolve around total building 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 — that is, fewer defects reduce rework, which reduces production disruption, which reduces the duration — which reduces costs and increases value (as per Deming), 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.

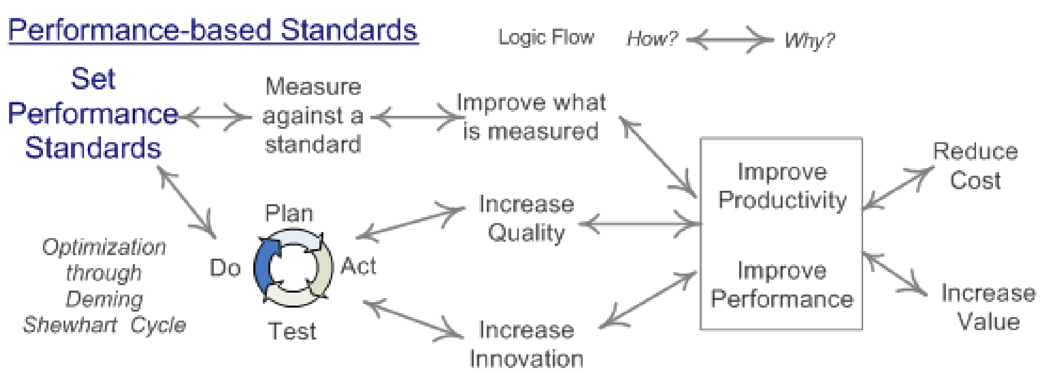

Figure 3: Logic Flow Chart showing the benefits of Performance-based Standards

The above chart shows *Why* (left to right) performance standards and measures lead to reduced costs, and *How* (right to left) reduced costs and increased value follow from performance standards and measures. The process for improving quality and innovation resembles Deming's cycle, although much of the "Act" and "Test" stages of the improvement cycle can be done — virtually — with today's modeling technology.

In this way, performance-based value opens up procurement and production to all sorts of innovations that commodity-based procurement discourages. Moreover, once a performance database is established, building teams will be able to access normalized market performance averages and know, for example, the standard heating/cooling performance of like buildings, which will become the performance standard for the team to beat.

Professional building teams will continue to seek the lowest cost solutions to fit the performance, but under the current industry dynamic, they only have traditional commodity-based materials and systems to work with, and their own compensation structures are established as a commodity as well, with little room to innovate beyond customary problem solving services. The current competitive bid process may be the short term and easy way to yield cost effectiveness, but it inhibits innovation and long term performance and productivity improvement.

Background: The Deming Standard

The logic behind performance standards and measures was developed by W. Edwards Deming who repeatedly taught both the importance of measurement and the importance of a system. The psychology behind measurement can be summed up: "train people to measure things and they will keep pushing their own standards higher to beat themselves." [iii] In Deming's argument, until people are trained to measure performance, they will not be able to push performance standards higher. The importance of systems thinking was developed in his theory of "profound knowledge." According to Deming, a system is a "network of interdependent components that work together to try to accomplish the aim of the system" (*ibid.*, 20). The aim of the system is its most important feature: "A system must have an aim. Without an aim, there is no system. Management's role," continues Deming, "requires knowledge of the interrelationships between all components within the system and of the people that work in it." For construction, this means understanding all component parts as a network of interdependent disciplines, sub-disciplines, production tiers, etc. working together to try to accomplish the aim of the system: total building performance. Aiming for total building performance is the most important feature of the construction system. Management's role, therefore, requires knowledge of the interrelationships between all the various disciplines, production tiers, planning stages, etc.

Performance Measures

Truly systemic standards and measures range from the most general (total building criteria: e.g., area and project capital costs, building operating costs, etc.) to the minutely particular (point-of-production: e.g., number of defects per unit of finished surface, or the average length of ¾" conduit installed per man-hour).

The two broadest indices proposed are, (1) the *Capital Expense Effectiveness Index (CEI),* which rates a project's quality and first cost effectiveness, and (2) the *Building Performance Index (BPI),* which rates a completed building's operating performance (including the capital expense). Also proposed is a series of second tier indices to guide the process of achieving high productivity and performance. Third and forth tiers indices will be applied at the material production and sub-discipline or trade (point-of-production) levels, respectively. These indices were chosen because they best correspond with the objectives of productivity and sustainability. Others will be created as needed.

Standards as Baselines (Norm and Objectives)

Creating and using these indices depends on *baseline* or *benchmark* control standards. Any given measured value has up to three standard baselines: first, the ***Market Average Baseline (MAB)*** — the current market norm, i.e., the average value in the current industry market in a given baseline year; second, the ***Industry Objective Baseline (IOB)*** — a standard set by a given organization (an owner user group, market sector group, or other authority). This baseline can be optional, particularly for projects not represented by some collective market sector resource. This should not be an arbitrary value or one that is used to establish a quota or ranking of employees; and third the ***Project Objective Baseline (POB) —*** a baseline objective set by the owner and/or the project team.

The starting point for a project will be the Market Average Baseline (MAB) which resembles the "appraised value" common in the real estate business. The appraised value for the whole real estate asset is based on comparables (COMPS) of like real estate. Residential real estate is a more straightforward process because, (1) the current and proposed uses are considered the same, and typically do not require a value consideration for adaptive re-use capital investment, and (2) there is typically a sufficient number of like homes from which to derive a one-to-one comparable. Commercial real estate appraisals are more complicated. However, in both residential and commercial, the purpose of the appraisal (MAB) is to determine value under the current market conditions.

Figure 4 below shows the relationship between the three baselines. The market average may begin as a simulated model, but will gain accuracy as more **COMPS (Actual Project Comparables)** are compiled and normalized to the prospective project.

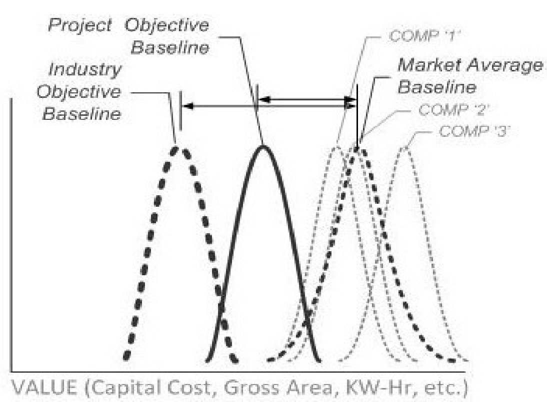

Figure 4: Illustration of the statistical relationships between the Market Average, the Industry Objective and Project Objective Baselines

What to Measure?

Again, there should be at least four tiers ranging from the total project level to the point-of-production, point-of-delivery, point-of-installation level, etc. The first tier of measures will encompass the total project, including such measures as Program Spaces, Capital Expense (CapEx), Total True Expense (TruEx), Man-hours (direct and indirect). For the completed operating building Energy Consumption, Waste (recyclable and non), Service and Maintenance Costs, etc. will be among the key measures. Each project type could have its own key performance metrics around which the current market averages are calculated, as well as the objectives.

Each of these values should be normalized according to the type of project/spaces, location, climate, time, quality, hours of facility operation, scope or massing, etc. Although the task of normalization will require some initial effort, this will be a fraction of the effort that normalization will save. The organization of this data will produce the market standards for performance, conservation and sustainability against which future projects will be measured, evaluated and improved.

Eventually, the function-based modeling process for a given project will have two preliminary stages: first, the various values of the Market Average Baseline (MAB) will be established based on modeling, and then the Performance Objective Baselines (IOB and/or POB) will be determined by the owner and/or delivery team's estimation. Again, as more actual project and facility data is collected, modeling will become increasingly accurate.

The Performance Index

The performance index — a single number that gauges performance against a standard — is particularly important because of the variability of project to project. Just like a school report card, or safety's EMR (Experience Modification Rate), the performance index will tell how the producer or the project (building) is performing against the standard.

The index numerator is the value associated with the prospective project or system within a project. The denominator is the normalized standard against which the prospective project is measured (either the market average (MAB) or the project objective (POB)). The various performance measures span the whole gamut of building: from total project costs, to instances of defects. The master index, the *Building Performance Index (BPI),* will be the number that tells all, as it is the basket that contains both cost effectiveness and performance of the project development. This master index, BPI, will measure the operating performance of the completed facility or infrastructure, and will include the Capital Expense Effectiveness Index (CEI). Some of the secondary indices should include:

1. Project Development: Capital Productivity Index, Labor Productivity Index, Space Use Effectiveness Index, and Energy Consumption Index, Indirect Labor Productivity Index, Direct Labor Productivity Index, and Project Material Waste Index
2. Manufactured and Prefabricated Products and Systems: Product Productivity Index, Material Waste Index
3. Completed Facility Operations: Energy Performance Index, and Facility Performance Index

These indices will report where the current project stands against the market average and performance objectives; this information allows the team to track their progress and understand what must be done to beat the objective.

Each discipline and production tier (design to production) will also establish its own performance standards, measures and indices. These will be woven into the various "index baskets" representing quality, safety, productivity, schedule/milestone adherence, change management, and other building process aspects.

Defining and Normalizing Data Measures

Performance definitions and norms do not appear in nature, and therefore must be constructed, which is an important task. When a *performance index* is being defined, there must be a commensurate ("apples-to-apples") relationship between subject project unit and the standard unit against which it is measured. In an obvious example: it would be pointless to compare a university building with an HVAC system tied to a central chilling plant on campus to the market average baseline building with an integral chilled water system, without normalizing the difference in the systems. In a less obvious example which demonstrates the importance of the task, consider the Capital Cost Effectiveness Index (CEI = Capital Cost/Baseline Cost Project Productivity Index). Although by normal definition the Capital Cost includes sitework costs, these should be segregated out in performance definitions because the variations that occur in sitework are extreme, and if included with a sampling of like building types, would obscure the accuracy of the building measures. Likewise, although Capital Cost does not include construction interest, that value should be aggregated in because it is directly affected by productivity, and consequently the duration of the building construction. Sitework segregation and construction interest aggregation are foreign to conventional budget and tracking standards, but they nevertheless provide a more accurate assessment of project performance.

Besides performance definition (which delimits a performance measure) *performance norms* must be established. Performance norms bring all data and measures onto a common scale so that they can be accurately compared. Data will be normalized to include: Space types and use, market location/index, time index, climate characteristics, scope and massing, quality level, etc. These are just a few of the variables that affect a project’s cost and energy consumption. Information technology systems to address these must be as comprehensive as possible in establishing pre-defined variations to be normalized, but also nimble enough to allow the building team to incorporate variations.

The importance of normalizing data is illustrated by the Department of Energy’s program to collect data from so-called high performance building submissions. There are currently 124 such projects that have been submitted. These projects are scattered around the nation, ranging in function and size (from about 3,000 sf to over a million sf). Most startling is the range of annual purchased energy, from -4.23 to +358 kBtu/ft^2. This one measure is of little value until these projects are processed through some system of data normalization. This highlights the need for a computational modeling system that will normalize and organize the projects according to the many variables the project is subject to. The resulting data then becomes very useful in establishing the standards to pursue improvement against.

The Proper Use of Measures

Like all performance tools, there's a bad (fragmented) way and a good (systemic) way to use standards and measures. The bad way is making the various trades and disciplines compete against each other for better performance indices. Internal competition, even with standards and measures, leads to the imbalanced success of some disciplines and failures of others at the expense of the overall building goal. The good way is by establishing an informed building performance objective and understanding how all the component indices will work together to achieve that system-wide goal.

Breakthrough Modeling Technology Advancing Performance Standards

Maybe construction is more complex than anything Deming ever had to deal with, but today's technology is more complex than his and, complexity being even, Deming's theory of "profound knowledge" is as valid for construction as it was for manufacturing. In Deming's theory, "knowledge" is a prediction that comes true. If the vagaries of construction confounded past producers, today's producers can submit those vagaries to a sophisticated modeling system good enough to produce accurate predictions. That is, today's building producers, with functional modeling technologies in hand, are capable of profoundly knowing construction -- *if the data is collected and available.*

Prediction and Validation Science

Most commercial and industrial building projects have dozens of attributes (function, scope and quality, physical and market-related constraints) that could easily skew a prediction if not accounted for. Therefore, it's necessary to have a modeling system with a broad range of data as well as accommodation to aberrations that lack historical comparables. The full scale of the functional modeling technology incorporates all these needs. This schematic summarizes how the technology works.

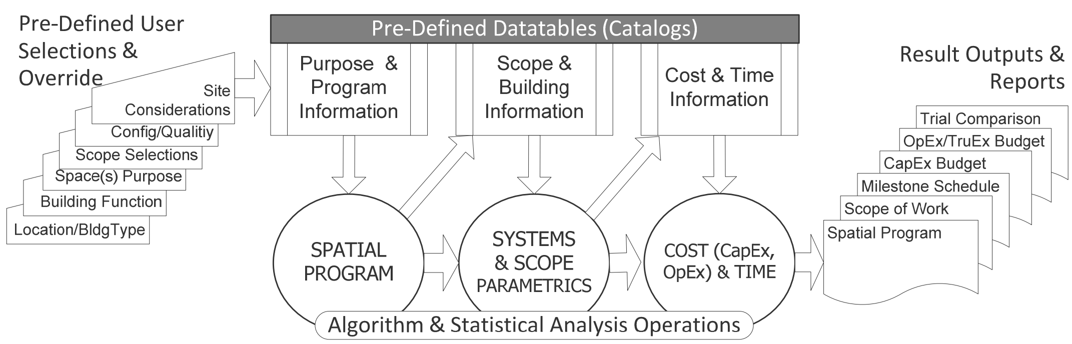

Figure 5: Schematic Flow Chart of the Function-based Modeling Technology

Clarification: *"bottom up"* vs. *"top down" modeling*. Top down modeling begins with a functional overview of the building (tiers 1 and 2) and then formulates data models for the physical systems. In other words, top down modeling converts project performance criteria (a building's function, program scope and quality definitions, as well as a project's physical and market constraints) into physical building characteristics: program spaces, systems scope, cost, schedule, etc. These conversions are based on pre-established relationships between criteria and physical characteristics (e.g., a building with function x will generate spaces ranging from y to z). Bottom up modeling pieces together the sub-systems that eventually give rise to system composites, and ultimately the whole-building system.

Standards and Prediction *for the whole building*

Currently commodity standards exist only in tiers 3 and 4, where the commodity averages of sub-systems are simple enough to determine manually and use for predictions. In a tier 4 example, an electrical contractor is trying to determine the number of work hours for a project that requires 20,000-lf of ¾" conduit. The contractor knows from his past 50 projects that the average productivity for installation of ¾" conduit is 40 ft/hr. Based on this performance standard, the contractor determines the number of hours for the proposed scope would be 500 hours (20,000/40 = 500).

Determining the *production performance* standard for conduit installation is fairly straightforward, but determining the *production performance* standard for the entire electrical system or an entire building requires many identical projects that, of course, do not exist. Clearly manually calculated performance standards for tiers 1 and 2 are impossible for the vast majority of projects: with the exception of identical prototypical buildings (like a McDonald's restaurant). However, getting performance standards for tiers 1 and 2 is essential for planning, designing and producing a high performance building.

Why? Again, per Deming: measure things and people will improve them. If you can measure whole building performance against a standard, building performance will improve. Top down planning *begins* planning with performance standards and measures for the whole building and for the compound systems (building enclosure, mechanical system, etc.). If project teams have access to standards and measures modeled for their particular project early in the planning process, they can identify standard problems for their project and pursue measures for improvement. For example, a project manager with access to averages for total indirect labor hours in like projects can anticipate ways to reduce those hours in an informed way and right away.

The dilemma: performance standards and measures are essential for the whole building and compound systems, yet for the vast majority of projects it's impossible to establish standards for measure, whether it is gross building area, capital expense, power consumption, labor hours, etc.

Function-based BIM resolves the dilemma by simulating the performance standards: taking real data and information from actual completed projects and then predicting the standards for the prospective project's data and information. The effect is an estimate (a prediction of the standard) of what the prospective project should be *as if there were, say, 20 prior near-identical actual completed projects* available as comparables. The theory and science is this: The real data and information for the 20 actual projects are used to *validate and calibrate the functional computational system that is modeling the prospective project*. If that modeling system is validated and adjusted based on the strength of actual projects, it will be valid and will adjust to establish the standard from the prospective project. This is particularly true if some portion of the actual 20 projects have similar functions (space and systems) as the prospective project, even though the scope, location, climate, are significantly different. This is how it works:

1. The functional model will include catalogs of composites of functional spaces, building systems, unit measures (costs, hours, energy consumption, etc.). Algorithms then relate the function, scope and constraint inputs to spaces and systems. It also includes adjustment factors (for location, climate, mass, soil conditions, etc.) This information is composed by specialists in the respective fields who establish both standards and statistical variations to the standards. The user inputs the functions, scope and constraints from which the functional model, using the catalogs and algorithms, calculates the parametrics: spatial program, scope and quality definition, cost, schedule, etc.

2. The first stage is to model the actual completed projects (the below illustrates five of the twenty) and then establish the calibration factor by taking the actual data (in this illustration, the Capital Expense), and dividing it by the like modeled data.

This matrix provides a snap shot of a variety of building designs and floor plan test fits based on a proposed the program. As part of the planning and design process we will be able to provide rapid scenario planning at various levels of analysis in order for the user to make the best informed decisions possible.

	Test Fit 1			Test Fit 2			Test Fit 3		
	Building	Connector	Total	Building	Connector	Total	Building	Connector	Total
	35,000	750	35,750	29,403	750	30,153	21,500	1,200	22,700

Standard Building

1a - 12'-8" to Deck			2a - 12'-8" to Deck			3a - 12'-8" to Deck		
Sitework	$4.26	$152,286	Sitework	$4.55	$137,058	Sitework	$5.03	$114,215
Building	$86.41	$3,089,170	Building	$91.18	$2,749,361	Building	$102.07	$2,316,878
RFP Reqm't	$20.99	$750,562	RFP Reqm't	$24.89	$750,562	RFP Reqm't	$33.06	$750,562
Contingency	$2.72	$97,244	Contingency	$2.87	$86,593	Contingency	$3.21	$72,933
Total	$114.38	$4,089,262	Total	$123.49	$3,723,574	Total	$143.37	$3,254,587

1b - Highbay 18'-8" to Deck			2b - Highbay 18'-8" to Deck			3b - Highbay 18'-8" to Deck		
Sitework	$4.26	$152,286	Sitework	$4.55	$137,058	Sitework	$5.03	$114,215
Building	$94.60	$3,381,897	Building	$99.82	$3,009,888	Building	$111.74	$2,536,423
RFP Reqm't	$20.99	$750,562	RFP Reqm't	$24.89	$750,562	RFP Reqm't	$33.06	$750,562
Contingency	$2.97	$106,025	Contingency	$3.13	$94,408	Contingency	$3.50	$79,519
Total	$122.82	$4,390,771	Total	$132.39	$3,991,916	Total	$153.34	$3,480,718

Feature Building

1c - 12'-8" to Deck			2c - 12'-8" to Deck			3c - 12'-8" to Deck		
Sitework	$4.47	$159,784	Sitework	$4.77	$143,805	Sitework	$5.28	$119,838
Building	$98.92	$3,536,266	Building	$104.38	$3,147,277	Building	$116.84	$2,652,199
RFP Reqm't	$20.99	$750,562	RFP Reqm't	$24.89	$750,562	RFP Reqm't	$33.06	$750,562
Contingency	$3.10	$110,881	Contingency	$3.27	$98,732	Contingency	$3.66	$83,161
Total	$127.48	$4,557,493	Total	$137.31	$4,140,376	Total	$158.84	$3,605,760

1d - Highbay 18'-8" to Deck			2d - Highbay 18'-8" to Deck			3d - Highbay 18'-8" to Deck		
Sitework	$4.47	$159,784	Sitework	$4.77	$143,805	Sitework	$5.28	$119,838
Building	$112.70	$4,028,903	Building	$118.92	$3,585,724	Building	$133.11	$3,021,678
RFP Reqm't	$20.99	$750,562	RFP Reqm't	$24.89	$750,562	RFP Reqm't	$33.06	$750,562
Contingency	$3.51	$125,661	Contingency	$3.71	$111,886	Contingency	$4.15	$94,245
Total	$141.68	$5,064,910	Total	$152.29	$4,591,977	Total	$175.61	$3,986,323

Barrel Vault Building

1e - Barrel Vault			2e - Barrel Vault			3e - Barrel Vault		
Sitework	$4.47	$159,784	Sitework	$4.77	$143,805	Sitework	$5.28	$119,838
Building	$133.70	$4,779,653	Building	$141.08	$4,253,892	Building	$157.92	$3,584,740
RFP Reqm't	$20.99	$750,562	RFP Reqm't	$24.89	$750,562	RFP Reqm't	$33.06	$750,562
Contingency	$4.14	$148,183	Contingency	$4.38	$131,931	Contingency	$4.90	$111,137
Total	$163.31	$5,838,182	Total	$175.11	$5,280,190	Total	$201.16	$4,566,277

Figure 6: Illustration of how Whole-building Metrics can be established

3. After the 20 actual completed projects are measured, the next step is the calculation of the average (and the variations) of ratios of actual/control to model results.
4. Finally, the proposed project is processed through the functional model in the same way that the actual completed projects were. It is essential that this project run through the identical model as the actual projects. The results from the model are then adjusted by the above ratio (actual completed project to the proposed project model data). This calculation then produces the standard measure — and also the variation to the standard.

Let's use an example of gross building area as the measure: taking the first of the actual completed projects, the functional model calculates the mean gross building area (GBA) to be 65,000-sf. The actual GBA turns out to be 62,400-sf. The ratio of actual to model for this first project is .96 (62,400/65,000 = .96). This calculation is performed on the other 19 actual projects, with the results: Mean = 1.03, one standard deviation = .02.

Again, this is the validation and calibration of the functional model by actual projects. If the deviation is small, like this shows, then confidence in the standards, the actual project data, and the modeling science is high. If the deviation is high, then further investigation is needed to determine the patterns and sources of variation. This will generate a great deal of discovery which will in turn lead to opportunities for improvement.

Next, the proposed project is processed through the functional model. It produces a mean GBA equal to 92,000 sf. Based on the 20 actual completed projects, the prediction of the standard GBA would be 94,760-sf (92,000 x 1.03 = 94,760) — the market average baseline. The resulting statistical expression of the GBA standard (based on one standard deviation): between 92,865-sf and 96,566-sf (94,760 +/- .02 x 94,760).

The principle here: *predictive knowledge of standards for whole-building projects can be accurately established using available market information.* Without a representative sampling from actual projects, a specific project has only the data supplied by the designer and whatever collective experience the project team brings (the current system). Without functional modeling, there is no other known way to, (1) convert actual whole-building project data into standards and measures, and (2) apply the standards to create market average baselines for future projects. With functional modeling, estimating and budgeting techniques such as Target Value Design (Costing) can begin even before the site is selected or the building is sited, massed and oriented.

Standards and Measures Authority

For standards and measures to be useful to anyone, they will have to be the same for everyone; that is, performance units and methods need to be the same across market sectors, disciplines, and production tiers. This will require an organization to the establish industry standards and measures of performance, productivity, efficiency, quality, etc. In this case, such an organization's functions should include: (1) defining standards and measures, (2) collecting, archiving and publishing data, (3) developing and using baselines and improvement objectives, and (4) promoting, equipping and implementing the improvement cycle.

When such an organization emerges, it needs to be endorsed and acknowledged as the industry authority by public and private stakeholders, analysts, owners and practitioners. Otherwise, a variety of organizations or factions within organizations will emerge, all promulgating *different* standards and data collection approaches.

Conclusion

The emerging energy economy is demanding innovative, cost-effective, high performance buildings. A low performing construction industry can't deliver these buildings. A lean and powerful construction industry is what is needed. Many analysts agree that performance standards and measures are vital to the development of such an industry, but until now there has not been a computing system that would enable this to happen.

Through research and technology development, this dilemma can now be resolved. Performance standards and measures + function-based modeling becomes a fantastically powerful information processing engine that brings a breakthrough measurement and statistical analysis to *all levels and dimensions of a project, from planning, to production to facility operation*.

Research and development that proceeds from the ideas in this paper include the following:

- **Performance Metric Science** — Projects that capture and assess data baselines (norms and objectives) from actual completed construction projects. This will enable the establishment of standards, measures, performance indices, normalization methods, and statistical analysis. There will up to four such research projects: the first relates to the metrics of the completed and operating building (as a product), and the other three relate to the building development process (tiers 1 through 4 described in this paper).
- **Technology Supporting Metric Science** — Projects that develop the computing science and technology for collecting, processing, normalizing, and publishing performance and productivity standards and measures.
- **Standards Consolidation and Integration** — A project that develops the theory and practice for organizing and administering performance standards and measures across a wide variety of market sectors, disciplines and processes throughout construction. The goal is that this would lead to an authoritative national organization.

Attribution

This paper is derived from a paper published on the website of The Performance Building Institute www.performancebuilding.org.

Abbreviations

BIM – Building Information Modeling

BPI – Building Performance Index

CapEx – Capital Expenses

CBECS - Commercial Building Energy Consumption Survey

CCI – City Cost Index

CEI – Capital Expense Effectiveness Index

EIA - Energy Information Administration

EISA - Energy Independence and Security Act

EMR – Experience Modification Rate

EPA - US Environmental Protection Agency

GBA – Gross Building Area

IOB - Industry Objective Baseline

LEED - Leadership in Energy and Environmental Design

MAB – Market Average Baseline

OpEx – Operating Expenses

POB - Project Objective Baseline

TruEx – True Expenses

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