Building information modeling (BIM): Measurement of design progress on large capital projects

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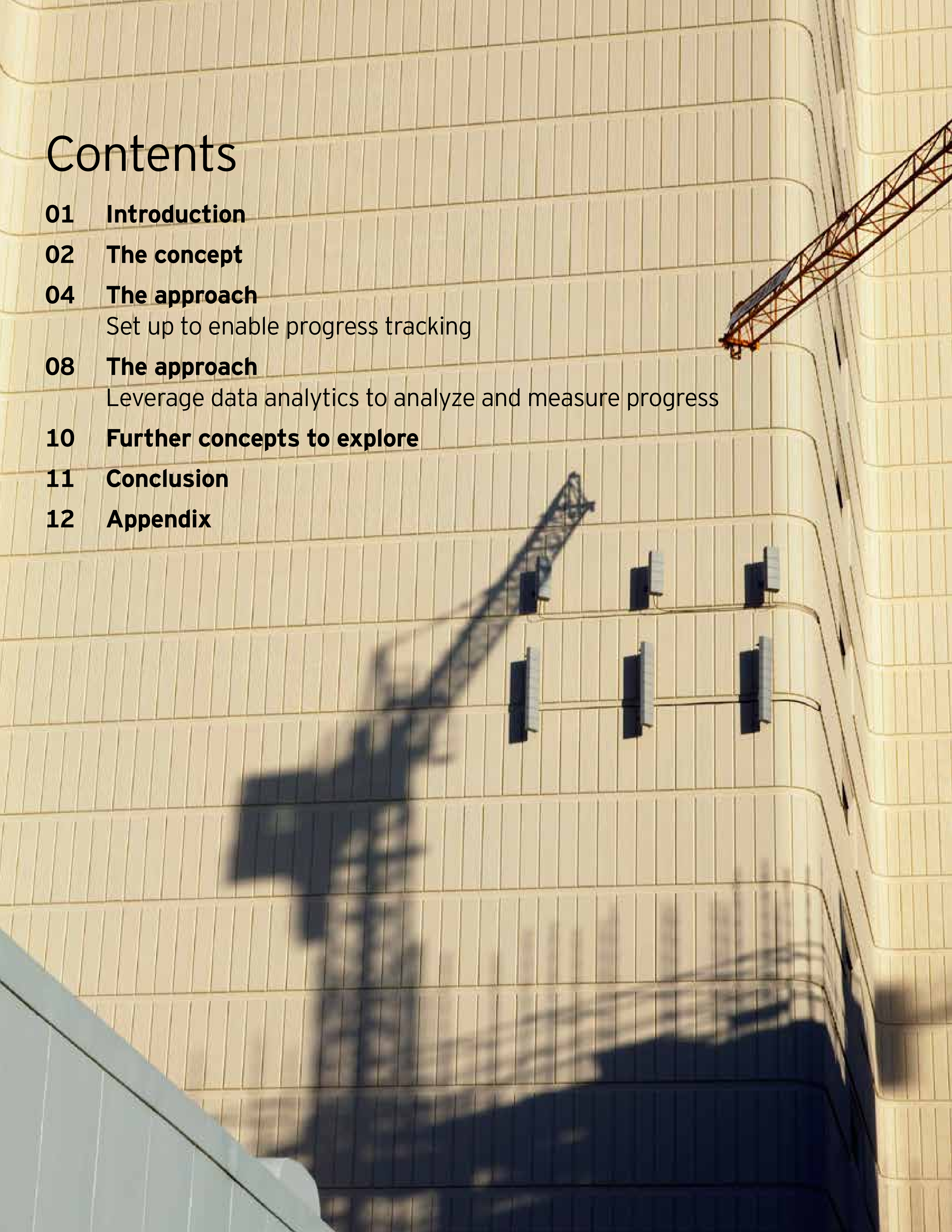


Contents

Introduction

This white paper was developed with the assumption that its readers have intermediate to advanced knowledge of BIM and hands-on experience in managing BIM during design and construction.

The adoption and use of BIM (building information modeling) or EIM (engineering integration management) has moved from bleeding edge to mainstream in the North American construction industry since the early 2000s. In the past 14 years, BIM efforts have made leaps and bounds in terms of software, hardware, talent buildup, processes, established industry practices and policies.

Yet BIM is still exhibiting varying states of maturity among its participants. Analogous to the concepts of lean startup found in *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses* by Eric Ries, BIM adoption has mostly stumbled upon the early-stage version of the minimum viable product (MVP) approach, where new concepts and practices are pioneered, continuously deployed and validated by the early adopters and then gradually rippled through the industry as evidence of success that is part scientific and part anecdotal.

BIM is still exhibiting varying states of maturity among its participants.

One of the key challenges faced by practitioners is the measurement of design progress in a BIM model. Unlike 2-D or hand-drawn information, BIM models require an alternative way to track design progress, as the model tends to evolve rather than progress in a linear fashion. In order to discuss how to improve the maturity and adoption of BIM among practitioners, we are proposing an analytical approach focused on the measurement of progress and productivity of BIM during the design phase, by leveraging hands-on experiences in BIM management on large capital projects as well as industry leading practices in business analytics. The approach is also complemented by a sample set of actionable metrics derived from a combination of authors' hands-on experiences, existing industry BIM standards and business intelligence measurements practiced by various business functions.

The concept

The challenge in brief

Accurate measurement of BIM design over the life cycle of a design model is an essential success enabler in the design and construction of large capital projects across industries. Without such capability, owners are exposed to risks in terms of schedule delays, budget overruns and quality deficiencies. Attempts by owners to better the situation have mostly been technical and human resources fixes rather than through business analytics and process re-engineering.

Figure 1: The solution in brief

Objective

- Increase transparency and improve maturity of design BIM monitoring and control
- Explore business performance metrics and data analytics for design BIM measurement
- Brainstorm additional concepts and areas of value-add

Inputs

- Contracts
- Design intent
- Specifications/ building codes
- Design and engineering calculations
- Architect and engineering Revit models and/or AutoCAD drawings
- Vendor materials catalog
- Design activities and milestones schedule
- Design schedule of values

Approach

- Establish level of development (LOD) definitions
- Create layering of model elements
- Schedule, categorize and link activities to model elements
- Track inputs of productivity
- Perform data analytics against established metrics

Intent

- Enable structuring of model elements based on LOD definitions
- Structure model elements for progress measurement
- Create linkage between schedule and model elements
- Track real-world productivity (aka labor)
- Link real-world productivity to virtual-world productivity
- Identify areas of improvement based on productivity data

Sample enablers

- AIA E202-2008, "Building Information Modeling Protocol Exhibit"
- AIA G202-2013, "Project Building Information Modeling Protocol Form"
- AIA E203-2013, "Building Information Modeling and Digital Data Exhibit"
- BIMForum, "2013 Level of Development Specification"
- CSI MasterFormat
- WBS structure
- Scheduling software
- Spreadsheet software

Data analytics

Sample outputs

- Hours spent per LOD percentage complete
- Hours spent per category per LOD percentage complete
- BIM efficiency ratios
- BIM weighted-average-efficiency ratio
- Design schedule of values used to confirm design progress and progress payments

Further concepts to explore

- RACI
- Organizational alignment
- Advanced technology platform
- Regression analysis and benchmarking

Source: *EY* Chart captures the essence of progress measurement during BIM design phase by leveraging business metrics and data analytics.

The approach

Set up to enable progress tracking

LOD definitions

As best explained by BIMForum in its *2013 Level of Development Specification,* "Level of Development (LOD) is a reference that enables practitioners in the architecture engineering and construction (AEC) industry to specify and articulate with a high level of clarity the content and reliability of BIM [elements] at various stages in the design and construction process." The proposed approach begins with the definition of LOD. Below is a list of fundamental LOD definitions abridged from the aforementioned document:

- **LOD 100:** model element may be graphically represented in the model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200.
- **LOD 200:** model element is graphically represented within the model as a generic system, object or assembly with approximate quantities, size, shape, location and orientation. Non-graphic information may also be attached to the model element.
- **LOD 300:** model element is graphically represented within the model as a specific system, object or assembly in terms of quantity, size, shape, location and orientation. Non-graphic information may also be attached to the model element.
- **LOD 350:** model element is graphically represented within the model as a specific system, object or assembly in terms of quantity, size, shape, orientation and interfaces with other building systems. Non-graphic information may also be attached to the model element.
- **LOD 400:** model element is graphically represented within the model as a specific system, object or assembly in terms of size, shape, location, quantity and orientation with detailing, fabrication, assembly and installation information. Non-graphic information may also be attached to the model element.
- **LOD 500:** model element is a field-verified representation in terms of size, shape, location, quantity and orientation. Non-graphic information may also be attached to the model elements.

Please refer to the "LOD definitions and graphics" section within the Appendix for graphical representation of LOD 100 through 350. The authors of this white paper suggest that a customized LOD definition be adopted for efficiency in BIM integration and coordination. As suggested in BIMForum's publication, the following are two key reasons for customizations:

1. The establishment of LOD 350 to enable sufficient coordination between disciplines
2. The exclusion of LOD 400 and 500, where such levels of detail have greater implication for prefabrication and field verification rather than design coordination

This customized LOD definition is to be accompanied with the use of the model progression table (MPT), as suggested in *New York City (NYC) School Construction Authority (SCA) Building Information Modeling Guidelines and Standards for Architects and Engineers*, where element LOD specifications, phases of design and ownership are clearly defined and communicated. Additionally, general notes following the CSI MasterFormat included in this publication contain specifics per discipline and element. See Figure 2 for a sample MPT.

Figure 2: Example of customary unit measure per element per

Architectural				
Model progression table				
Description of building elements to be modeled	**Level of detail**			
Category/building element	**LOD100**	**LOD200**	**LOD300**	**LOD350**
Sitework				
00000 – Site plans	●	– – – –	– – – –	– – – –
02200 – Earthwork	●	– – – –	– – – –	– – – –
02200A – Earthwork (flow-through turf AF)	●	– – – –	– – – –	– – – –
02200B – Earthwork (float drain turf on natural grass AF)	●	– – – –	– – – –	– – – –
02215 – Controlled low strength material	●	– – – –	– – – –	– – – –
02511 – Asphaltic concrete paving	●	– – – –	– – – –	– – – –
02515 – Unit pavers	●	– – – –	– – – –	– – – –
02516 – Exposed porous asphalt paving and aggregate base	●	– – – –	– – – –	– – – –
02531 – Resilient surfacing	Elements not shown in the model			
02532 – Resilient surfacing – porous base				
02533 – Colored athletic wearing surface				
02541 – Synthetic turf – TPE infill	●	– – – –	– – – –	– – – –
02580 – Track/court/playground markings	●	Elements not shown in the model		
02711 – Wall subdrainage systems	●	– – – –	– – – –	– – – –
02721 – Trench drains	●	– – – –	– – – –	– – – –
02722 – Precast concrete basins and manholes	●	– – – –	– – – –	– – – –
02723 – Storm drainage systems	●	– – – –	– – – –	– – – –
02724 – Underdrain system for porous asphalt paving	●	– – – –	– – – –	– – – –
02725 – Underdrain system for skinned areas	●	– – – –	– – – –	– – – –
02831 – Chain link fences and gates	●	– – – –	– – – –	– – – –
02860 – Early childhood playground equipment	●	– – – –	– – – –	– – – –
02862 – Outdoor game equipment	●	– – – –	– – – –	– – – –
02870 – Site and street furnishings	●	– – – –	– – – –	– – – –
02900 – Landscaping	●	– – – –	– – – –	– – – –
10350 – Flagpole (site)	●	– – – –	– – – –	– – – –
16420 – Transformer vaults	●	– – – –	– – – –	– – – –

Source: *New York City (NYC) School Construction Authority (SCA), Building Information Modeling Guidelines and Standards for Architects and Engineers, 28 April 2014*.

In addition to leveraging customized LOD definitions aggregated in an MPT shown in figure 2, we also suggest adding a customary unit measurement per element per LOD (see Figure 3 below). For instance, for structural steel columns from LOD 100 to LOD 350, the count of completed columns per LOD definition as a percentage of the total number of columns per LOD would be the measurement of percentage completion. In the case of concrete, volumetric automatic take-off within a modeling platform would provide the amount of concrete modeled. This modeled volume divided by total concrete volume take-off from an estimate can establish the baseline for measurement of percentage completion during LOD 100. As the design refines and the model matures from LOD 100 to LOD 350, total estimate and percentage completion may be modified, but mostly within reasonable tolerance levels that can also be established with a control parameter.

Grouping and layering of model elements

In addition to the traditional naming and definition of layers and objects used in a model for the purpose of design and coordination, elements should be separated with their respective LODs by layers. See Figure 4 for graphic illustration of grouping and layering of model elements. For instance, for a structural steel column, the initial LOD 100 development would be a simple rectangular mass that can be used in early phase design. As design progresses into LOD 200 and 300, extrusion of a specific steel section would take its place on separate LOD 200 and LOD 300 layers. As it enters LOD 350 toward the later phase of the design, base plate and anchor bolts would be present, perhaps with fireproofing. These LOD 350 elements would be kept on LOD 350 layers. The final structural steel column assembly design would be a combination of the extruded steel section from the LOD 300 layer and associated LOD 350 elements, such as the base plate and anchor bolts, from the LOD 350 layer.

Schedule, categorize and link activities to model elements

BIM design and coordination typically follow a modeling and coordination schedule that is often broken down by areas, buildings, floors, systems and subsystems. Each activity has its own unique duration and work breakdown structure (WBS) code. The authors of this white paper suggest adding the BIM categorical property to each activity, by indicating whether the activity would be for design/engineering, modeling, coordination, revision, re-coordination, etc. This information would be the perfect complement to MPT by attaching each model element at the various LODs with a specific WBS code, linking it to the activity in schedule and its associated schedule properties.

Figure 3: Example of customary unit measure per element per LOD

WBS	CSI code	Model element	Base count	Unit	Overall % complete	LOD 100 modeled	LOD 100 % complete	LOD 200 modeled	LOD 200 % complete	LOD 300 modeled	LOD 300 % complete	LOD 350 modeled	LOD 350 % complete
1.2.09	15200	Piping	550	ft	58%	550	100%	450	82%	350	64%	250	45%
1.2.11	5100	Structural metal framing	100	unit	43%	85	85%	75	75%	40	40%	15	15%

Source: *EY*

The result of this linkage creates a living data set of elements by LODs, ownerships and schedule properties. The data can then be pivoted by any one or multiple properties in preparation for progress monitoring and analysis. This assumes that both the MPT and the schedule would be updated throughout the design so that the latest status information is linked for meaningful progress measurement.

Track inputs of productivity

Corresponding to the tracking of the outputs of design modeling through definition of LOD linked by WBS codes to their respective schedule properties, the inputs of productivity should also be tracked in a similar fashion. Participating architects, engineers and consultants of BIM should log and track hours spent and roles involved on time sheets linked to the same activity categories via established WBS codes and as suggested earlier.

The beauty of this effort is that most, if not all, architects, engineers and consultants would be already practicing time tracking to a varying degree. The emphasis in this case is on the consistent definition of categories, roles and linking of WBS codes.

Some potential downsides to relying on input hours as part of the measurement of productivity could include inaccurate tracking and/or categorization of hours, incorrect linking of WBS codes, and artificial inflation/deflation of hours. Such downsides can be mitigated via various management practices and technology platforms that are outside the scope of this paper.

Figure 4: Graphic showing the layering and grouping of model elements to enable progress tracking

Model file

Model elements captured in the LOD 300 layer

WBS 1.2.11.3
CSI code – 05100
Model element: Structural metal framing

Element		**LOD 100**	**LOD 200**	**LOD 300**	**LOD 350**	
1	Structural steel	Wide flange column, framing members	Base plate	Stiffner plates, splice plate, foundation design	Connection detail, anchor bolts	Model group – structural steel
2	Secondary steel		Struts	Kicker	Bolts, special kicker configurations	Model group – secondary steel

WBS 2.2.1.7
CSI code – 50114
Model element: HVAC – air systems

Element		**LOD 100**	**LOD 200**	**LOD 300**	**LOD 350**	
1	Air handler	Main (trunk) piping, air handler	Secondary piping, air vents	Miscellaneous piping, shutoff valves	Thermometers, strainer valves	Model group – air handler
2	Duct work	Main (trunk) ductwork	Secondary ductwork, tees	Miscellaneous ductwork, damper/grill, straps, kickers	Insulation	Model group – duct work

LOD 100	LOD 200	LOD 300	LOD 350
LOD 100 master file x-reference L100 layer	LOD 100 master file x-reference L100 layer	LOD 100 master file x-reference L100 layer	LOD 100 master file x-reference L100 layer

Source: *EY*

The approach

Leverage data analytics to analyze and measure progress

Data preparation and aggregation

To enable progress tracking, the combination of input hours tracked in time sheets and the model output tracked by LODs in layers and connected via WBS to the schedule properties creates a living data set, where pivots can be created to dissect this data against one or multiple properties.

To enhance the robustness of this set of data, and to introduce a predictive component to the review, Monte Carlo analysis can be used to simulate the duration range of key activities along the critical path. Doing so enables a more accurate projection of critical path activities, enhancing the precision of individual activity tracking, while providing a range estimate rather than a point estimate of the expected schedule completion.

Data analytics

Similar to spend analysis that a business would perform to gain visibility and measure efficiency of its monetary spending, the input hours spent during BIM design and coordination are essential resources spent for the project that would benefit from insightful analytics. There is a wide range of sophisticated data analytics that are performed in spend analysis. The authors of this paper intend to illustrate this concept by sharing brief examples of spend analysis that could be used to track and measure BIM design progress.

Input hours spent during BIM design and coordination are essential resources spent for the project that would benefit from insightful analytics.

1. **Hours spent per LOD percentage completion**
   Pivot the overall data set against LOD percentage completion (aggregated from individual element percentage completion per LOD level) and input hours spent per LOD level. This is one of the most basic analyses that can be performed to provide visibility into effort spent per progress percentage point gained. One can reasonably expect that this metric would trend upward as LOD increases to a point where some systems no longer require a further level of development as it no longer adds value to the outcome of design or coordination.
2. **Hours spent per category per LOD percentage completion**
   Expanding on the previous concept by including data on activity/element categories (design, modeling, coordination, revision, re-coordination, etc.) would expose areas where categories of efforts were spent proportional or disproportional to the percentage completion by LOD. See Figure 5 for an example of hours spent per category per LOD percentage completion. For instance, this analysis may expose the fact that many hours were spent in re-coordination, which would trigger thoughts of whether upstream activities, such as design, initial modeling and initial coordination, were properly and effectively completed.

Figure 5: Example of hours spent per category per LOD percentage completion

WBS	CSI code	Division	LOD 100 % Complete	Design hours	Hr/%	Modeling hours	Hr/%	Coordination hours	Hr/%	Revision hours	Hr/%	Re-coordination hours	Hr/%
1.5.03	5	Metals	0.78	40	0.51	20	0.26	40	0.51	10	0.13	5	0.06
1.1.10	15	Unit Piping Mechanical	0.65	80	1.23	40	0.62	30	0.46	20	0.31	15	0.23

Source: *EY* The above table shows that, because Mechanical's overall efforts are hypothetically twice those of Metals, the hours spent per category for Metals appears high and worth further investigation.

The concept of spend analysis applied in BIM design measurement enables owners to gain visibility to the design progress, pinpoint potential areas of bottleneck, and plan and respond to efforts accordingly. The concept of vertical and horizontal analysis found in financial statement analysis enables BIM design to be measured as a function of its total output and over time. Below are examples illustrating such metrics in vertical and horizontal analyses.

3. **Vertical analysis — the BIM "efficiency" ratio**
   One of the key metrics of a business is the profitability ratio, which is defined as the delta between net sales and cost of goods sold over net sales. This is a key metric that defines the success or failure of a business. A similar approach can be adapted to BIM design to measure efficiency. In BIM design, hours spent redesigning, remodeling and recoordinating are essentially waste in the system. The greater percentage of hours spent in initial design, modeling and coordination that led to the final completed LOD, the less waste in the system.

   Hence, by obtaining hours based on a pivot of the data set against initial design, modeling and coordination hours and dividing that over the total number of hours spent per LOD, the percentage obtained would be an essential measure of efficiency in achieving completion of a particular LOD.

4. **Horizontal analysis — the BIM "weighted-average-efficiency" ratio**
   As mentioned previously in the concept of MPT, which blends model elements with scheduled activities through WBS, the data set enables pivoting of a particular phase of schedule against the LODs. Each phase of the schedule may have a particular portfolio of LODs. The early phase of a design will have a higher concentration of LOD 100s, while the later phase of a design will encounter a higher concentration of LOD 350s. Expanding on the BIM "efficiency" ratio per LOD, a weighted-average-efficiency per phase can be constructed in a similar manner. This would provide oversight of efficiency over a particular time period of the design, as well as offer a trending measure over the various phases of a design project.

Further concepts to explore

Use of RACI to allocate tasks to individuals

Project-specific roles and activities for each participant in the form of a responsible, accountable, consulted and informed (RACI) matrix can be developed. Such a RACI matrix can then be used to perform vertical and horizontal RACI analysis against each individual assigned across each activity to spot overlaps and gaps of RACI. Performing this analysis early on enhances clarity of individual responsibilities. The RACI attributes linked to each individual and activity also enable data analytics (discussed later) to be performed during progress measurement.

Regression analysis and benchmarking

Sample concepts thus far have applied to per-project basis, leveraging established industry definitions and tools and paralleling business concepts. However, the value of BIM design measurement does not stop at the individual project level. The data collected and analytics performed on individual projects would form the basis of single and multivariable regression analysis. Applied at the owner level, such statistics and regression analysis can be leveraged as part of the decision criteria during source selection of architects and engineers on future projects. Applied at the architect and engineer level, the information and insights can help optimize its BIM design delivery process on a continued basis.

Applied at the owner level, such statistics and regression analysis can be leveraged as part of the decision criteria during source selection of architects and engineers on future projects.

Linking element/activity to schedule of values

One of the challenges faced by owners and architects/ engineers on a monthly basis is agreeing to the monthly payments based on actual modeling progress made and validated against the agreed-upon schedule of values. To date, such effort is a combination of estimates mixed with an art of negotiation from both sides. However, having a granular schedule of values defined per activity based on the actual schedule enables tracking and measurement of model elements directly against scheduled values, or ultimately the budget. While establishing this may be a substantial undertaking at the inception of the project, the initial efforts could potentially generate dividends throughout the design cycle by enabling accurate monthly progress payments.

Advanced technology platform

While many commercial and custom BIM solutions exist today, most of these are focused on one of the following categories: design modeling, design coordination, energy and rendering simulation, asset management tracking, mobile and field management, or basic earned valued analysis. The authors of this paper hypothesize a solution that would enable BIM design management, in its entirety, with the creation of a BIM intelligence dashboard where data can be automatically siphoned from the latest models and schedules and analytics can be performed on a real-time basis. Whether the design model follows the single BIM or parallel BIM approach, the way to track, measure and manage the successful outcome of BIM design would be the same.

Organizational alignment

The most common form of team structure on a large capital project is a functional matrix structure involving horizontal process flow owners (i.e., design managers and project managers) intersecting with vertical functional owners (i.e., schedulers and cost engineers). This crisscrossing of processes and functions has traditionally been met with restrictive processes and policies to control the flow of information.

BIM was conceived as a potential technology solution that enables information aggregation, storage, transportation and dissection to break away from the confines of the organization structure and liberate the flow of information in a nonlinear fashion. Most leading literature suggests accomplishing the integration of BIM technology with project management processes using a BIM implementation maturity model by identifying where the organization is currently in terms of BIM use (point A), the maturity level the organization would like to target (point B), and how to move from point A to point B.

Such an approach neglects the fact that BIM implementation, similar to any large technology-enabled business transformation effort, is predominantly a business/project process re-engineering undertaking. Hence, a case-by-case in-depth analysis of both the workflows and processes of a proposed team structure is required. The analysis results should then be compared to the workflows and processes required by the complement of BIM tools used to identify implementation gaps and solutions to best align the two. A systematic study of the above-proposed approach would be worth further investigation.

Conclusion

The concepts, approaches and metrics illustrated in this paper present a set of tactical steps that describe a journey of BIM design measurement through the establishment, aggregation and analytics of inputs and outputs. The authors also suggested areas of further undertakings in terms of benchmarking and technology enablement.

But more important is having the understanding and conviction of why effective BIM design measurement is a strategic value-add to the overall capital project delivery process. By leveraging and adapting the concept of product value chain (as illustrated in *The Innovator's Solution: Creating and Sustaining Successful Growth* by Clayton Christensen), a company can best focus its efforts on identifying the greatest cost savings within the overall capital project delivery process. In this case, the ability to effectively manage efficiency, quality, cost and schedule during design would lead to the greatest impact in saving both time and money while improving quality. BIM design measurement implemented with the approach as suggested in this paper could be one of the first solutions in addressing such a strategic need among owners and architects/engineers of capital projects across industries.

Appendix

References

Common BIM resources such as the following are referenced throughout the paper.

"AIA E202-2008, Building Information Management Protocol Exhibit," The American Institute of Architects (AIA), 2008.
a. Level of development (LOD)
b. Model element table (MEA)

Brad Hardin, LEED AP, AIA, *BIM and Construction Management: Proven Tools, Methods, and Workflows.* (Sybex, 2009).
a. Model coordination plan (MCP)
b. Information exchange plan (IEP)

Eric Ries, *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses* (Crown Business, 2011).

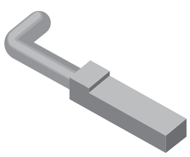
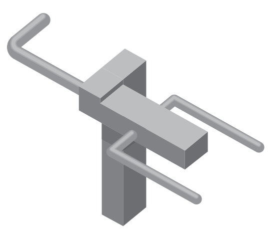
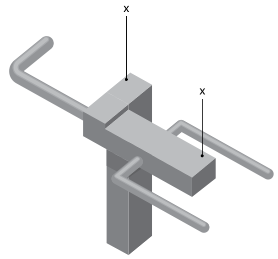
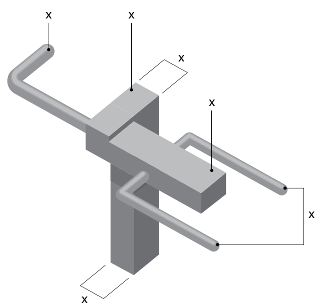
"2013 Level of Development Specification," BIMForum, 22 August 2013.

"Building Information Modeling Guidelines and Standards for Architects and Engineers," New York City (NYC) School Construction Authority (SCA), 28 April 2014.
a. Model progression table (MPT)

"Building Information Modeling Planning Guide for Facility Owners, Version 1.0," The Pennsylvania State University Computer Integrated Construction Research Program, April 2012.

Clayton Christensen, *The Innovator's Solution: Creating and Sustaining Successful Growth*, (Harvard Business School Press, 2013).

Figure 6: LOD definitions and graphics

LOD	Definition	Graphics
100	‣ Model element may be graphically represented in the model with a symbol or other generic block placeholder representation. ‣ This is the conceptual design of the model and would consist of overall building mass and form optimization.	
200	‣ Model element is graphically represented within the model as a generic system, object or assembly with approximate quantities, size, shape, location and orientation. ‣ Non-graphic information may also be attached to the model element. ‣ Detail appropriate for the schematic design or design development stage.	
300	‣ Model element is graphically represented within the model as a specific system, object or assembly in terms of quantity, size, shape, location and orientation. ‣ Non-graphic information may also be attached to the model element. ‣ Detail appropriate for construction documents.	
350	‣ Model element is graphically represented within the model as a specific system, object or assembly in terms of size, shape, location, quantity and orientation with sufficient detailing for coordination purposes.	

Source: *BIMForum*

EY | Assurance | Tax | Transactions | Advisory

EYG No. DF0200
1412-1365415
ED None

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The authors would like to acknowledge input from Mark Gibson, partner at Ernst & Young LLP's Irvine office; John Wescott, senior manager from the same office; Jay Purdy, senior from the New York, New York, office; and all leading practitioners interviewed.

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