Building Information Modeling and the Interactive Capability Maturity Model

Tammy L. McCuen, MSCS, MBA
University of Oklahoma
Norman, Oklahoma

Increasingly the building design and construction industry is finding that BIM provides for traditional business process improvements and that building owners are beginning to require BIM on projects. This paper includes a discussion about the identification of a "minimum BIM" and an introduction to the National BIM Standard (NBIMS) Interactive Capability Maturity Model (I-CMM). This paper also includes a case study demonstrating the application of the I-CMM to one of the 2007 AIA TAP (Technology in Architecture Practice) BIM award winners. Outcomes from the case study include a score for the maturity of the BIM and an analysis of each category evaluated within the I-CMM. This paper provides researchers and industry with a tool they can utilize to establish a starting point in BIM and as a tool for improving BIM with a consistent scientific method of measurement.

Keywords: BIM, National BIM Standard, Interactive Capability Maturity Model, minimum BIM, M.A. Mortenson BIM

Introduction

Project overruns in the building design and construction schedule and cost components, combined with the lack of an interoperable information exchange and storage process about a facility, are the two major business drivers leading the Architecture/Engineering/Construction (A/E/C) industry to adopt BIM (NISTIR 7417, 2007). In 2004, the Construction User Roundtable (CURT) discussed the same issues plaguing the A/E/C industry and creating project overruns. The National Institute of Standards and Technology (NIST) study *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry* (NIST GCR 04-867, 2004), provides additional evidence supporting the CURT and NISTIR 7417 findings. The NIST study reports that all stakeholders are wasting money looking for, validating and/or recreating facility information that should be readily available during the entire lifecycle of the facility. Building Information Modeling (BIM) provides the A/E/C industry with an opportunity to improve business processes in the design, construction, operations and maintenance of a facility. The *General Buildings Information Handover Guide* (Fallon and Palmer, 2007) identifies two important contributions BIM makes in improving the inadequate processes that currently exist in the A/E/C industry. The first is that BIM provides a single, non-redundant, interoperable information repository supporting design, analysis, cost estimating, procurement, detailing, construction simulation, construction/erection, maintenance, and operation of a facility. BIM also provides structured machine-interpretable data for managing the information contained within a building model (NISTIR 7417, 2007). Each of the above reports and recommendations from industry experts suggests BIM is the answer for improving the inefficiencies in the traditional business processes of Architecture, Engineering, and Construction.

Typical questions from industry stakeholders interested in BIM include; "Where does an organization start with BIM?" and "What information and processes should a BIM include?" This paper provides answers to those questions. Within this paper is a synthesis of information about BIM from the technical standards' literature, along with a case study of a completed project created using BIM. This paper does not focus on the software or hardware required to produce a BIM, but rather on the business processes and collaboration needed in a BIM. This paper emphasizes the significance of the business processes and collaboration with a demonstration of an evaluation tool designed specifically for evaluating a BIM's maturity level and for planning future development of BIM within an organization. Based on the areas of importance evaluated by the tool, BIM users can see the interrelationship between business processes, collaboration, maturity level, and project outcomes necessary within a BIM.

This paper focuses on the use of the evaluation tool provided by the National BIM Standard (NBIMS) provided for users to utilize for analysis of individual BIMs. This paper begins with an overview and definition of BIM. Next, the author provides background information about BIM and discusses BIM as an information exchange process. The author then introduces the NBIMS Interactive Capability Maturity Model (I-CMM) as a tool for evaluation of individual BIMs to rate its maturity level. A case study is next in which the author evaluates an award winning BIM project using the I-CMMM. Based on the case study there is a discussion about implications for industry and conclusions about the study's findings.

Background

BIM is a tool intended for use horizontally across the entire lifecycle of a facility through which integrated building information is gathered, applied, preserved, and interchanged efficiently using open and interoperable technology (NBIMS, 2007). The National BIM Standard Project Committee defines BIM as:

> "Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle, defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder." (AEC-ST, 2007)

The National BIM Standard Project Committee is a committee of the National Institute of Building Sciences (NIBS) Facility Information Council (FIC) whose vision is for improved planning, design, construction, operation, and maintenance processes utilizing a standardized machine-readable information model for each facility. The standardized information model should be in a format useable by all stakeholders throughout its lifecycle (NBIMS, 2007). To support its mission, the committee focuses its efforts on the development of the National BIM Standard (NBIMS). NBIMS focuses on open and interoperable information related to all business function aspects of the facility lifecycle (NBIMS, 2007). The US Army Corps of Engineers (USACE) requires facility lifecycle interoperability be accomplished using the National BIM Standard no later than 2010 (USACE, 2006). The Corps' Roadmap for BIM implementation uses NBIMS as its guide throughout the process. The General Services Administration (GSA) Office of the Chief Architect (OCA) also supports NBIMS as an open standard for information exchange in its 3D-4D BIM Overview (GSA, 2007). The reference and support of NBIMS by both the USACE and GSA legitimizes its efforts as a standard for BIM development. NBIMS is a standard based on open information exchange and interoperability and is neutral to any industry, organization, or supplier influences.

To assure full comprehension of BIM, it is important to clarify that BIM is more than software and technology. The GSA (2007) emphasizes that BIM is more than stringing together a series of unintelligent 3D CAD drawings. BIM is an intelligent model created by combining a graphical and data model. The "I" in BIM is what represents the true concept and intent of BIM as it excludes previous available unintelligent models from classification as BIM (GSA, 2007). BIM provides team members with current and reliable documents that are useful in preconstruction, construction, and post construction activities (Elvin, 2007). In summary, the information about BIM presented to this point, emphasizes BIM as a standardized interoperable information model driven by industry demands to improve traditional business processes and collaboration between stakeholders. With a strong understanding of the definition of BIM, the discussion progresses to what constitutes a BIM and how users can measure progress in BIM.

Minimum BIM and the Capability Maturity Model

Logic dictates that there must be a starting point for BIM and as logic would have it, there is a definition for a "minimum BIM". Inherent in the minimum BIM is the idea of a "useful minimum". This idea of a "useful minimum" stems from an argument presented by Hietanen and Lehtinen (2006) that stated it would be better to initially concentrate on a small useful scope of information exchange requirements than to try to solve a large set of data exchange requirements all at once. This argument provided NBIMS with a basis for defining a minimum BIM. From this useful minimum, NBIMS (2007) establishes the characteristics associated with certain capabilities of a minimum BIM. The following table presents the seven areas of capabilities, along with the characteristics of each that are required of a minimum BIM.

Area of Interest	Characteristics
Data Richness	Having some level of expanded data collected so that the model is a worthwhile source of information about a facility
Roles or Disciplines	The basis for a BIM includes sharing of information between disciplines, so a minimum level of information sharing is required.
Business Process	While business process interoperability is a cornerstone of BIM, only a minimum level of business processes must integrate their data collection at the minimum BIM level.
Delivery Method	In order for a data set to be called a BIM, it must be implemented on a network so discipline information can be shared; however, robust information assurance need not yet be implemented and may be limited to simple password access control to the systems.
Graphical Information	Since all drawing should at this point be National CAD standard compliant, NBIMS is making this a requirement for a minimum BIM. This demonstrates that standards are being considered whenever possible
Information Accuracy	It is a critical element to ensure that ground truth has been implemented, meaning that polygons are located and used to compute space and volume and to identify what areas have been identified.
Interoperability/IFC Support	Things may not flow as smoothly as desired at this point in time, therefore NBIMS is only requiring that "forced interoperability" occur in the minimum BIM, but some level of interoperability must occur.

Table 1 Minimum BIM Areas of Capabilities and Characteristics

NBIMS identifies the capabilities, or areas of interest, of a BIM in its Capability Maturity Model (CMM) (NBIMS, 2007). The concept of a Capability Maturity Model is not unique to NBIMS. Its roots are in the software industry where developers at the Software Engineering Institute created the Capability Maturity Model for Software (SW-CMM) as a "roadmap" to describe "evolutionary stages" consisting of key practices that guide in improving software capability (Software Engineering Institute, 1998). NBIMS followed the Software Engineering Institute's lead and developed its tabular CMM for BIM users. NBIMS created the CMM for use as a tool by which BIM users can evaluate their business practices along a continuum of desired technical level of functionality. The vision is that BIM users will use the CMM to plot their current location and to set goals for their future operations (NBIMS, 2007). BIM technology will take time to mature and it will take time for the industry to adopt (USACE, 2006). During this time, the CMM is available for use as a standardized tool to assist users with BIM evaluation and development. The CMM is a matrix with eleven areas of interest on the x-axis and ten levels of maturity on the y-axis (see Appendix A). Areas of interest include; data richness, life-cycle views, change management (formerly ITIL maturity assessment), roles or disciplines, business processes, timeliness/response, delivery method, graphical information, spatial capability, information accuracy, and interoperability/IFC support (McCuen and Suermann, 2007).

From the tabular CMM, NBIMS developed the Interactive Capability Maturity Model (I-CMM) which contains all the same information, but enters the information on a graphical user interface. The intent of the graphical interface is to make the information easier to understand (NBIMS, 2007). The I-CMM is a multi-tab Microsoft Excel workbook, which includes several interdependent worksheets of functionality. The worksheets are interactive and actively update the BIM's maturity level as the user enters information (McCuen and Suermann, 2007). Figure 1 below displays the I-CMM, which is free and is available for download at http://www.facilityinformationcouncil.org/bim/pdfs/BIM_CMM_v1.8.xls.

A closer look at the areas of interest, the weighted importance of each, and explanation for each may help better understand the I-CMM and its intended use as a tool for evaluation. Following is a screen shot of the I-CMM showing the layout of the maturity model along with the tabs for the additional worksheets and information. The administration portion of the I-CMM provides categories for scores levels within the model. These categories range from "Minimum BIM" to "Platinum". The scoring levels within the I-CMM reflect the maturity level of an individual BIM as measured against a set of weighted criteria agreed to be desirable in a BIM. The I-CMM is not a tool intended for use to compare BIMs or BIM implementations, but only to measure an individual BIM's maturity level (McCuen and Suermann, 2007). The measurements within the I-CMM are designed to leverage information management.

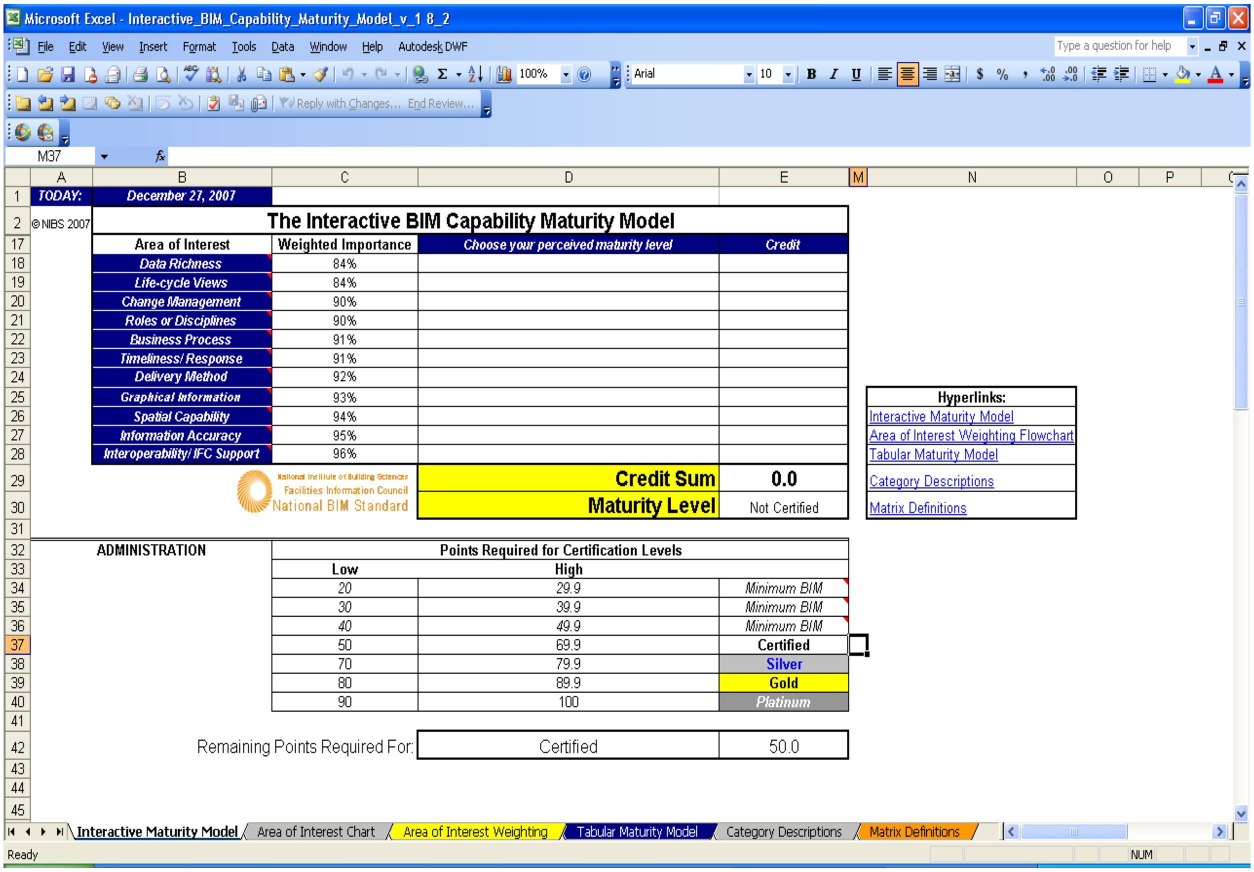

Figure 1 The Interactive Capability Maturity Model

Case Study

The case study in this paper is the M.A. Mortenson Construction Company's completed BIM project for the Benjamin D. Hall Research Building at the University of Washington. The author selected this project based on familiarity with the project, extensive research on the project, and the project's award winning status.

As a member of the NBIMS Testing Team, the author recently participated in a project in which the AIA and NBIMS agreed to partner on a project to test the Interactive Capability Maturity Model for BIM. The Testing Team's task was to apply the I-CMM to each of the 2007 TAP BIM award winners. It is important to note that the purpose of the test project was to focus on the I-CMM tool and not on conclusions about the BIM projects themselves. The Testing Team's focus was to apply the scientific method provided by the I-CMM to "real" BIM projects. In doing so, the project's outcome would provide adequate evidence and analysis in support of the validity of the Capability Maturity Model (McCuen and Suermann, 2007).

M.A. Mortenson Construction Company received the 2007 AIA TAP BIM award in "Design/Delivery Process Innovation Using BIM" category for its Design-Build-Operate-Maintain project. For the past three years, the AIA has received and evaluated projects submitted for consideration as exemplary BIM projects. Criteria used by the AIA for the 2007 awards included: (AIA, 2007)

- Quantifiable benefits in cost, schedule, or quality

- Interoperability between software applications
- Effective team collaboration
- Project change that "moves the ball forward"
- Cultural change
- Return on value
- *Additional emphasis on: Teams, not individuals*

Methodology

The author utilizes the case study method described by Yin (1994) to furnish a methodology for data collection and analysis of an award winning BIM project to demonstrate the application and interpretation of the NBIMS Interactive Capability Maturity Model. Yin furnishes three guiding principles for case study development (Yin 2004). The first is the use of "multiple" sources." In this study, the sources consist of information about the case from multiple sources, the case study project data from the I-CMM, and interviews with Mortenson's Design Coordinator. The next principle is "creation of a database." The database in this study is the data created from the application of the I-CMM to the BIM for the Mortenson project and the subsequent data contained within each area of interest in the model. The final principle is "maintaining a chain of evidence." In this case, this principle of the chain of evidence is the "chain" developed between the I-CMM BIM maturity guidelines, the detailed case study of the I-CMM and the actual maturity score of the BIM for the project. Having held to the Yin model in this study, its results, and conclusions offer an authoritative study for this particular case.

M.A. Mortenson's Benjamin D. Hall Research Building

The Descriptive Data Sheet submitted for the 2007 AIA TAP BIM awards provides information about the BIM within the architect, contractor, and owner statements. All three parties attribute the success of the project to the team's use of BIM. In their submission, Mortenson states that, "The model has proven comprehensive and durable enough to assist in all phases of the project lifecycle—from conception, through design and construction, to operations and maintenance." The project architect states that BIM was a key factor in the project's end result of an aesthetically pleasing, cost effective, and functioning building that meet the owner's needs. The owner's statement further supports the contribution of BIM in their statement that the project team delivered the project ahead of schedule and within budget, while exceeding the University's quality and scope expectations. Furthermore, the owner attributes the project's success to the team's dedication to BIM. The final score calculated by the I-CMM for this project substantiates the above statements by the project's stakeholders.

Findings

Rating each area of interest within the I-CMM for the Benjamin Hall Building reveals a maturity score of 80.1 (out of a possible 100) for the BIM on that project. Two independent evaluators from the NBIMS Testing Team assigned maturity levels to each area of interest within the I-CMM based on the Descriptive Data Sheet and the Project Narrative included with the project's submission to the AIA TAP BIM awards. The author of this paper was the primary evaluator on the project. After the initial evaluation, the primary evaluator interviewed the Design Coordinator at Mortenson who served as the team's leader. The interview confirmed the score and provided an opportunity to reconcile any discrepancies that may have existed between the I-CMM rating and the actual BIM on the project. Figure 2 displays the I-CMM for the Benjamin Hall Research Building from the NBIMS Testing Team project.

The Interactive BIM Capability Maturity Model			
Area of Interest	Weighted Importance	*Choose your perceived maturity level*	*Credit*
Data Richness	84%	Completely Authoritative Information	*6.7*
Life-cycle Views	84%	Includes Operations & Warranty	*5.9*
ITIL Maturity Assessment	90%	Limited Control	*4.5*
Roles or Disciplines	90%	Operations & Sustainment Supported	*7.2*
Business Process	91%	All BP Collect & Maintain Info	*7.3*
Timeliness/ Response	91%	Real Time Access w/ Live Feeds	*9.1*
Delivery Method	92%	Web Enabled Services - Secure	*7.4*
Graphical Information	93%	4D - Add Time	*8.4*
Spatial Capability	94%	Integrated into a complete GIS	*8.5*
Information Accuracy	95%	Computed Ground Truth w/Full Metrics	*9.5*
Interoperability/ IFC Support	96%	Full Info Transfers Between COTS	*5.8*
National Institute of Building Sciences Facilities Information Council National BIM Standard		**Credit Sum**	**80.1**
		Maturity Level	**Gold**

Figure 2 I-CMM for the Benjamin Hall Research Building

Review and discussion about each of the areas of interest in the I-CMM above for the Benjamin Hall Research Building BIM reveals the areas current maturity level along with each level's distance from the most mature level achievable for each area of interest. Below is a breakdown of each area of interest.

- Data Richness identifies the completeness of the data contained within the BIM from the most rudimentary unrelated data to complete data for full information and knowledge about the model. Weighted Importance is 84%. This project scored 6.7 for its rating at the level of "completely authoritative information", two levels short of the highest maturity level available.
- Life-cycle Views describes the number of individual stove pipes being linked together within the BIM as authoritative sources of information. Weighted Importance for this area of interest is 84%. This category scored a 5.9 because the project "includes operations & warranty" in its life-cycle views, three levels below the maximum maturity level.
- ITIL Maturity Assessment refers to the information technology infrastructure library, which provides a set of best practice approaches for information management by BIM users. Weighted Importance is 90%. This project scored a 4.5 for its "limited control", five levels below the highest maturity level of full optimization.
- Roles or Disciplines refers to the players involved in the business processes and their participation in the BIM. Weighted Importance is 90%. This project scored a 7.2 with "operations & sustainment supported", two levels below the maximum, which includes support of both internal and external roles and disciplines.
- Business Processes refers to the steps established to accomplish business in the BIM and

if the data and information collection occurs as part of the BIM process to ensure accurate and efficient exchanges in business processes. Weighted Importance is 91%. This BIM received a 7.3 rating for "all business processes collect & maintain information, only two levels below the maximum possible score.

- Timeliness/Response measures information contained within the BIM relative to accurate real time information that is reliable even in critical emergency situations. Weighted Importance for this area of interest is 91%. This project scored the maximum points available with its rating of 9.1 for "real time access w/live feeds".
- Delivery Method measures data delivery and availability for team members using the BIM. Weighted Importance is 92%. The BIM in this study scored a 7.4 for its "web enabled services – secure", only two levels below the highest maturity level available in this category.
- Graphical Information helps paint a clearer picture for all users starting which starts with 3D and expands to include time (4D) and cost (5D) information interfaces. The Weighted Importance for this area of interest on the I-CMM is 93%. The graphical information for this project scored 8.4 with "4D – add time", only one level below the maximum of "nD – time & cost".
- Spatial Capability is the capability of the BIM to locate the structure in space to improve richness of information by relating a structure to its surroundings and environmental elements impacting the project. Its Weighted Importance is 94%. With a score of 8.5 "integrated into a complete GIS", this project only lacks full information exchange for the highest rating available.
- Information Accuracy provided through electronic calculations of spaces and polygons provides mathematical ground truth capability, which allows for better management of information, its accuracy, and its compliance with project requirements. Weighted Importance is 96%. This project received a 9.5 for "computed ground truth w/full metrics", which is the highest possible score and therefore considered mature in this category.
- Interoperability/IFC Support measures a BIM's ability for accurate information exchange based on open standards and industry foundation classes. Weighted Importance is 96%. This project scored a 5.8 for "full info transfers between COTS" with four more levels to achieve before interoperable and considered mature in this category.

Included in this paper also is the tabular Capability Maturity Model from the I-CMM Excel worksheet. The tabular CMM is available in Appendix A. The tabular Capability Maturity Model displays each maturity level on the y-axis with 1 being the least mature to 10 being the most mature. The eleven areas of interest are along the x-axis at the top of the table. The appendix is for reference to compare the various levels of maturity within each area to the Benjamin Hall Research Building's maturity level in each area of interest.

Discussion

The key to success in BIM is not to simply automate existing processes, but rather to create a new leaner business process enabled by BIM technology (USACE, 2006). Findings from the Mortenson case study reveal that the architect, contractor, and owner all agreed that BIM facilitated an improved process with more effective and efficient performance of the entire team. Applying the I-CMM to the project provides a scientific method for evaluating the BIM and a starting point to reference for improving business processes. Utilization of the I-CMM to evaluate the BIM post-project completion reveals that although the BIM created for this project surpasses expectations, there were still areas for improvement and a standard by which the team can work toward reaching the highest maturity level.

The I-CMM provides BIM users in the A/E/C industry with a tool to establish a starting point and as a tool that is useful for development of future BIMs. The primary objective for the NBIMS Testing Team with the AIA TAP project was to evaluate and score the award winning BIMs based solely on the measurements within the I-CMM rather than to perform evaluations based on architectural, engineering, construction, or management metrics (McCuen and Suermann, 2007).

Conclusion

This paper introduces the NBIMS Interactive Capability Maturity Model, it provides an explanation of the I-CMM intent, and it discusses the method for use of the I-CMM. The NBIMS I-CMM is a tool for BIM users to utilize as a guide for BIM implementation. This paper provides an analysis of the BIM from M.A. Mortenson's Benjamin Hall Research Building. In addition, this paper provides BIM users a process for evaluation using business processes and a better understanding of the I-CMM tool and a guide for its use. Mortenson utilized BIM to integrate the pieces required for a successful Design-Build-Operate-Maintain project delivery. The integration combined a cross-functional team, performance objectives, and BIM to exceed the project's objectives. The NBIMS I-CMM is a tool for researchers and industry to use in establishing a starting point with BIM; it is a guide to improving BIM capabilities; and is a consistent method for mapping BIM development and maturity.

Appendix A

Tabular BIM Capability Maturity Model 5/30/2006

Maturity Level	*A* *Data Richness*	*B* *Life-cycle Views*	*C* *Roles Or Disciplines*	*G* *Change Management*	*D* *Business process*	*F* *Timeliness/ Response*	*E* *Delivery Method*	*H* *Graphical Information*	*I* *Spatial Capability*	*J* *Information Accuracy*	*K* *Interoperability/ IFC Support*
1	Basic Core Data	No Complete Project Phase	No Single Role Fully Supported	No CM Capability	Separate Processes Not Integrated	Most Response Info manually re-collected - Slow	Single Point Access No IA	Primarily Text - No Technical Graphics	Not Spatially Located	No Ground Truth	No Interoperability
2	Expanded Data Set	Planning & Design	Only One Role Supported	Aware of CM	Few Bus Processes Collect Info	Most Response Info manually re-collected	Single Point Access w/ Limited IA	2D Non-Intelligent As Designed	Basic Spatial Location	Initial Ground Truth	Forced Interoperability
3	Enhanced Data Set	Add Construction/ Supply	Two Roles Partially Supported	Aware of CM and Root Cause Analysis	Some Bus Process Collect Info	Data Calls Not In BIM But Most Other Data Is	Network Access w/ Basic IA	NCS 2D Non-Intelligent As Designed	Spatially Located	Limited Ground Truth - Int Spaces	Limited Interoperability
4	Data Plus Some Information	Includes Construction/ Supply	Two Roles Fully Supported	Aware CM, RCA and Feedback	Most Bus Processes Collect Info	Limited Response Info Available In BIM	Network Access w/ Full IA	NCS 2D Intelligent As Designed	Located w/ Limited Info Sharing	Full Ground Truth - Int Spaces	Limited Info Transfers Between COTS
5	Data Plus Expanded Information	Includes Constr/Supply & Fabrication	Partial Plan, Design&Constr Supported	Implementing CM	All Business Process(BP) Collect Info	Most Response Info Available In BIM	Limited Web Enabled Services	NCS 2D Intelligent As-Builts	Spatially located w/Metadata	Limited Ground Truth - Int & Ext	Most Info Transfers Between COTS
6	Data w/Limited Authoritative Information	Add Limited Operations & Warranty	Plan, Design & Construction Supported	CM Capability	Few BP Collect & Maintain Info	All Response Info Available In BIM	Full Web Enabled Services	NCS 2D Intelligent And Current	Spatially located w/Full Info Share	Full Ground Truth - Int And Ext	Full Info Transfers Between COTS
7	Data w/ Mostly Authoritative Information	Includes Operations & Warranty	Partial Ops & Sustainment Supported	Implemented	Some BP Collect & Maintain Info	All Response Info From BIM & Timely	Full Web Enabled Services w/IA	3D - Intelligent Graphics	Part of a limited GIS	Limited Comp Areas & Ground Truth	Limited Info Uses IFC's For Interoperability
8	Completely Authoritative Information	Add Financial	Operations & Sustainment Supported	Implementing CM and Root Cause Analysis	All BP Collect & Maintain Info	Limited Real Time Access From BIM	Web Enabled Services - Secure	3D - Current And Intelligent	Part of a more complete GIS	Full Computed Areas & Ground Truth	Expanded Info Uses IFC's For Interoperability
9	Limited Knowledge Management	Full Facility Life-cycle Collection	All Facility Life-Cycle Roles Supported	CM and RCA capability implemented	Some BP Collect&Maint In Real Time	Full Real Time Access From BIM	Netcentric SOA Based CAC Access	4D - Add Time	Integrated into a complete GIS	Comp GT w/Limited Metrics	Most Info Uses IFC's For Interoperability
10	Full Knowledge Management	Supports External Efforts	Internal and External Roles Supported	Implementing CM & RCA and feedback	All BP Collect&Maint In Real Time	Real Time Access w/ Live Feeds	Netcentric SOA Role Based CAC	nD - Time & Cost	Integrated into GIS w/ Full Info Flow	Computed Ground Truth w/Full Metrics	All Info Uses IFC's For Interoperability

References

AEC-ST National BIM Conference Session W25, *Overview of the National BIM Standard*, Washington DC, December 12, 2007.

American Institute of Architects, Technology in Architecture Practice, *Call for Entries 2008 BIM Awards*, Retrieved from http://www.aia.org/SiteObjects/files/TAP_BIM_2008_cfe_final_100207.pdf

Brucker, Beth A., & Case, Michael P., & East, E. William, & Huston, Brian K., & Nachtigall, Susan D., & Shockley, Johnette C., & Spangler, Steve C., and Wilson, James T., *Building Information Modeling (BIM) A Road Map for Implementation To Support MILCON Transformation and Civil Works Projects within the U.S. Army Corps of Engineers (ERDC TR-06-10)*, US Army Corps of Engineers, Engineer Research and Development Center, October 2006.

Construction Users Roundtable (CURT) Architectural/Engineering Productivity Committee, *Collaboration, Integrated Information and the Project Lifecycle in Building Design, Construction and Operation (WP-1201)*, August 2004.

Elvin, George, (2007), *Integrated Practice in Architecture.* New Jersey: John Wiley & Sons.

Fallon, Kristine K. and Palmer, Mark E., *General Buildings Information Handover Guide: Principles, Methodology and Case Studies (NISTIR 7417),* August 2007.

Gallaher, Michael P., O'Connor, Alan C., Dettbarn, John L. Jr., and Gilday Linda T., *Cost Analysis of Inadequate Interoperability in theU.S. Capital Facilities Industry (NIST GCR 04-867),* August 2004.

Hietanen, J., and Lehtinen, S., *The Useful Minimum*, Tampere University of Technology, Virtual Building Laboratory, 2006, Retrieved from http://www.facilityinformationcouncil.org/bim/pdfs/usefulminimum.pdf

McCuen, Tammy, and Suermann, Major Patrick, P.E., *The Interactive Capability Maturity Model and 2007 AIA TAP BIM Award Winners*, Viewpoint #33, AECbytes, December 6, 2007. Retrieved from http://www.aecbytes.com/viewpoint/2007/issue_33.html

Software Engineering Institute, Carnegie Mellon University, *Introduction: Capability Maturity Model Integration,*1998, Retrieved December 15, 2007, from http://www.sei.cmu.edu/news-at-sei/features/1998/sep/introduction_sept98.pdf

U.S. General Services Administration, Office of the Chief Architect, *GSA Building Information Modeling Guide Series 01 – Overview*, Version 0.60, May 2007.

Yin, Robert K., (1994). *Case study Research, Second Edition*, California: Sage Publications.