ACHIEVING BIM AND CIM IMPLEMENTATION THROUGH QUALITY MANAGEMENT

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ABSTRACT

This paper presents a studied proposition that the domain of Building Information Modeling (BIM)/Civil Information Modeling (CIM)/Facilities Information Modeling (FIM) is Quality Management. The proposition is approached from a thorough review of BIM/CIM/FIM capabilities, the operation actualization in design and construction, the individual value added and extracted throughout the workflow process, and the value added to the owner in delivering an accurate model. The paper first presents background on BIM, and the value added/received through information modeling; secondly the paper addresses industry workflow associated with the information model's production and exchange, from model inception to archival record; it follows this with a discussion on the alignment of the model with various operational focuses with the cycle of model documentation, utilization, model maintenance, commissioning, and owner transfer. The paper closes with insight into Quality Management as the most appropriate champion forwarding the integration of the information modeling for adding maximum value to the development of the built facility.

Keywords: Quality management, building information modeling, civil information modeling, facility management, IFC

1. INTRODUCTION

Currently Building Information Modeling (BIM) discussions have ignored the function of quality management in the assurance of information exchanges in the AEC industry. Hopefully this is just an oversight that will be corrected in the future. This paper is attempt to begin the dialogue. It will address the organizational processes of Quality Management (QM), and not focus on information technology (IT) as the mechanism to bring about transformative change in how AEC information is produced, exchanged, or managed. The industry's current transformative efforts, led by BuildingSMART Alliance is exclusively focused in using IFC (Industry Foundation Class) as a universal language for interoperability of information exchanges, often citing the associated financial cost of interoperability (BuildingSMART 2010). This concentration is making significant inroads in BIM software development with good results. Although IFC advances will assist in a universal BIM exchange language, the author believes that other opportunities exist to simplify for owner's their ability to implement currently stalled aspects of moving BIM integration forward. This advancement opportunity is acheiveable through in place quality management systems (QMS).

To move AEC information modeling toward a fully integrated digital simulation of the physical facility, the recognition and implementation of a business process management strategy that crosses the different participants self-need is necessary. Without some form of business rules governing exchange processes that recognize owners as end users the industry will be unable to define BIM deliverables nor fully implement BIM as a value-added deliverable. Additional research is needed on BIM business practices in order to move development from idea to practice. The author proposes that QM is the natural area to achieve AEC information exchange integration. QM provides the neutrality that can assure both interim and end value of the model by its:

1. position as the management function that spans the project lifecycle,

2. established procedural focus on documenting and certifying the inclusion of project information inputs including process/product compliance,
3. capacity to address model integrity,
4. longstanding responsibility for delivering closeout documentation.

Without the infusion of QM to guide model development the resultant product becomes garbage in garbage out, the ultimate in unreliability.

2. BROAD BIM

The basic information needed to build a facility are drawings and specifications. All proposed facilities require these documents to produce the facility as required by the owner's needs. Drawings are currently produced in 2D and 3D with 2D drawings the ultimate issued for construction documentation, referred to by some as IFC's, not to be confused with Industry Foundation Class (IFC). As a designer intent on delivering issued for construction drawings to support construction the temptation and practicality is to take IFC modeling shortcuts (e.g., using a concrete floor slab object as a roof slab object) is apparent. With 2D paper drawings as final document (graphical model) output goal, design shortcuts coupled with no final BIM deliverable requirement a significant impact on the quality and accuracy of BIM documentation occurs.

Although BIM is well into its third decade of existence (similar to CAD's lifespan) it still struggles for an identity. Among the many industry descriptors of BIM are that it is a 3D visual model, a space validation tool, or a coordination medium for objects or project participants. There is an obvious BIM identity crisis in the industry. The Associated General Contractors of America (AGC) defines BIM's as *'data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility,*'(Ernstrom and et al. 2006) while Eastman et al. (2008) define BIM as *'a modeling technology and associated set of processes to produce, communicate, and analyze building models…'* The AGC seems limited by its reference to facility delivery when project lifecycle is central to client (owner) benefits. A better and more arching definition is available from the National Institute of Building Sciences (NIBS): '*A Building Information Model (BIM) 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 lifecycle from inception onward* (Smith and Edgar 2008).

Suffice to say there are wide ranging definitions of BIM. At present some of these seem short-sighted in the strength and breadth of extending the BIM concept beyond buildings to encompass modeling information applicable to the larger spectrum of built facilities, including civil infrastructure work. The author agrees with Laiserin's (2007) BIM definition that broadly states *'BIM is a process of representation, which creates and maintains multidimensional, data-rich views throughout a project lifecycle to support communication…, collaboration…, simulation…, and optimization….*' Laiserin continues that BIM is a focus on processes independent of software or databases and as a business process extends beyond buildings. It is evident that BIM's strength and value come from its diverse capabilities and value added by the different participants expertise at different stages throughout a facility's lifecycle. In the end the real driver for extracting maximum value from BIM processes will be owners and operators. At present there is little understanding by owner's and operator's on what can be delivered, how it can be delivered, and what it will cost in return. Therefore BIM lacks a clear mandate for a full range implementation. It is the author's belief that the domain of quality management is the area of concentration that offers owners a natural path to move BIM toward greater returns while maximizing participant value. In the AEC industry the sole value of information exchange is to build and operate a facility, be it a building, bridge, road, or utility infrastructure. There is no value added until the facility is built and occupied.

3. WHAT'S BEYOND BIM

First evidenced in the early 1980's as Building Product Models and coined as Building Modeling in 1986 the term Building Information Modeling was introduced in 1992 by van Nederveen and Tolman (Eastman et al. 2008). With the exception of ArchiCAD's parametric modeler known as Virtual Construction it wasn't until early in the

2000's that BIM became a commercially viable application. Since Autodesk's 2002 purchase of a BIM software application known as Revit, 2-D CAD (Computer-Aided Design) usage has declined and BIM sales have soared. In the past decade BIM has become the de facto replacement for CAD. A report by McGraw Hill Construction (2008) states that over 50% of the AEC industry BIM users employ BIM at moderate to high levels with rapid increases expected through the next few years. This rapid growth is also noted by Dennis Neely, a writer for Reed Construction Data, who forecasts that based on the speed of BIM adoption that within two years (2012) approximately 95% of the architects and 50% of constructors will be using BIM. (Neeley 2010). It is evident from this rapid adoption that BIM's value is actual, not perceived.

A overview of the literature confirms that value is variable based on the project participant and software capabilities. Neither owner nor architectural designer need concrete lift drawings to process the design, nor does a constructor need egress calculations to build the facility. At present, the expansive growth of BIM is characterized by the individual value that each participant can extract from the model during their involvement. Much like the past, individual participants are creating their own models to maximize their own needs. As owners have involvement throughout the entire process they stand to benefit the most, at project turnover, by maximizing the quality of information integration within a unified model. An operational realization of individual participant benefits versus owner needs is crucial to advancing BIM in the industry. Staring in fiscal year 2006 the US General Services Administration (GSA) stipulated that it would require the use of BIM as part of the AEC industry's work proposals. As the largest landlord in the US this effort was primarily aimed at achieving accurate spatial program verifications. Due to the magnitude of impact this decision had on the AEC industry it is a milestone in the evolutionary life of BIM. It is undeniable that owners will benefit the most from a full implementation of information modeling. What is at question is how will owners be able to stipulate the value they need and at the same time not overburden other AEC participants with mundane data capture and allow the opportunity for others to extract maximum value as the information model transits a facility's lifecycle.

One natural extension of BIM is Civil Information Modeling (CIM) and although unknowingly practiced by many it does not have the recognition that BIM enjoys. CIM can be characterized in the same manner as Eastman or Laiserin characterizes BIM, it is a modeling technology and associated set of processes to produce, communicate, collaborate, analyze, and optimize facility models. Bridge Information Modeling (BrIM) (Bentley 2007), Road Information Modeling (RIM), and Infrastructure Modeling (IM) offer the same if not greater value-added opportunities to the AEC/O community through a broader Facilities Information Management Modeling (FIMM) capacity, by creating Facility Information Models (FIM). As an example, CIM has the capability of allowing transportation designers to prepare visualizations for citizen groups while being able to compare design alternatives for vehicle passing sightlines, headlight distances, and minimum turning radius, etc. by comparing to established American Association of State Highway and Traffic Officials (AASHTO) rule tables. A form of automated design compliance checking. Grading cut and fill calculations along road alignments can be quantified and optimized, modeling is excellent at quantifying. Additionally, horizontal and vertical controls are able to be passed to/from automated machine controlled equipment allowing automated real-time as-built documentation wirelessly relayed and archived to a land based server. Water, storm drain, sewer, communications cabling, and other utility routings can be integrated into design constructability reviews and simulated for construction sequencing, scheduling, and collision avoidance through CIM. For further information the US Army Corps of Engineers (USACE) proposed strategy to implement CIM see their CIM roadmap (Brucker et al. 2006).

The success of accurate information exchanges is based on the accuracy of the information resident within the model. The reliability of an accurate model can only be assured through the implementation and maintenance of a consistently applied Quality Management System (QMS) aimed at developing value-added content for downstream participant use. A mandated QMS beginning at project inception and carried through to project turnover can assure the beneficial reliability and maximize usable value of facility information modeling, whether it's called BIM, CIM, or FIM.

4. VALUE ADDED MODELING

The project lifecycle extends from project vision through to end-of-life facility decisions, including rehabilitation, renovations, or deconstruction. Over this lifecycle facility owners are tasked with the project management functions of scope, cost, schedule, and quality. These are fundamental aspects and requirements of the US federal governments facility acquisition Project Management Plan (PMP) (US Army Corps of Engineers 2006). These are initiated during the project visioning sessions, and follow throughout the project lifecycle including pre-design, design, procurement, construction, operation, and end-of-life. In order to achieve the objectives of formally managing the process BIM, CIM, or FIM necessitate a process to coordinate and deliver maximum value throughout the process. There is considerable work being done on BIM IT, primarily aimed at improved interoperability and data use across project lifecycle, notable recent articles press this effort to by aiming at developing specifications criteria for software content exchanges as a proposed national BIM standard (Eastman et al. 2010) and granulating work task identification for productivity in object manipulation (Lucas et al. 2010). Efforts are being expended to craft a software solution that minimizes redundant entry and allows a transparent data exchange in a query capable and manipulative manner.

Though these efforts are necessary, work is also required to develop a human processes environment that allows humans some capacity to decide what information is needed and to extract that information from current (previous) models in a manner usable to the differing party. This is necessary even to the point of having to 'redraw' the information with another software application. For example a survey crew will need x, y, z coordinates in machine readable format. It is currently simpler, less time consuming, and more reliable to remodel the information than attempting to extract this information from current design models. Different people need information in different formats and producing the needed information should lie with those producing the work. Structural designers do not produce electrical designs and consulting designers may lack the knowledgeable to design for constructability, or they lack the construction sequence knowledge to develop the exact granularity required for a constructor's particular 4D simulation.

In a QM environment a quality system would establish a structure for model enrichment from inception to end-of-life, including quality control and assurance processes. This model would be transformative in content and layered (integrated) as lifecycle BIM to develop a lean (waste free) model that meets downstream customer needs without burdensome content, hence one of the pushes for Integrated Project Delivery (IPD). If IFC structure can be incorporated into the software to let designers meet their needs, and constructor's to use the model without a redraw, fabricator's to meet their needs, and operator's theirs then so much the better, but the expertise rules needed to anticipate client side needs seems extensive and improbable.

5. FACILITY INFORMATION MODEL QUALITY MANAGEMENT

In delivering a facility to an owner/occupant, quality is a measure of the product delivered and is the system by which the quality is assured. This is consistent with Ashford's (1989) identification of the major function of quality insistence, to assure that a product is acceptable to the market and is the mechanism by which value is returned for the compensation paid with a goal of maximizing the quality of the goods or service . In design and construction much like other enterprises the customer supply chain extends vertically and horizontally, from owner to designer, to constructor, to supplier, fabricator, installer, operator, and to user. QM of this supply chain must rely primarily on the producer of goods, the FIM producer in this instance. Much like a built facility FIM's are the resultant of numerous information suppliers working in an open exchange system to accurately supply digital information to downstream customers. This can be reports, drawings, pictures, product data, geometry, etc.

5.1 Design and construction quality management

From a design documentation perspective, including Design-Build, all US federal projects utilize a server-based tool known as Design Review and Checking System (DrChecks) to capture and evaluate the process of facility design, bid-ability, constructability, and operability. DrChecks acts as a single point of integrated design quality management (DQM) allowing access by project managers, reviewers, customers, designers, lessons-learned points of contact, and administrators for project review comments, and integration back into the design documents as project revisions. The four objectives of DrChecks are similar to what is being touted as the integrated opportunities available within BIM; 1) improved project quality, 2) reduced construction change orders, 3) a large life-cycle return, and 4) improved user satisfaction and facility usefulness. All are functions of a QMS. In fact DrChecks was recognized by the Office of the US Secretary of Defense, Quality Management as a "Quality Management Best Practice" in 1999 (East et al. 2001). Since 1999 it has become the standard design review mechanism for all US federal projects.

At the inception of an AEC project the US Army Corps of Engineers Quality Management System (USACE QMS) requires development of a quality assurance (QA) plan as part of the USACE PMP. The intent is to maximize customer satisfaction and maintain continuous improvement. The US federal government requires construction contractor's to establish and demonstrate an extensive QMS that administers the project on a daily basis and is responsible for meeting project closeout requirements. The constructor's QM team must address and comply with submittal requirements in the following major categorical areas.

- Pre-construction submittals
- Shop drawings
- Product data
- Samples
- Design data
- Test reports.
- Certificates
- Manufacturer's instructions
- Manufacturer's field reports
- Operation and maintenance manuals
- Close out submittals

The constructer's QM personnel are responsible for approximately 45 discrete categories of information exchanges (not including daily information exchanges) from among these eleven submittal areas. It becomes natural to identify information modeling as a logical addition to the QMS. At present this on-site management of exchanged information is aided by an owner furnished server-based Quality Control System (QCS) system. Within this system all the pertinent information regarding product data, shop drawings, structural and life safety inspections, material compliance certificates, warranties, etc. are uploaded and stored. Final CAD as-built drawings are the single exception to the required server-based final deliverables. These are are usually required to be completed by the designer and submitted on CD-ROM (US Department of Defense (a) 2010). The addition of a FIM QM specification is a logical extension (or replacement) of the current CAD QM specification with an accurate as-built model submitted to the owner/operator.

5.2 Transformative strategy for implementing Facilities Information Modeling

Without a defined output model each user will simply adapt and extract from the (current) model what's of value for producing their scope of work. A user may enrich the model with usable downstream information in the process, or they may recreate the model but not pass the information back into a singular integrated end model. There are no requirements to put it all together in a model at the end. The ultimate endgame for an information model may not look like what some perceive. Facility geometry may be accessible in a no-cost graphical output application (e.g., Solibri Model Viewer) while operating and maintenance (O&M) manuals are accessed using text based reader application (e.g., PDF reader). A current prototype model being proposed for US government facilities is Construction Operations Building Information Exchange (COBIE). COBIE is IFC friendly but functions within desktop software applications (spreadsheets, digital images, and PDF's). COBIE identifies the contents deliverables for information exchanges during design, construction, commissioning, and closeout and archives them in a spreadsheet. COBIE is a perfect example of a multimedia based BIM that is delivered at the conclusion of the construction phase (East et al. 2010).

Recent developments by the BuildingSMART Alliance attempts to identify Information Delivery Manuals (IDM) and Model View Definitions (MVD) as exchange links among the customer supply chain and the BIM. The IDM is intended to presented in a non-technical language and perspective of the professional participant while MVD in an IFC nomenclature that speaks to the software (BuildingSMART 2008). What remains absent is insight into how an owner can specify the needed model inputs to effect a maximizing of the FIM output. It still sounds like computer speak to the author.

One approach toward an industry language user defined model structure is to identify the commonly described informational transactions that eventuate during a project's lifecycle. Table 1 begins such a strategy. Currently broad QM requirements from USACE and GSA quality guidelines are identified in Table 1 using industry standard English. The information is presented as a matrix for linking contemporary QCS information transactions with potential FIM capabilities that could be transformed within a FIM QMS. It identifies and maps current QM deliverables to proposed FIM capabilities. The mapping addresses who produces, supplies, and consumes information and draws on a similar information deliverable strategy from East, et al. (2010).

Table 1 - Model Linked QM Output Strategy							
	In process QM verification		O=Owner; D=Designer; C=Constructor; S=Supplier; F=Fabricator; Op=Operator			TR=Transitory TF=Transformative P=Permanent	D=Discard-able I=Integrated
Phase/Scope	QM Required	FIM Capable	Produce	Supply	Consume	Info Type	Final model integration
Project Conception							
• Visioning			O	O	D	TF	D
• Space programming	✓	✓	D	D	D	TF	D
• Space Analysis	✓	✓	D	D	D, O	TF	D
• Estimate	✓	✓	D	D	O	TR	D
• Schedule	✓		D	D	O	TR	D
Design & Construction Documentation							
• Spatial layout	✓	✓	D	D	C	P	I
• Geometry	✓	✓	D	D	C	P	I
• Visualization			D	D	O, C	P	
• Computations							
•Structural	✓	✓	D	D	D	P	I
•Energy	✓	✓	D	D	D, Op	P	I
•Life safety	✓	✓	D	D	D	P	I
•Sustainability	✓	✓	D	D	D	P	I
• Product specifications	✓	✓	D	D	C, S, F	P	I
Procurement							
• Quantities		✓	D	D	C, S	TR	D
• Cost estimate			C	C	O	TF	D
• Work packages	✓	✓	C	C	C	TR	D
• Subcontractors	✓	✓	C	C	C	P	
• Suppliers	✓	✓	S	S	C	P	
• Schedule			C	C	C	TR	D
• Owner furnished items	✓	✓	O	O	C	TR	D
Construction							
• Geometry control	✓	✓	D	D	C	TF	I
• Spatial layout	✓	✓	D	D	D,O	P	I
• Survey	✓	✓	C	C	C	TF	I
• Shop/Fab drawings	✓	✓	C, S, F	C, S, F	C, F	TF	I
• Product specs	✓	✓	D	D	C, S, F	P	I
• Inspection	✓	✓	C, S, F	C, S, F	C, O	TR	D
• Warranty	✓	✓	C	C, S, F	C, O	TR	I
• Cost report			C	C	C	TR	D
• Change control	✓	✓	C	C	C, O	TR	D
• Schedule			C	C	C, S, F	TRD	
• Commissioning	✓	✓	C	C	O, Op	TR	P
Facility Management							
• Spatial layout	✓	✓	D	C	C	TF	I
• Operation manuals	✓	✓	C	C, S	O, Op	P	I
• Maintenance instructions	✓	✓	C, S	C, S	O, Op	P	I
• Energy management	✓	✓	C, S	C, S	O, Op	P	I
• Test & balance report	✓		C	C	O, Op	TR	I
• As-built documentation	✓	✓	C, D	C	O, Op	P	I
End of Life							
• As-built documentation		✓	C, O	O, Op	D, C, O	P	I
• Product specifications		✓	D, C, S	O	D, C, O	P	I

Additional fields are provided to initiate discussions on the permanency of information. The implementer's of information modeling must remain aware of the balance required between information exchange and information overload to maximize the integrated model's benefits. Eppler and Mengis's (2004) study on information overload notes from a review of the literature that difficulties in identifying relevant information and subsequently selecting usable information leads to increased time in separating detail from overall perspectives and results in delayed and inaccurate decision-making when information supply exceeds the process capacity of an individual. By simply placing all available information in a FIM the industry runs the rise of information overload.

A critical aspect of Table 1 is the use of industry friendly AEC nomenclature that is illustrative of common information transactions. By piggybacking on current FIM information transactions an opportunity exists for information mapping within a FIM that can work toward greater industry engagement. An example of reading the table is to review as-built scope and from the table determine that; 1) as-builts are a current QM deliverable, 2) they are FIM capable, 3) they are produced by the constructor or designer from constructor supplied conditions, and consumed by owners and operators, and 4) they are permanently integrated into the model. Although Table 1 seems elementary, its focus is to demonstrate that existing QMS's are natural vehicles for extending FIM into the industry using a familiar language infrastructure. One advancement of the proposed matrix is a strategy to identify the defined deliverables of a QMS and map these to cross-over (similar to Table 1) from an industry vernacular language defining interim and end deliverables to an IFC schema, see Table 2 for an sample indication.

Table 2: Examples of QCS deliverables to FIM Linkage			
Defined final project deliverables	QM Required	FIM Capable	IFC
Deficiency tracking.	✓	✓	
Design data calculations	✓	✓	
Environmental protection plan	✓	✓	
Features of work list	✓	✓	
Final acceptance test	✓	✓	
Final approved shop drawings	✓	✓	
Final record as-built drawings/model	✓	✓	

This strategy would provide a lead in for owners to write an FIM enabled specification that can be used to replace current specifications for final project deliverables. Using a QM to implement adherence to the mapping would assure an accurate quality model upon project turnover. From the matrix, information producers can from their perspectives develop the most efficient and valued-added strategy to reuse the model where they can or recreate when advantageous.

6. CONCLUSION

The key FIM business question facing the AEC/O industry is what strategies can be employed throughout the project process to coordinate and validate included and linked and facility information that is intended to be stored, exchanged, reused, and ultimately archived as it transits the project lifecycle. To repeat earlier points in the paper, different people need information in different formats and producing the needed information should lie with those producing the work therefore more academic and industry work is required to develop a human processes environment that allows humans the capacity to decide what information is required and to extract that information from current (previous) models in a manner usable to them even to the point of reproducing the information. Industry participants are inventive enough to recognize how value can be engaged and added during information exchanges and will develop FIM interfaces to meet owner needs and serve their competitiveness. Future work as identified may provide an more expressive mechanism to achieve an improved vocabulary for advancing FIM in current AEC/O practices. Currently the strategy in FIM documentation is no different than how CAD documentation has been handled since its inception in the early 1980's. Everyone is on their own, to seek out the information and if exchanged, to use it at their own risk (US Department of Defense (b) 2010). The author doesn't see this changing in the next 30 years but the validity of the information should become more reliable if operating within the QM domain.

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