WHOLE-BUILDING MEASUREMENT AND COMPUTING SCIENCE: BIM FOR LEAN PROGRAMMING AND PERFORMANCE

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ABSTRACT

The construction industry is poised to enter into an era of high performance and production by merging Lean Construction practices with comprehensive whole-building and systems measurement. W. Edwards Deming urged, "Train people to measure things and they will keep pushing their own standards to beat themselves." To even have standards there must be a basis by which they are measured against. Comprehensive measurement systems must be instituted in order for the Lean Construction vision to be fully realized. To achieve this, sophisticated computing science applications are called for. This paper presents a vision for whole-building measurement integration into the different phases of Lean Project Delivery. A program-based BIM (Building Information Modeling)[3] system is developed to provide such a measurement application. This program-based BIM provides for the early planning and programing stages, what the geometric-based BIM systems provide for design. More than that, it provides total life-cycle cost simulation.

With the adoption of standards from which to measure against, the construction industry will experience a re-training of the mind, as Deming proved in other industries. This re-training begins with top-down whole-building measurement in combination with bottom-up component and sub-system measurement. The computing science and modeling technology now exists and soon ready for market. The next need is data: both for baseline (business as usual) actual whole-building results, as well as benchmark (improvement) cause and effect claims.

KEYWORDS

Whole-Building Measurement, Performance Measurement, Lean Programming, Benchmarking, Performance Baselines, Program-based BIM

INTRODUCTION

Lean Construction combines new practices that are specific to the construction industry like the Last Planner® System, with proven practices that can be adapted from other industries (Koskela 2000, Ballard 2000, Abdelhamid et al. 2008). Many practices used in lean can be traced back to the work of Deming, a statistician who

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[3] From the Whole Building Design Guide (www.wbdg.org): A Building Information Model (Model) is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward.

brought meticulous measurement to every process that needed improvement (Liker 2004). Could it be that many of the lean applications that are used today came from innovations inspired by measurement?

Deming also answers the question of "what to measure toward?" in his widely quoted saying (Deming 1986) "A system must have an aim. Without an aim, there is no system. Management's role requires knowledge of the interrelationships between all components with the system and of the people that work in it." All of the component parts have to be working toward a complete system. In the case of real estate, that would be the successful operation and life of a building or infrastructure system. In the construction industry, there are a variety of disparate measurement systems at the component level, but very little, if any, that would accurately fulfill the aim of the system - the whole-building. Program-based BIM is presented to address resolve this.

PROBLEM

Measurement systems within the construction industry - particularly in the programming and planning stages of a project are: (1) seldom able to measure against a standard, (2) fail to integrate into an overall system or whole-building aim, and/or (3) have such a high relative standard of error (RSE) as to be useful. There is an exception in the safety sector with the Experience Modification Rate (EMR).

The reasons for the measurement problem are at least two fold. The first relates to the complexity and multi-variable nature of the building and building process. There are many different and dynamically interacting parts to effectively measure (Ackoff et al. 2010). The second relates to the fragmentation existing in the building process. For any given "custom" or "one-off" building, the assembly of people and organizations are new and unique to the project. The industry looks more like a one-night stand than it is a life time marriage commitment.

The implication for the lack of empirical standards on custom built projects is realized at two key measures: the baseline (business as usual) and the benchmark (exemplar, optimized or target improvement). There are just too many interacting variables affecting both the baseline and the benchmark for a manual calculus to resolve. And if there were such a computing option, there will be a lag in developing the independent and inter-relational survey data to draw from.

Another dimension is the three inter-relating categories from which both the baseline and benchmarks need to be established and measured against. They are (1) space program (plus scope and quality), (2) facility performance and, (3) building production. In most current practice cases the interactive measurement (cause and effect) between these is largely intuitive or single issue oriented. Traditionally, the facility operation management has been divorced from the building development program. This leads to sub-optimization of both, but especially for the facility operations (Ackoff et al. 2010). The reality has been that there hasn't been a way to measure cause and effect of all three of these in relationship to the other, especially at the whole-building level. And without effective measurement there can be no known way to determine, or therefore attain, optimization of the whole.

APPROACH

The underlying hypothesis is that a computing and modeling system that accurately predicts measured results of many completed buildings, can also predict the measurable results of proposed buildings. In this hypothesis, we see a key strategy in developing the computing and modeling system and its data sets. Actual "whole-building" results and data should be available to validate and calibrate the computing science and modeling system. The more actual projects that are used to calibrate the modeler, the higher the accuracy in predicting proposed projects.

We propose a Program-based BIM (Building Information Modeling) solution that is able to predict — within a range of confidence — the program, scope, and total cost of ownership (TCO or O_{TC}). For illustration purposes, we are using the Catalyst Modeler[4] system to demonstrate this proposed BIM solution. Program-based BIM considers many program variables in predicting the baseline results. Figure 1 shows the relationships between several of those variables. The computing science employed simulates the mean, low and high range values for both the baseline (business as usual) and the various benchmark (improvement) results.

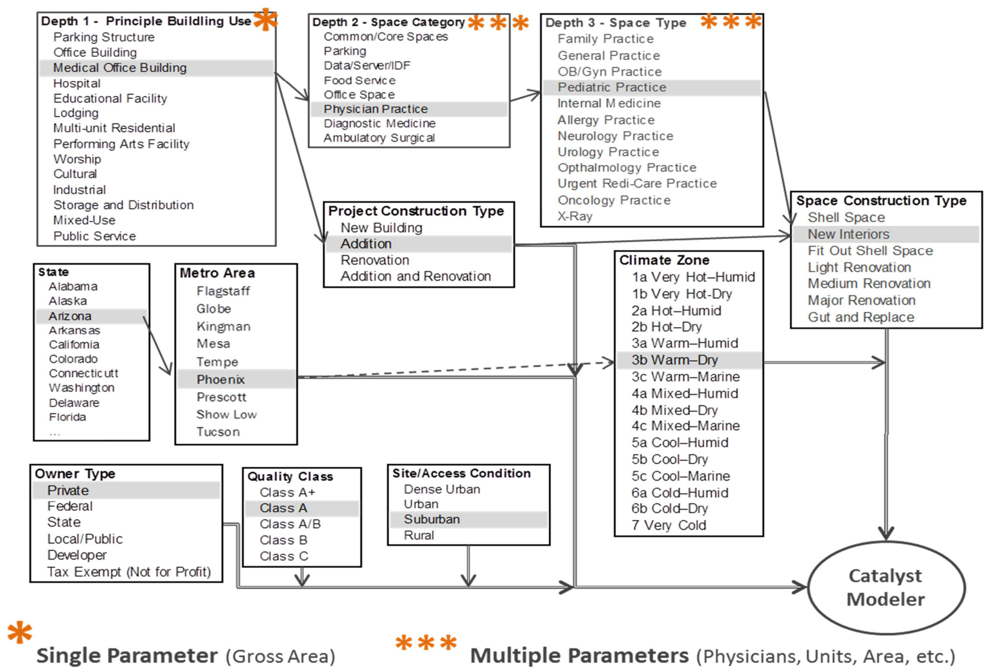


Figure 1: Examples of Program-based BIM User Program Selections

The O_{TC} is composed of the net present value sum of the capital development costs (CapEx), the lifecycle operating (OpEx) and recapitalization (RV_{eq}) equivalent values, and future value FV represented by this formula (simplified version):

$$O_{TC} = \int \sum \mathrm{CapEx}(\mathrm{Pr, Ds, Cn, Fe, Sf}) + \int \sum \mathrm{OpEx}(\mathrm{Ut, Sm, Op...}) \times \frac{(1+i)^n - 1}{i(1+i)^n} + \frac{\int \sum \mathrm{RV}_{eq}(\mathrm{Rf, EW, Mc, El, Fn, Ff...}) + \int \sum \mathrm{FV}(\mathrm{Pr, Bl...})}{(1+i)^n}$$

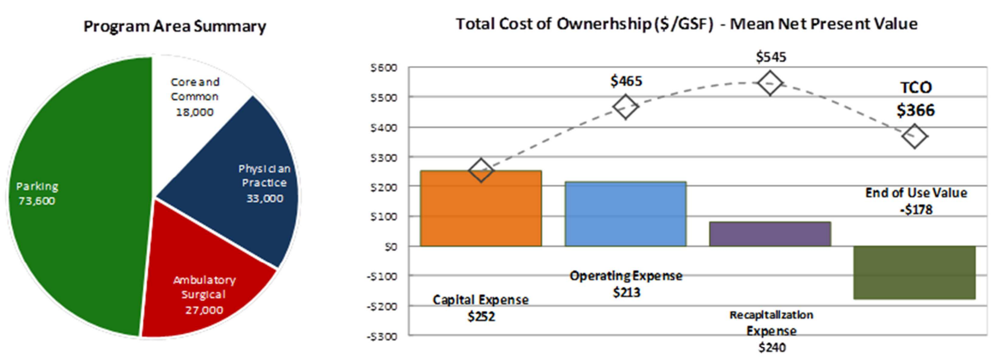
[4] Currently under development by Performance Building Systems, and will be available for Beta testing in the 4th quarter of 2012.

The O_{TC} Variables: CapEx = Capital Expense; Pr = Property (Land); Ds = Design; Cn = Construction; Fe = Furnishings, Equipment and Technology; Sf = Soft and Development Costs; OpEx = Annual Operating Expense; Ut = Utilities; Sm = Service and Maintenance; Op = Operating Expense; Cl = Cleaning; Mg = Management; Tx = Taxes; In = Insurance; VD = Voice Data; RV_{eq} = ReCapitalization Expense; Rf = Roof System; EW = Exterior Wall; Mc = Mechanical; El = Electrical; Fn = Finishes; Ff = Furnishings; FV = Future Value; Pr = Property; Bl = Building.

These variables, together with the parametric selections and several defaulted intermediate calculations of building systems and spaces, are processed through Program-based BIM to develop any number of scenarios that predict Capital Expense, Operating Expense, ReCapitalization and Future Value, which is the Total Cost of Ownership (O_{TC}). Note that there are a number of components that cannot be predicted, in which case the user is able to furnish those values. These include land value, environmental remediation, local utility assessments, off-site infrastructure, etc.

This BIM approach enables the user to perform early rapid-scenario planning of many optional solutions. If the owner is considering a number of existing or new building and/or site solutions, Catalyst will assess and compare each one in real time. This improves the owners ability to thoroughly assess many options that it would typically not even venture to consider because of the cost and time involved. This is taking Target Value Design (TVD), derived from Toyota's set-based design practice, and moving it up into the early planning and site selection stage.

The baseline (business as usual) is the starting point, and is derived from the measure of the standard existing building stock (at the time). Today's baseline would not be informed by Lean Construction, or other production improvement methods.



Summary Results	Low Range			Mean Total		High Range		
Gross Building Area	146,700	GBSF	-4%	152,000	GBSF	160,500	GBSF	6%
Life Cycle Cost	NPV	$/SF	Pct	NPV	$/SF	NPV	$/SF	Pct
Capital Expense (CapEx)	$36,740,000	$242	-4%	$38,297,000	$252	$40,650,000	$267	6%
Operating Expense (OpEx)	$30,200,000	$199	-7%	$32,380,000	$213	$36,270,000	$239	12%
Annual	*$1,404,338*	*$9*		*$1,505,710*	*$10*	*$1,686,600*	*$11*	
ReCapitalization Expense (RCapEx)	$10,110,000	$67	-17%	$12,140,000	$80	$14,240,000	$94	17%
End of Use Value	-$29,740,000	-$196	10%	-$27,125,000	-$178	-$23,640,000	-$156	-13%
Total Cost of Ownership	$52,440,000	$345	-6%	$55,700,000	$366	$60,870,000	$400	9%

Figure 2: Example of the Total Cost of Ownership (TCO) Output

For many architects and builders, whose responsibilities do not include total cost of ownership, this BIM approach is still very powerful for planning purposes. It enables the practitioner to drill down two more levels into the Capital Expense and Labor Hours (Direct and Indirect). Though not shown here, the line items get down to at least the ASTM Uniformat Level 2 - Foundations, Superstructure, Vertical Exterior Enclosure, etc. In order to do this, this program-based BIM computes the net functional space as well as core and common areas; key parametrics such as number of occupants, rooms, doors, elevators, stairs, plumbing fixtures; and surface areas of structure, roof, wall, glazing, etc.

Whole-Building Measurement needed to affect lean programming and performance will increasingly expand from the traditional focus of Capital Cost toward Total Cost of Ownership. This will bring a heightened real estate analysis of cause and effect between capital development and the asset valuation of the property. Figure 2 represents Catalyst's dashboard output for the Total Cost of Ownership.

SCENARIO COMPARISONS

This decision making power in program-based BIM is seen with the scenario comparison feature. The idea is that the user will game many different cause and effect combinations together with the non-Real Estate enterprise analysis. So, not only will the user be able to assess cost-benefit more effectively with regard to the real estate, program-based BIM helps provide a methodology for holistic enterprise planning and budgeting.

The OPR Tool[5] and Catalyst applications build in varying degrees of performance standards that help guide the owner and project team toward optimum energy consumption and facility operations. As demonstrated below Catalyst goes a step further, helping the team to optimize the space program, scope, and building production through the combination of whole-building measurement and Lean Construction.

To illustrate, a hypothetical medical office and ambulatory surgery center project is used. After the program scope is finalized this illustration assesses three different sites and building configurations:

- **Option 1:** 5 story center plus 2 levels of parking in an downtown location
- **Option 2**: 4 story suburban center with all surface parking
- **Option 3**: 2 story suburban center with all surface parking

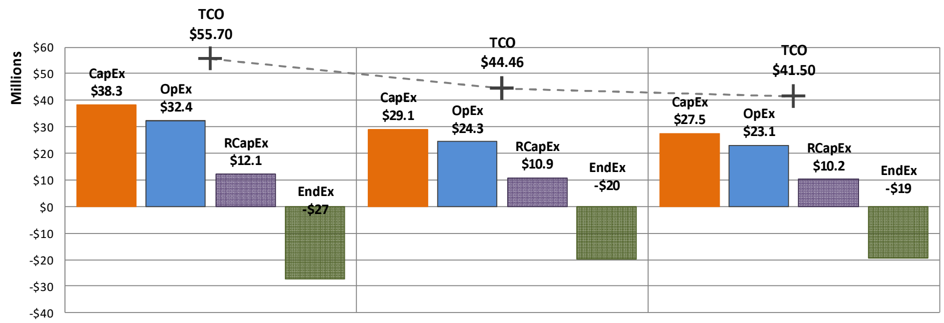
The downtown setting, with very small land area requires taller building plus underground parking. As Figure 3 shows, the same program in the urban setting will incur a capital expense (CapEx) over \$38 million vs. \$29 and \$27.5 million for the other two suburban solutions. The cost/SF is lower in the urban setting because the total structure becomes so much larger due to the structured parking surface.

Over the life of the facility, and in this case assuming a sale of the property and building, the total cost of ownership (TCO) for urban scenario is \$55.7 million vs. \$44.5 or \$41.5 for the suburban scenarios. Equipped with these comparative results the owner can build their total business comparison model based on census, revenues, medical operating costs, and other quantitative and qualitative factors.

[5] The OPR Tool has been developed from the Catalyst platform for the National Institute of Building Sciences (NIBS) and the Department of Homeland Security (DHS) for Performance-based Building Design. See (www.oprtool.org)

Scenario	MOB - 5 Story + UG Prking Urban	MOB - 4 Story SubuUrban	MOB - 2 Story Suburban

Total Cost of Ownership



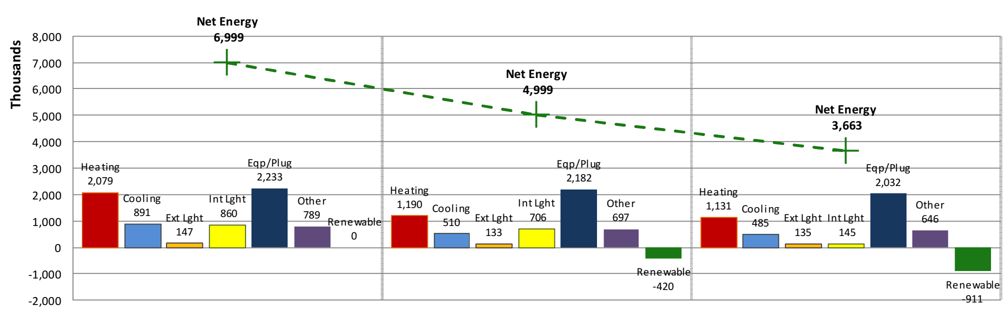
	Net Present Value and $/GBSF						
CapEx	Capital Expense	$38,297,000	$252 /SF	$29,088,000	$404 /SF	$27,549,000	$405 /SF
CapEx	Operating Expense	$32,380,000	$213 /SF	$24,310,000	$338 /SF	$23,090,000	$340 /SF
CapEx	ReCapital Expense	$12,140,000	$80 /SF	$10,860,000	$151 /SF	$10,160,000	$149 /SF
CapEx	End Value	-$27,125,000	-$178 /SF	-$19,805,000	-$275 /SF	-$19,301,000	-$284 /SF
	Total Cost of Ownerhip	**$55,700,000**	**$366** /SF	**$44,460,000**	**$618** /SF	**$41,500,000**	**$610** /SF

Figure 3: Total Cost of Ownership Comparison Dashboard

To carry the illustration further, after the site and building configuration has been established the next step will be to establish facility performance standards. Two key attributes to be considered are energy efficiency and building durability or service life. Taking the energy attribute, the key measure is energy consumption measured in KBtu. Figure 4 shows three standards, a baseline and two improvement benchmarks. The baseline (ASHRAE 90.1 1999 or equivalent) consumption shown here is 103 KBtu/SF. The added investment to raise the standard to 2010 or the Advanced Energy Design Guide (AEDG), will be $972,000 or $1,745,000 respectively. These will achieve dramatic energy savings of about 30% and 50% respectively. The owner will need to decide if the return on investment of around 7% is an acceptable cost-benefit.

Energy Consumption

Standard	Baseline	ASHRAE 90.1 2010	ASHRAE 90.1/2010 - 20% (AEDG)



	Energy Consumption and KBtu/GBSF									
Heat	Heating	2,079,000	31	Ktbu/SF	1,190,000	18	Ktbu/SF	1,131,000	17	Ktbu/SF
Cool	Cooling	891,000	13	Ktbu/SF	510,000	8	Ktbu/SF	485,000	7	Ktbu/SF
Ex Lght	Ext Lighting	147,000	2	Ktbu/SF	133,000	2	Ktbu/SF	135,000	2	Ktbu/SF
In Lght	Int Lighting	860,000	13	Ktbu/SF	706,000	10	Ktbu/SF	145,000	2	Ktbu/SF
Plug	Int Equipment (incl Plug)	2,233,000	33	Ktbu/SF	2,182,000	32	Ktbu/SF	2,032,000	30	Ktbu/SF
Other	Other Energy Consumption	789,000	12	Ktbu/SF	697,000	10	Ktbu/SF	646,000	9	Ktbu/SF
	Gross Energy Consumption	**6,999,000**	**103**	Ktbu/SF	**5,418,000**	**80**	Ktbu/SF	**4,574,000**	**67**	Ktbu/SF
Renew	Renewable Offsets	-	-	Ktbu/SF	(420,000)	(6)	Ktbu/SF	(911,000)	(13)	Ktbu/SF
	Net Energy Consumption	**6,999,000**	**103**	Ktbu/SF	**4,998,000**	**74**	Ktbu/SF	**3,663,000**	**54**	Ktbu/SF
	Energy Investment	$0			$972,000			$1,745,000		
	Return on Investment	0%			7.5%			7.0%		

Figure 4: Energy Consumption Comparison Dashboard

As the green building movement continues, the measurement of energy and green-house gases becomes increasingly important. Program-based BIM draws from many variables such as climate, occupancy, building configuration, etc. to simulated energy and CO_2 equivalent consumption, again starting with a baseline. It breaks down the loads from: Heating, Cooling, Exterior Lighting, Interior Lighting, Function Equipment (plug), and Other (building equipment). This is illustrated in figure 4.

Although program-based BIM is not a design tool, it will bridge the planning and design by evaluating the cost-benefit for categories of energy solutions, in this case. Figure 5 shows 15 categories from which energy improvement will be achieved. As you can see, four of them generate ROI's in excess of 10%, and another 6 of them may still be a worthwhile investment.

Energy Solutions Summary
Basis of Design: ASHRAE 90.1/2010 - 20% (AEDG)

Solution Category	Mean Results CapEx	ROI
Commissioning	$1.1	19.5%
Energy Conservation		
Thermal Resistance	$1.8	7.7%
Solar Shading/Resistance	$0.2	10.5%
Air Barrier	$0.2	8.4%
Daylighting	$2.0	13.9%
Natural Ventilation	$0.0	
BAS Controls	$2.3	7.7%
Lamps/Ballasts	$0.9	15.3%
HVAC Equipment	$1.9	8.0%
Functional Equip Efficiency	$3.9	2.8%
Energy Harvesting		
Solar PV	$4.6	3.8%
Wind Turbine	$2.8	3.8%
Fuel Cells	$0.4	4.9%
Geo-thermal	$1.7	8.4%
Energy Storage	$1.9	4.2%
Total Project	**$25.7**	**7.0%**

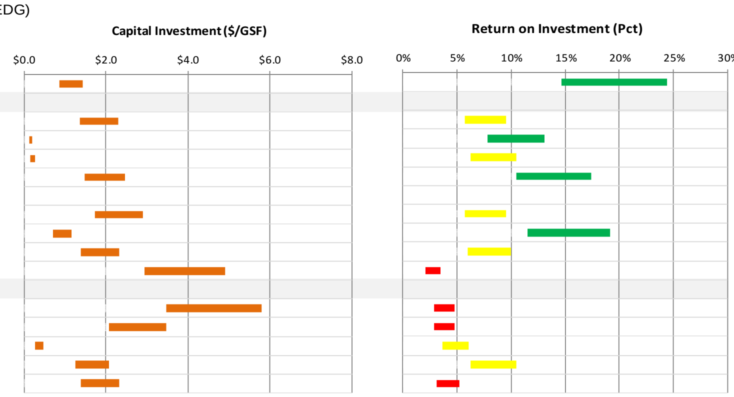


Figure 5: Energy Solutions Dashboard

BUILDING PRODUCTION

Lean practices have been integrated with whole-building measurement throughout the above facility planning, programming and performance optimization routines and comparisons. Many of these lean practices can be applied even under traditional design and delivery systems.

In order to achieve much higher degrees of optimization throughout the whole spectrum of real estate development, the whole-building measurement approach is combined with more highly integrated forms of delivery, lean practices, and prototype applications.

We are now able to see how significantly Lean Construction departs from the traditional construction practices. The matrix shown in Figure 6 lists 13 categories of advancements, each of which are simply not able to be applied to today's traditional one-off building program. Each of these advancements serves to drive out waste and improve quality — which, therefore, increases performance and production.

Figure 6 shows three combinations of Project Delivery, Lean Application and Prototype Application. There are dozens of combinations, each of which would fall into one of three Production Categories: Baseline, Improved Production or High Production. It is important to note that any High Production combination would include at least a "Kit-of-Parts" prototype application. This is where the product and systems manufacturers are integrated into the production process, through the development of off-site manufactured, prototypical assemblies and solutions. It is also important to note the principle of "mass customization" that is enabled, which effectively allows a "custom building design" that 90%+ among the design community would appreciated. This should especially be the case because cost effective, higher and more aesthetic design could be offered. Lean means saving money and/or getting more or higher quality building for each investment dollar.

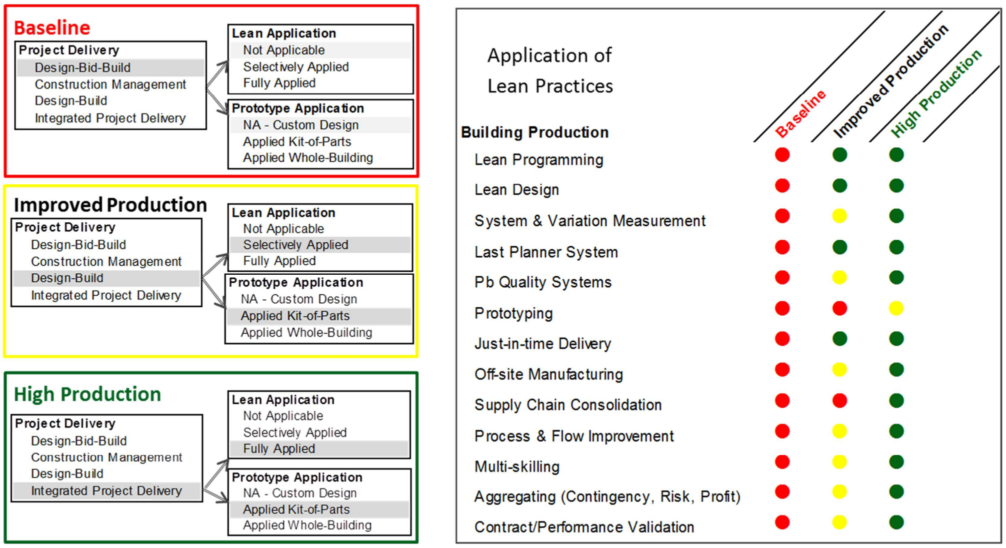
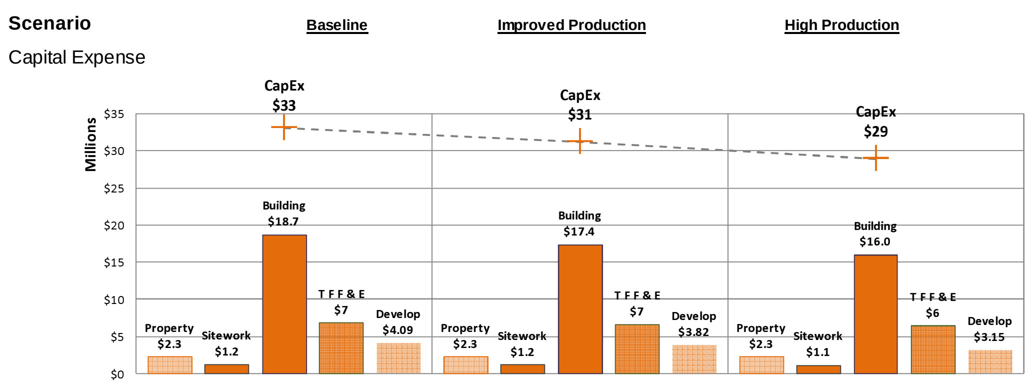


Figure 6: Application of Lean Practices based on Project Delivery with Application of Lean + Prototyping

Figures 4 (Energy Consumption) and 7 (Capital Expense) show whole-building measures by comparing performance and production improvement to a baseline (business as usual) condition.



	Capital Expense and $/GBSF	Baseline	$/SF	Improved Production	$/SF	High Production	$/SF
Prpty	Property Acquisition	$2,255,000	$32 /SF	$2,255,000	$32 /SF	$2,255,000	$32 /SF
Site	Site Development	$1,229,000	$17 /SF	$1,170,000	$16 /SF	$1,111,000	$16 /SF
Bldg	Building Development	$18,690,000	$263 /SF	$17,351,000	$244 /SF	$16,010,000	$225 /SF
T FF&E	Technology, F F & E	$6,821,000	$96 /SF	$6,587,000	$93 /SF	$6,396,000	$90 /SF
Develop	Development Work	$4,087,000	$58 /SF	$3,824,000	$54 /SF	$3,151,000	$44 /SF
	Total Capital Expense	**$33,082,000**	**$466** /SF	**$31,187,000**	**$439** /SF	**$28,923,000**	**$407** /SF

Figure 7: Production Optimization Example – Capital Expense Comparison

As shown in Figure 7: for essentially the same building program, the high production scenario generates over $4 million in savings. An important thing to note here is that with the program-based BIM approach, that it would be very difficult to artificially inflate the baseline in order to make the savings appear much higher. This is because the baseline is calibrated by actual historical project data.

COMPUTING APPROACH: Program-based BIM computing science, applied through Catalyst Modeler, is driven by bottom-up or component predictions by industry specialists, based on mean and variation value determinations. These values (both quantities and costs) are based on project information, apart from design solutions. The knowable variables (building use, space uses, scope, owner type, quality class, demands (climate, seismic, wind, soil conditions, etc.), height, etc.) are all factored, and interactions accounted for, in the data simulation model. The key to this modelling technology is the validation process. For baseline validation, top-down or whole-building comparison and calibration is performed on as many buildings as possible. For benchmark validation, other methods are used. Energy consumption, for example is validated by use of EnergyPlus (DOE technology). In all cases the more projects or energy models that are used for validation, the more accurate (and tighter) the range of variation.

CONCLUSION

As the industry re-trains itself toward whole-building measurement, then the measurement systems will work their way into the depths of the process. This will enable the measurement of variation, and what Deming refers to as defects. After a couple generations of building programs, other baseline standards will emerge for measuring: Changes, RFIs, Punchlist, Rework, Double-Handling, Takt and/or Cycle Time, Material Waste and other non-productive efforts on a project.

Another Deming principle is that measuring production does not improve production (Deming 1986). Rather, measuring variation (defects) is what is needed to improve production. This principle is underlying the genius of the Last Planner® System. The PPC drives the resolution of failed commitments.

In real estate there are many interrelating sub-systems that make up the entirety of the system — the Whole-Building. So, in being reminded that measurement is vital to that which needs improving, we see that the measurement must ultimately roll up to the whole-building — the optimization of the whole system. Again, Deming summarizes the critical need for objective, whole-building measurement, "A system must have an aim. Without an aim, there is no system. Management's role requires knowledge of the interrelationships between all components with the system and of the people that work in it."

The construction industry remains seriously flawed due to its fragmented state. Many attempts to de-fragment or integrate it have, and continue, to be pursued. Ultimately, however, the struggle will continue until a measurement system that integrates all the interacting sub-systems is provided and proven. Program-based BIM, as applied by The Catalyst Modeler, both purports to fulfill that need, and also calls for the data to validate and calibrate it.

There is no immediate way for construction industry product manufacturers to start producing integrated, multi-disciplinary assemblies and systems that can be assembled on site in days and weeks instead of months and years. There is a way, however, to get started in that direction by extracting waste from the current one-brick-at-a-time approach. That way begins with top-down whole-building measurement in combination with bottom-up component and sub-system measurement. Program-based BIM is proposed as a measurement system that achieves both. The computing science and modeling technology now exists and soon ready for market. The next need is data: both for baseline (business as usual) actual whole-building results, as well as benchmark (improvement) cause and effect claims.

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