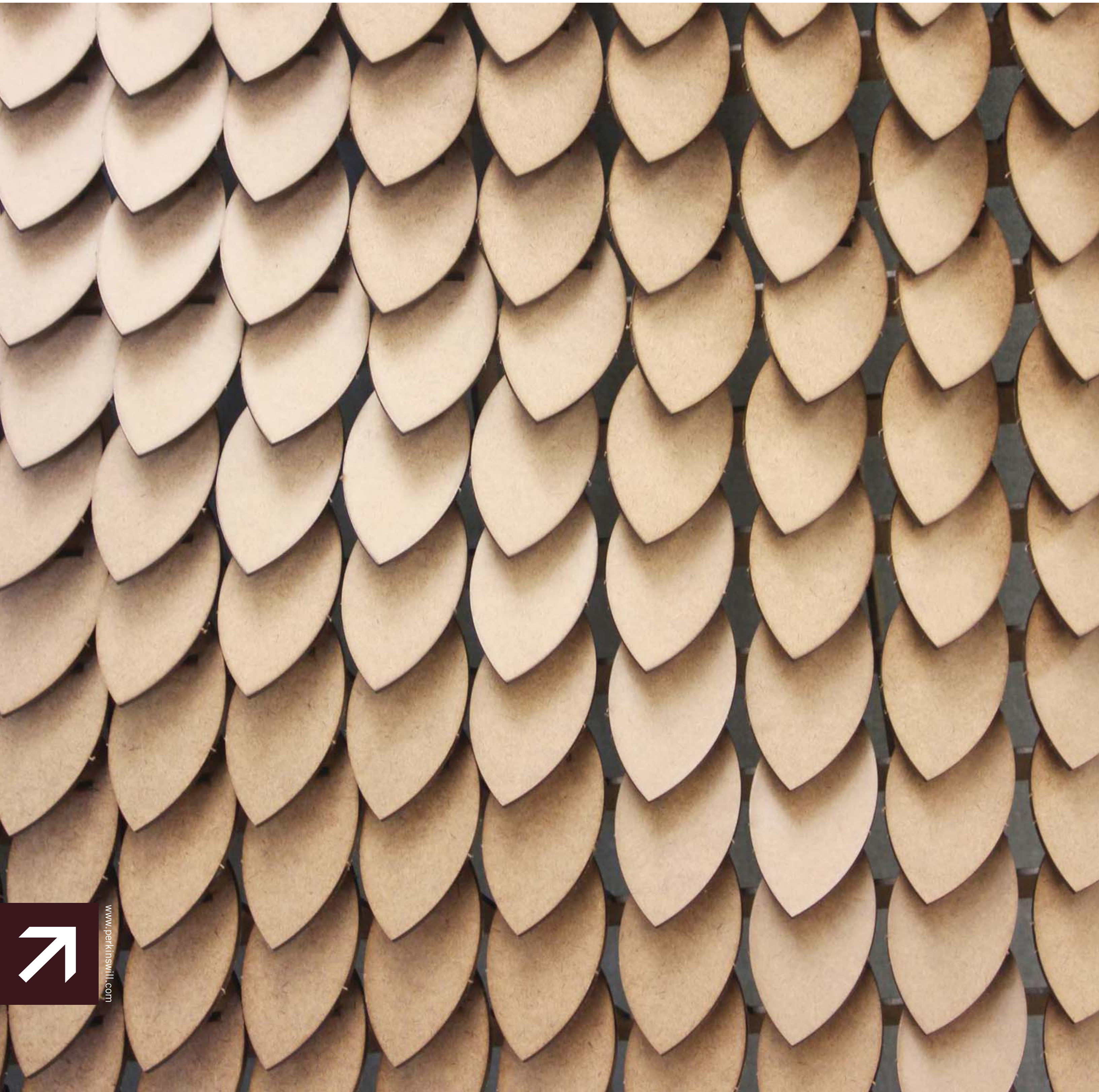
PERKINS+WILL

Research Journal

2011 / VOL 03.02



www.perkinswill.com

03.
THE INFORMATION CONTENT OF BIM:
An Information Theory Analysis of Building Information Model (BIM) Content

Mario Guttman, AIA, LEED AP, *mario.guttman@perkinswill.com*

ABSTRACT

The application of general information theory to pragmatic problems within the architecture, engineering, construction, owner and operator (AECOO) industry is explored in this article. Some basic principles about the nature of information and how it provides value are defined and applied to current issues in the use of building information modeling (BIM) and integrated project delivery (IPD) in design and construction. The analysis exposes some common misconceptions that have led to unsatisfactory results and tensions within the industry. It concludes that the general principles of information theory are applicable to BIM and that this approach will enhance the way BIM and IPD are discussed. Some ways of improving project outcomes by basing decisions on a more rigorous theoretical basis are suggested.

KEYWORDS: cost, value, model-based design, documentation, practice

1.0 INTRODUCTION

The architecture-engineering-construction-owner-operator (AECOO) industry is undergoing a process transformation that is generally discussed in terms of building information modeling (BIM) and integrated project delivery (IPD). While there is little doubt that this change is both positive and of historic magnitude, this article looks critically at some aspects of it. This criticism is not based in nostalgia for old methods or reactionary objections to new ones. Rather, it comes from the author's conviction that this kind of transformation requires detailed development grounded in critical thinking even more than it requires visionary thinking.

For example, the mission of the mid-twentieth century to put a man on the moon was not a new idea and it was not achieved through seminars on the desirability of the journey. Instead, it entailed engineering, especially about the many ways in which the mission could fail. Likewise, the notions of BIM are not a recent invention: Engelbart's *Augmenting Human Intellect: A Conceptual Framework,* outlined the basic principles of BIM and with amazingly prescient detail in 1962[1]. What has changed between then and now has not been the vision, but the technological capabilities of the computer industry; and these are the result of disciplined development more than philosophical refinement of the objectives.

It is in that spirit that this analysis examines some particular aspects of current BIM and IPD practice. The purpose is not to indict these innovations, but to acknowledge them as necessary and inevitable improvements to the industry and to understand how to better manage the factors that make them valuable.

While the topics of BIM and IPD often appear together, they actually do not address exactly the same kind of process change. BIM is a technology innovation that enables a better way of working and design documentation while IPD defines a legal and contractual context in which this work takes place. Moreover, these are complex topics that are not consistently defined within the industry and that, even when taken together, do not represent the full extent of the information topics that are relevant to this industry. For these reasons, the context of this paper is defined as follows:

- The discussion is limited to the AECOO industry and generally refers to *buildings* as distinguished from civil engineering, landscape architecture and other kinds of construction.
- It is assumed that the larger team (including the owner, architect, design consultants, builder and sub-contractors) are facile with using BIM and committed to a BIM-based work process. In this context, BIM means a set of 3-D object-based models including non-geometric data, which is ca-

pable of representing all aspects of how the building will be built and operated. Moreover, every instance of each building component is represented, so that these elements can potentially be managed individually over the entire life of the building. Insofar as the BIM is augmented with conventional 2D drawings and textual documents (such as specifications and schedules), these will be considered part of the BIM, without concern as to whether this is a proper definition in other contexts.
- It is further assumed that the AECOO team is working within a contractual and legal framework that is effectively a true IPD, irrespective of the actual details of these kinds of contracts as they are emerging in the industry. In this sense, the analysis really applies primarily to BIM and the discussion will focus on how information is managed when it is shared freely amongst all of the participants in whichever technological data form is most useful. IPD is referenced only because it has become the common way of referring to this open exchange and the term is used here in the broadest and most inclusive way. In particular, none of the information theoretical aspects of BIM are excluded even where they depend on being part of an IPD-like process.

Within this context, AECOO industry practitioners have acquired a large body of experience and examples of using BIM to create projects. These include many that strongly suggest that this new way of working should and will largely replace traditional methods over the next several decades. At the same time, significant problems have emerged with these new processes. These have led to an ongoing debate about which specific procedures should be adopted by the industry. While this activity is substantive and probably healthy, it has been documented and analyzed in a way that is relatively non-scientific in its methodology. Specifically lacking is an awareness that the "information" implicit in "building information model" behaves according to scientific principles that are broader than the AECOO industry.
- The premise of this study is that general principles of information theory are applicable to BIM. Its purpose is to show how such analysis will enhance the industry conversation about BIM-related practice and improve the outcomes of the projects that result from its use. However, information theory is a broad topic that is not generally familiar to an AECOO audience, so for purposes of this article, it needs to be defined in simple terms. To this end, it is defined as a science in the sense that it proposes principles that can be tested, which is concerned with how information behaves in very general ways, irrespective of whether it is information about a particular profession or project.
- The approach is necessarily somewhat mathematical. However, the AECOO industry (or the author, for that matter) does not use truly rigorous mathematics in its work. For these reasons, the assertions are quite abstract and do not include rigorous definitions or proofs. At this time there is no practical likelihood that the industry will have good measurements for the values we are analyzing (information content and effort) and there is no compelling reason to attempt a more quantitative approach, perhaps based on accounting data, for now.
- In general, quantities are expressed without units and relationships are expressed as proportions using the symbol "α" (rather than as equalities using "=".) This acknowledges that the actual values are not going to be known while still permitting study of the relationships.

A more rigorous mathematical approach and the development of better quantitative data would be welcome contributions of further research.

2.0 BACKGROUND

The history and basic concepts of information theory are nicely developed in Glieck's recent book *The Information*[2]. This paper draws heavily on that background and does not attempt to replicate even parts of it. What is especially significant to the AECOO industry is that information theory is a true science as distinguished from an unstructured collection of opinions. Further, as Glieck's history points out, disciplines that make formal use of information methods, particularly the computer industry, are likely to overwhelm those that remain rooted in a pre-information-age point of view.

Authoritative sources for scientific theory on BIM and IPD are sorely lacking. The bulk of the conversation within the industry has taken place in PowerPoint, often copied from other PowerPoints and without references or trustworthy sources or even accompanying text. Probably the best organized and most comprehensive book about BIM is Eastman, Teicholz and Liston's *BIM Handbook,* which gives a broad overview of the topic and ventures into some practical guidance on how to practice it[3]. Jernigan's *BIG BIM little bim,* promotes a particular point of view that the "right" way to do BIM requires rich information and a high level of team integration[4]. The *National BIM Standard,* developed by a wide range of industry experts under the auspices of the National Institute of Building Science (NIBS), is a widely referenced resource that is currently in development of its second version[5]. The American Institute of Architects (AIA)'s *Integrated Project Delivery: A Guide,* initiated by a committee of the AIA California Council and then rewritten as a publication of the National body, has served as a quasi-standard for how IPD is defined in the industry and what its goals should be[6]. Unfortunately, all of these references suffer from a writing style that is characteristic of the AECOO industry, in which process analysis is based on anecdote and relatively lacking in general theory. Particularly troubling is the blurring of actual experiences with anticipations of how the authors hope to see the industry change. One of the objectives of this article is to provide a basis for a more rigorous way of talking about these topics.

Analyses of information usage sometime make reference to the *data/information/knowledge/wisdom* (DIKW) hierarchy as the basis for certain process strategies[7]. This philosophy dates at least back to the American philosopher Mortimer Adler's writings in the early part of the twentieth century. It distinguishes *data* (raw information), *information* (organized data), *knowledge* (applicable information) and *wisdom* (the ability to use knowledge appropriately). While potentially useful, the DIKW hierarchy terminology differs from common usage in the AECOO industry, so it is avoided in this discussion. In particular, the implication that data is explicitly transformed into information does not reflect how BIM is typically applied. Where the DIKW system distinguishes data from information, in this industry it is often the same thing that is being referred to, even as its usefulness changes. Likewise, at the other extreme, whether the information in a BIM constitutes knowledge or even wisdom is not addressed. Rather, *information* is used in this discussion in the common, practical sense that a BIM or other documents contain information necessary to construct a building. An extension of this discussion to explore the use of knowledge would be another area of useful research.

3.0 PRINCIPLES

It is possible to consider *information* as analogous to *energy* as it is described in the physical sciences (the analogy is not precise, but contributes to understanding). In this sense, information is something slightly ethereal that we can sense, measure and use, even though we cannot really see it or know exactly what it is. The analogy is useful because it suggests ways in which fundamental principles can be applied to information in general, independent of any specific instance.

3.1 Cost of Information

Like energy, information is relatively easy to obtain, but not necessarily of value. Just as the heat energy that is a byproduct of equipment is usually a wasteful liability, unstructured information is typically not useful. We can even see it become detrimental when it overloads our data servers and obscures the information that we are actually looking for.

In the next section of this article, the value of information is defined in more detail. At this point it is enough to observe that some information (what we will call *High-value Information*) is worth more than other information (*Low-value Information*).

Moreover, just as there are no *perpetual motion machines* in physics, there is no free information. Like energy, information has a tendency to degrade from a higher-value state to a lower-value one through a process of *entropy.* This occurs even if the information is not being used in any way; if it exists, it is in a process of being degraded. *Effort* is necessary to prevent this and maintain a steady state. This incurs a cost, which is manifested in acquiring data, interpreting and maintaining it, authoring models and so on.

The effort needed to maintain information that we already have is one of the most frequent sources of friction within the AECOO community. Idealism around BIM encouraged by marketing promotion includes an implicit misconception that all information is good and that more information is better. As a result, when BIM information is exchanged, the recipients often have unwarranted expectations about the value of the information being delivered to them.

This *cost of information* is expressed as the following *Principle 1*:

Principle 1:

The effort cost of acquiring and maintaining quality information is proportional to the amount of information.

Where,

$C_{INFORMATION}$ = the effort *cost* of creating and maintaining information and

$A_{INFORMATION}$ = the *amount* of information,

then:

$$C_{INFORMATION} \propto A_{INFORMATION}$$

This is a significant assertion. Potentially, capable practitioners could find ways to avoid its consequences, perhaps with economies of scale or very smart technology; or, it might be that crowdsourcing with the new social media will make information free. However, today we are increasingly burdened with excess information. Initially it impacts our information technology infrastructure, but even greater cost comes with the human activity of organizing, evaluating and (too infrequently) deleting it.

3.2 Value of Information

In balance to this cost, information also has *value*, which derives from its capacity to inform decisions (that, in turn, enable actions). This definition of value is based on a premise, adopted for purposes of this discussion, that AECOO practice is fundamentally about decision making. In this view, decisions may range from the very broad ones of conceptual design, to very specific ones during construction. They may affect aesthetics, costs, schedules, utility and many other things, but they are the fundamental actions that enable a project to be conceived and to go forward to completion.

However, these various decisions are not equally important. Clearly they differ in their scope ranging from those that are very focused to those with broad implications, but that scope is not significant to this discussion since we are not working with actual values and can assume the effect of scope has been normalized. On the other hand, there are two aspects of a decision that do make it important:

- Relevance: Some project entity, the design/building team during construction or the owner/operator following construction, must actually make the decision. Information that informs purely hypothetical questions is not considered valuable in this context.
- Cost Effect: The actual building elements that are affected by the decision must be relatively expensive in terms of their design, acquisition, installation and maintenance. Although there are other objectives in a project that are not monetary (aesthetics, for example), it is those that affect the budget that are the most difficult to resolve and consequently, make the most use of information.

The *value* of information comes from its ability to enable making these important, cost-related decisions. As a result, such value can be ranked on a scale that extends from low to high and is analogous to *potential* in physics:

- Low-value Information: Information that lacks relevance, cost significance or structure is not useful for decision making. It is similar to *raw heat* in physics; it is definitely there, but it is not useful.
- High-value Information: At the other extreme, information that can be used is like *potential energy*. It has the capacity to do the work of informing decisions, just as a power source can do work in a motor.

(Note that the term “potential information”, which might be more consistent with the energy terminology, is not used since its common meaning would be misleading.)

This *value of information* is expressed as the following *Principle 2*:

Principle 2:

The value of information is proportional to the cost of acquisition and maintenance of the relevant tangible building elements being modeled.

Where,

$V_{INFORMATION}$ = the *value* of information and

C_{ASSETS} = the *cost* of the relevant tangible building assets,

then:

$$V_{INFORMATION} \propto C_{ASSETS}$$

For example, when the design team spends excessive time modeling detail that does not have much useful value to the builders, such as the framing in a partition, their time is wasted. On the other hand, relatively detailed modeling of an expensive component, like the curtain wall, can prevent costly field adjustments and rework.

3.3 Combined BIM Process Value Equation

These principles 1 and 2 can be combined into a single cost-benefit expression of the *value of a BIM*, in both the sense that the process of creating it was informative and that it is useful as a finished product. This expression can be applied broadly to any of the tasks for which the extended team (designer, builder, owner and operator) elects to use BIM.

The value of a BIM process is defined by how it is useful to the project team. It will be derived more easily when the process is applied to construction elements that are expensive in some way (time consuming to design, costly to purchase, entails time to install, hard to maintain) and can be managed relatively easily in the BIM (well defined, modularized, can be abstracted.) Conversely, such value will be difficult to derive from less important, highly commoditized elements especially if they are difficult to model.

Looking at value and cost at the same time is useful because, even with the very imprecise quantitative values we are using, it helps to understand the relative costs and benefits of different kinds of BIM processes. In other words, it identifies which activities will be valuable to a project team and which will waste their resources.

This *combined value of a BIM process* is expressed as the following *Principle 3*:

Principle 3:

The value of a BIM process is proportional to the acquisition and maintenance cost of the relevant tangible building elements being modeled and inversely proportional to the quantity-based cost of developing and maintaining the information.

Where,

$\mathbf{V_{BIM}}$ = the ultimate *value* to a project of a BIM process and

$\mathbf{C_{ASSETS}}$ = the cost of the relevant tangible building assets and

$\mathbf{A_{INFORMATION}}$ = the *amount* of information,

then:

$$\mathbf{V_{BIM}} \propto \mathbf{C_{ASSETS}} / \mathbf{A_{INFORMATION}}$$

This principle is evident in *Computer-Aided Facility Management* (CAFM) where projects designed to track spaces, which have a high capital cost and do not require much information maintenance, tend to be more successful than attempts to track furniture, which is not inherently worth much and is very difficult to keep track of. In the planning and executing of CAFM projects, it is usually more important to ensure that the overall effort will not be too onerous and will provide real value than to focus on the selection and fine tuning of the CAFM software.

Failure to grasp this principle is another source of friction. For example, building owners have been frustrated in their efforts to adapt the BIM models used during the creation of their buildings to CAFM. In fact, this should not be surprising since these BIM models tend to contain a lot of information, which is costly to use relative to the cost of the facility elements being managed. For example, it is not currently practical to update a BIM model every time a light fixture is replaced; there simply is not enough information payback to justify the effort.

4.0 INHERENT INFORMATION IN MODEL-BASED DESIGN

Applying these principles in the context of typical project work requires establishing quantitative values for the amount of information that is inherent in the BIM model.

4.1 Distinction of Conventional and Model-based Representations

It is not realistically possible to measure the information content of a BIM in any absolute sense, but a relative measure of how it differs from an alternative approach is useful. For this purpose, two kinds of AECOO documentation are distinguished:

- Conventional: The design methodologies used in construction over roughly the last century, including “hand-drafting” and computer-aided design (CAD) seek to minimize the amount of documentation required to achieve the goals of a project. Although largely two-dimensional and drawing-centric, they have included three-dimensional components as well as other kinds of non-drawing media. What distinguishes them is that they rely heavily on an abstract language to represent typical conditions, which are then extrapolated to define the complete project. For example, a simple two-dimensional symbol consisting of one line and one arc that references a schedule is all that is necessary to represent a door. The schedule may include some additional detail about dimensions, frame conditions, lights etc., but even this information is fairly abstract. (Note that “CAD” in this context is used to mean “drafting” that uses a computer; it is not used to mean the broader category of all “use of computers in the aid of design.”)
- Model-based: In contrast to the conventional methods, the more recent model-based approaches seek to completely represent the full extent of the project. For every individual building element that will be constructed, there is exactly one corresponding model element. Moreover, the model elements include detailed geometry and possibly

non-geometric attributes that simulate the built elements in detail. To continue with the door example, a model typically includes a three-dimensional representation of the leaf including any openings, a frame with an accurate profile and even hardware for every door instance. (This is not to say that every detail of the project is modeled. Drafting is a legitimate component of BIM, but it is an adjunct to the model that is not relevant to the definition of "model-based"). What distinguishes the model-based approach from the conventional one is that it seeks to reduce the reliance on abstraction. Although there are practical limits, ideally a model represents the completed project in significant detail over its entire scope. (Current model-based design theory goes even beyond this adding non-graphic data to the model, such as product specifications, that would have been managed separately in a conventional approach. While important, such information is not included in this analysis.)

4.2 Information Content of Conventional and Model-based Representations

A model-based representation of a project requires more information than a conventional one. For example, to define a solid rectilinear element in conventional terms requires four two-dimensional points and a value for the third dimension. To represent the same element in three dimensions requires eight three-dimensional points.

Moreover, in conventional documentation this element would typically be detailed in one place and then explicitly keyed or implicitly inferred to apply to many instances where it occurs; whereas in the model-based representation, every instance is represented. This means that even a small difference in the information cost of a single item is multiplied many times.

There are a number of simplifications and exclusions in this analysis. For example, the conventional representations rely on cultural conventions for how two-dimensional documents represent three-dimensional shapes in plans and sections. Similarly, a model relies on a complex BIM authoring context that brings new capabilities to the design process. These contexts supply additional information making it more difficult to measure information quantity in any absolute sense. However, for purposes of this discussion, they will be assumed to be relatively insignificant and approximately equal so that they can be ignored.

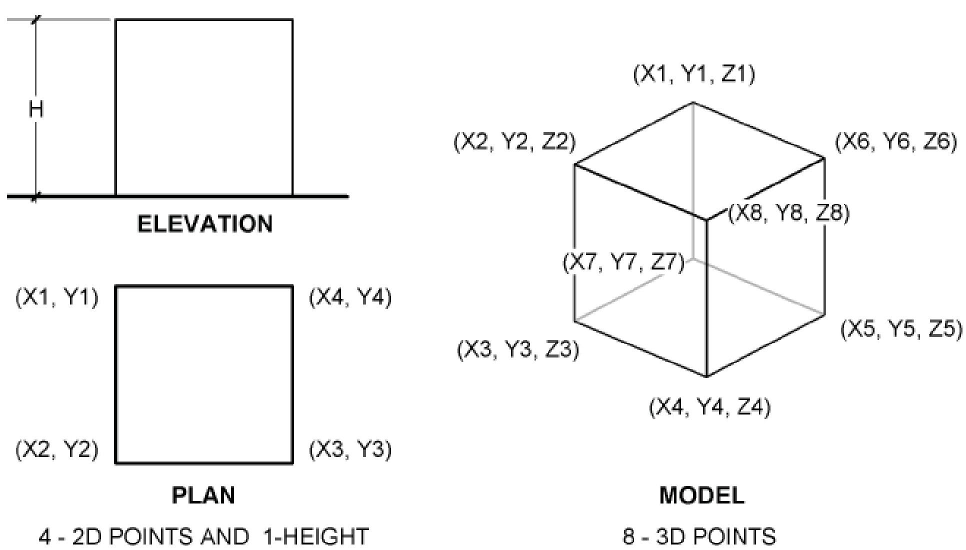


Figure 1: Data required to define shape.

The conventional form uses four two-dimensional points and a height.
The model-based form uses eight three-dimensional points.

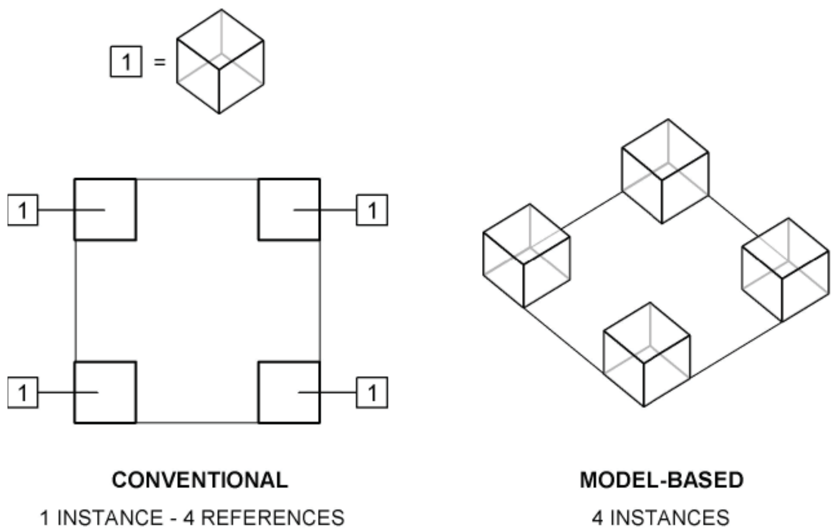


Figure 2: Data required for multiple occurrences of a shape.

The conventional form uses one instance and four references to that instance.
The model-based form uses four instances.

What the previous two figures illustrate is that, given a linear relationship between the number of objects in a project and the amount of information required to represent them with conventional means, a model based representation will increase that requirement by a significant factor. This is expressed in the following *Principle 4*:

Principle 4:

The quantity of information in a model-based representation of a project is greater than that of a conventional representation by a factor of the number of building elements.

Where,

$\mathbf{N}_{\mathbf{ELEMENTS}}$ = the *number* of building elements and

$\mathbf{A}_{\mathbf{CONVENTIONAL}}$ = the *amount* of information in a conventional representation,

$\mathbf{A}_{\mathbf{MODEL\text{-}BASED}}$ = the *amount* of information in a model-based representation

$\mathbf{k}$ = a factor > 1,

then:

$$\mathbf{A}_{\mathbf{CONVENTIONAL}} \ \alpha \ \mathbf{N}_{\mathbf{ELEMENTS}}$$
$$\mathbf{A}_{\mathbf{MODEL\text{-}BASED}} \ \alpha \ \mathbf{k} \times \mathbf{N}_{\mathbf{ELEMENTS}}$$

and therefore:

$$\mathbf{A}_{\mathbf{MODEL\text{-}BASED}} \ \alpha \ \mathbf{k} \times \mathbf{A}_{\mathbf{CONVENTIONAL}}$$

or,

$$\mathbf{A}_{\mathbf{MODEL\text{-}BASED}} > \mathbf{A}_{\mathbf{CONVENTIONAL}}$$

Of course, having an estimate for **k** would be very useful. No basis for one is included in the current discussion, but from an informal examination of file sizes and the work experience of project teams it is conjectured that **k** is at least 2 and possibly much more.

5.0 IMPACT ON BIM IMPLEMENTATION

Combining Principles 3 and 4

$$\mathbf{V}_{\mathbf{BIM}} \ \alpha \ \mathbf{C}_{\mathbf{ASSETS}} / \mathbf{A}_{\mathbf{INFORMATION}}$$
$$\mathbf{A}_{\mathbf{MODEL\text{-}BASED}} > \mathbf{A}_{\mathbf{CONVENTIONAL}}$$

and recalling that,

$\mathbf{V}_{\mathbf{BIM}}$ = the ultimate *value* to a project of a BIM process

a similar value expression for conventional representation could be defined as,

$\mathbf{V}_{\mathbf{CONVENTIONAL}}$ = the ultimate *value* to a project of a conventional process,

leading to a conclusion that:

$$\mathbf{V}_{\mathbf{BIM}} < \mathbf{V}_{\mathbf{CONVENTIONAL}}$$

In other words, that there is an inherent problem with model-based representations like BIM in that, for a given asset cost, the value return from BIM is less than that of a conventional process. This derivation is a formal way of stating a concern, sometimes voiced by designers that are not working in an IPD context, that BIM projects are less profitable than conventional ones. We do see examples of this effect when BIM is introduced into a design office that has been using conventional methods of design representation. A typical experience is something like:

- BIM is adopted as a way of reducing the amount of time required to document a project for the purpose of improving profitability.
- However, the initial BIM projects take longer to complete, resulting in lost profits. Although this is initially attributed to the cost of switching to BIM, the so-called "learning curve", the problem does not completely go away with subsequent projects.
- This results in a debate about the merits of a model-based approach. The proponents of BIM argue that the real problem is that the BIM information is not being properly leveraged to improve productivity during construction, through reduced changes, more advanced construction process and other advantages.
- Critics argue that this is not a valid comparison since recouping value during construction is not the primary goal of the BIM author. The general advancement of the firm's capabilities and those of the AECOO industry as a whole, while laudable, do not contribute to the design office's profitability.

This debate illustrates the mathematical derivation regarding the inherent difficulty with achieving value from BIM. However, the mathematical expression is not useful as a principle because we are not interested in holding the contributing factors as constants. On the contrary, for a number of reasons (outside of the scope of this discussion) there are compelling arguments that BIM should and will become the exclusive means of representing projects in our industry. The purpose of the current analysis is to understand how the factors that contribute to value can be manipulated in order to ensure that model-based BIM provides better value than conventional methods.

Principle 3 suggests two basic strategies for increasing $\mathbf{V}_{\mathrm{BIM}}$:

- Reducing $\mathbf{C}_{\mathrm{INFORMATION}}$ by reducing $\mathbf{A}_{\mathrm{INFORMATION}}$
- Increasing the leveraged impact of $\mathbf{C}_{\mathrm{ASSETS}}$

A number of possible means for achieving these are possible, three of which are developed in the following sections.

5.1 Lowering Information Costs Through the Use of Conventional Methods

Successful BIM projects make good use of conventional documentation techniques. Conversely, projects that attempt to represent every design decision in their models tend to require additional work to complete.

While some conventional representation occurs in all BIM projects, the ideal proportion of it and the specific kinds of decisions that it should be used to represent, are not obvious. A benefit of this information cost-value analysis is that it provides guidance on how the distinction should be made.

For example, a small reveal in the exterior skin of a building represents a relatively small construction and maintenance cost, but a large amount of information is required to represent it in a model. For these reasons, reveals are usually better not modeled, but represented as an abstraction (typically a three-dimensional model line or a two dimensional drafting line) and defined completely as drafted elements in details.

On the other hand, major building elements such as wall, floors and structure represent significant costs and are relatively easy to model. These elements are typically developed early in the BIM and maintained through the duration of the project.

Similarly, minor elements such as fixtures and furniture are often represented as plan symbols since they do not represent a lot of value and are difficult to model while significant equipment and systems such as those in hospitals and laboratories are increasingly being modeled because of their relative cost significance.

There are some subtle factors that may affect this balance. For example, if a client or user group needs to see a three-dimensional representation of the furniture in order to make decisions, then it becomes worthwhile to model the furniture in some detail. In terms of the information analysis, what this really represents is an increase in the cost of the furniture; the manufacturer's price may not have changed, but the cost of delivering it has. This can be expressed in the context of principle 3 as:

$$\mathbf{C}_{\mathrm{ASSETS-SIMPLE\ PURCHASE}} < \mathbf{C}_{\mathrm{ASSETS-THREE\text{-}DIMENSIONAL\ REVIEW}}$$

and therefore,

$$\text{if } \mathbf{A}_{\mathrm{INFORMATION}} = \text{fixed amount}$$

$$\mathbf{V}_{\mathrm{BIM-SIMPLE\ PURCHASE}} < \mathbf{V}_{\mathrm{BIM-THREE\text{-}DIMENSIONAL\ REVIEW}}$$

Some of the underlying factors may change over time as well. For example, engineers often prefer to represent structural, mechanical and other systems as abstractions (such as a single, two-dimensional line) while the design is evolving. The builder, who is concerned with constructability, may want to represent the same design decisions in a model. Again, in terms of information analysis, this really represents a change in the asset cost. The distinction is subtle since the asset does not appear to have changed, but it is there: the builder has to pay real money for materials and installation whereas the engineers have only invested in their means of service (i.e., they might need to revise the documents). This idea is developed further in the following section on BIM Execution Planning.

Although this strategy is often viewed as regressive in terms of moving forward with BIM, it is an important component of a firm's business strategy for adopting BIM. We should not try to "prove our BIM prowess" by asking project teams to create complex, multi-purpose models that overextend the team's capacity. Truly capable BIM practitioners are willing to represent themselves as also using conventional practice.

5.2 Lowering Information Costs through Design Automation

Nevertheless, as the industry shifts towards a greater proportion of model-based representation, the focus is on how to reduce the information cost of representing decisions. This strategy is initially useful because it can improve project profitability within the context of a conventional contract without depending on the benefits of some form of IPD.

The goal is to reduce the effect of Principle 1, namely to reduce the unit cost of creating information. This has two components: reducing the amount of information and reducing the cost of creating and maintaining a given amount of it.

Reducing the amount of information that must be managed is not the same as reducing the complexity or usefulness of the results. For example, a model-based representation of a wall created with primitive elements (lines and planes) requires a lot of information compared to a conventional plan representation. However, a wall created in a parametric BIM authoring tool may only require a start and an end point. The parametric version requires significantly less information to author even though its meaning, in terms of what will be constructed, is the same. (This is assuming that the wall is properly defined and does not include additional, low-value collateral information).

Reducing the cost of creating information is achieved through smart working methods that achieve a given amount of information more easily. For example, if a library of parametric walls is pre-defined, then walls can be created more easily than if the design team had to create them from scratch. Even the work of subsequent users necessary to ensure that they remain valid is reduced if they can refer back to the library for validation of the intrinsic decisions.

In general terms, these kinds of strategies are examples of *automation*. Although they are sometimes expressed in terms of "standardization", the benefit does not come from conformity, but from some processes that leverage consistency. In the examples, creating a wall with parametric commands is a direct example of automation as provided by computer programming; having the walls predefined is an indirect kind of automation in that it supports the use of the direct application. Even basic conventions, such as a standard sheet layout, are really components in a "soft" automation that is not implemented with computer commands. In other words, *standards* are really the *specifications* of an automated process, which may or may not (yet) be implemented as a parametric computer-based process.

5.3 Leveraging Information Value during Construction and Occupancy

The previous examples notwithstanding, it is ultimately a more successful business strategy to increase value than to reduce cost. The most significant gains will come from outside the scope of traditional services provided by architectural and engineering design firms. This includes both actual construction as well as the design that has traditionally been done by contractors and sub-contractors. For this reason, this strategy of increasing the information value of BIM, more than the previous options, must occur within a true IPD, a less explicit "IPD-ish" arrangement, a design-build agreement or a similar context where information is shared freely. There are several ways this can occur:

- Additional design usage of the BIM model: The fact that the BIM model exists may give rise to uses that were not planned when it was conceived. For example, an owner may use it for marketing purposes; or a building operator may use it to manage user expectations and plan moves. In many cases, these additional uses leverage counts and other non-graphic data that was not essential to the initial purpose of the BIM, but are a useful byproduct.

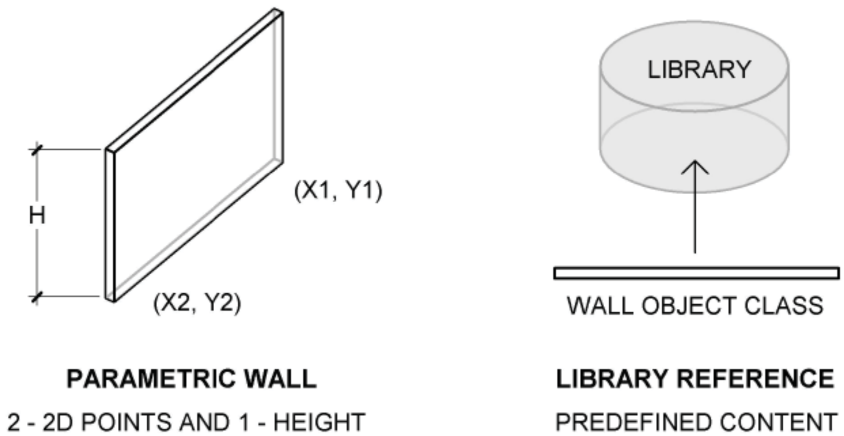


Figure 3: Use of automation to reduce the amount of information.

The parametric wall is defined with only two two-dimensional points.
A pre-defined library reduces the information required to define the parametric behavior.

- Savings during construction: Planning the *construction*, as distinguished from the *intent of the design*, can benefit from *virtual construction*, i.e. using BIM methodologies to simulate construction in advance of the actual construction. This has the potential to expose problems, reduce purchasing costs and enable more efficient planning and onsite construction processes.
- Support for computer-aided facility management (CAFM): Although a BIM model that was created for design and construction purposes is not directly usable for facility management purposes, there is potential that it could inform a CAFM system. It is also likely that building owners and operators will become more BIM capable and use models that are more appropriate to their needs.

In information terms, these additional uses really reflect hidden costs in the ultimate project. In the examples, the marketing and move-management costs were always there even if they were not initially associated with the BIM effort. Likewise the builder needs to manage constructability with or without a BIM and CAFM systems always require good information. The significance of analyzing these uses in terms of the cost-value of information is that articulating these relationships clarifies how the additional information costs of the BIM should be recouped from value identified in the marketing, moving, building and CAFM budgets.

This information analysis also defines more clearly where BIM strategies will achieve easier successes. Certainly they will be more applicable to high-cost, information-rich projects such as hospitals and laboratories, as differentiated from more generic projects like commercial office buildings and tenant improvement. In fact, empirical experience has shown that the former lead in the adoption of BIM while the latter are moving more slowly.

6.0 INFORMATION OVER TIME

Up to this point, the analysis has looked at the quantities of information and value as being static rather than its tendency to degrade over time. However, in actual projects especially as it is used by a wider team, information has different meanings at different times. This section looks at some of the implications in general terms. These are potential topics for a more detailed, mathematical analysis of the related costs and values.
For example, high-value information that is not yet needed is not very useful and relatively expensive to maintain. Likewise, missing information can have a high cost relative to its inherent information content. What is true may change with time as well. For example, accurate and detailed information about an out-of-date building code will suddenly change from high-value to low-value. This is especially an issue in fast-changing business, such as healthcare, where equipment requirements may change significantly between design and occupancy. Better ways of expressing this time component would be useful in determining what is important.

6.1 BIM Execution Planning

The phases of *design, building* and *operation* are becoming less distinct as the industry becomes more integrated in how project teams collaborate and as information management tools like BIM enable more non-linear processes. Nevertheless, from a business perspective the *designers, builders, owner* and *operators* still represent distinct groups with differing informational needs.

To address these, BIM project management increasingly includes the development of a *BIM Execution Plan* that defines the roles and responsibilities of the participants and schedules the major tasks. Typically, such a plan includes a *Level of Detail Matrix* that[8,9,10,11]:

- Cross references classes of built elements with the team members responsible for modeling those elements and tracks how these assignments change over the major phases of the project.
- Specifies for each phase, a "detail level" of the model typically expressed as "100", "200", … "500" or a similar measure.

This matrix is important to the BIM authors in planning their work, but it is more important to the project in terms of the underlying decisions that model evolution represents. In this sense, the term "Level of Detail" is misleading in that it implies that the components appear early in the project as very coarse objects, that are then replaced with more refined ones over time. While that may be true in a few cases, in actual practice model elements are typically missing entirely until a stage where they are represented by relatively detailed objects. In the early phases these may be unfinished constituting:

- Placeholders: Relatively detailed objects that do not necessarily represent the actual built element. For example, even an early-design BIM will likely include openings, furniture, equipment and other objects drawn from the same library that will ultimately be used to prepare construction documents.
- Estimates: Conservative boundaries that ensure space, budget and adjacency for something that will be designed in the future. For example, oversized structural steel members are estimated until the design has stabilized to the point where they can be engineered.

In other words, while the BIM may not be getting visibly more detailed, the underlying decisions that it represents are getting made. For this reason the term *Level of Completeness* is used in this examination of information content. Completeness, in this context, really expresses positions on the scale of low-value to high-value information defined earlier and suggests some principles for BIM planning:

- Completion derives from high-value information; low value information does not contribute, yet has a cost. For this reason the placeholder BIM element is not an ideal strategy because it introduces a lot of low-value information.
- The objective of BIM planning should be to defer completeness (where it does not affect other decisions) in order to reduce costs due to the quantity of information. This is contrary to a common assumption that "earlier is better"; asking construction subcontractors to waste time in conceptual design meetings, for example.

It would be very useful if the software industry were to provide BIM tools that are better at expressing these kinds of tentative decisions, but they currently do not. Project teams sometimes approximate an expression by making elements a particular color, transparent or some other graphic means, but this is not common practice.

6.2 Life-Cycle Information Management

Each stakeholder typically holds information in their own store and in a different form making information analysis most significant at the interfaces between them. This yields some useful guidelines for the team's objectives.

There has been extensive discussion in the industry about how much information is lost during these transitions with the inference that there is a lot of value to be captured by reducing this loss. For example, the National Institute of Standards and Technology (NIST) study *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*[12] and the subsequent response from the Construction Users Roundtable (CURT) *Collaboration, Integrated Information and the Project Lifecycle in Building Design, Construction and Operation*[13] attributes $-billions of waste to the lack of information interoperability at these points.

Much of the current thinking about IPD envisions an increasing number of smaller exchanges replacing the larger packages that have characterized the industry. In this vision, phases can be essentially eliminated in favor of a continuous flow of information that is timely and appropriate to the current need. However, while the current information loss is very real and the potential benefits of more integrated information management strategies are promising, these changes have not come easily to the industry. In many instances the rewards have been elusive and this is the source of some current frustration with BIM.

The reason for the difficulty can be understood in information terms by examining the low-to-high measure of information value. What conventional practice achieved in the hand-offs between phases was a significant reduction in low-value information. This did not represent a loss. In fact, it reduced the cost of the information. The historical importance of professionalism in disciplines like architecture and engineering came from their taking responsibility for the quality of the information they delivered. Great care was taken not to transfer information that was even potentially inaccurate.

The transition to BIM and the expectation that BIM models will be shared has disrupted this principle. The problem is often expressed as a concern about "liability", but the legal implications are not the issue in this analysis. Even if we assume a very close, completely indemnified relationship, it is still not good professionalism to deliver low-value information. The more fundamental problem is that information of uncertain quality must be assumed to have low value entailing a cost to be certified as high-value even if the information itself does not change. For example, an architectural model that shows the location of a pipe has no value to an owner unless the builder has actually verified its as-built location in an auditable way.

Certainly the industry direction is not to restrict sharing rather it will be to distinguish more clearly the quality of the information. Unfortunately, there is not yet an obviously good way of doing this. Today BIM models are typically delivered to other parties accompanied by a disclaimer that states, that the model is of uncertain accuracy and should be used entirely at the recipient's own risk. This seemingly legalistic tactic actually expresses a profound information fact: that the information value of the model is much lower to the recipient than it is to the author.

Unfortunately, this is sometimes discussed as if it were a defect in the source model. In fact, the BIM authors have very little knowledge about the downstream needs and even less motivation to service them. As a result, it has been common practice to essentially rebuild the model during the transition from the design team to the building team. This should not be surprising or discouraging. The cost of creating a BIM model from scratch is not very high. The true cost is the decisions that it represents. The process of rebuilding the model is not necessarily a wasteful exercise, but a relatively straightforward way of extracting high-value and eliminating low-value information.

This devaluation of the information value is not entirely a characteristic of the information itself, but a reflection of the social context of who authored it and how much it can be trusted as a result. One of the effects of a more integrated project structure is to raise that level of trust. This has the effect of reclassifying low-value information as high-value even though the information has not changed. It is hoped that these emerging improvements, based on better interpersonal relationships, will enable better use of a BIM model without trying to force fit it from its intended use to an inappropriate one.

7.0 CONCLUSION

This analysis demonstrates that the general principles of information theory are applicable to BIM. Further development of this approach will enhance the conversation about BIM and IPD and can improve project outcomes.

Some basic principles of information have been defined:

- Information has an inherent cost, which is proportional to the quantity of information and subject to a process of entropy.
- The value of information is a function of its quality, which is defined in terms of its usefulness in making decisions.
- Although model-based documentation has inherently more information, this does not necessarily result in more cost if automation and other strategies are used to produce it more efficiently and its value is leveraged over additional uses.

This approach helps to explain some problems with BIM adoption by exposing misunderstandings and unrealistic expectations, such as the failure to understand that:

- All information is not of equal value and may even be detrimental. Simply having more information is not necessarily useful.
- Applying information to lower-value decisions is inherently inefficient and will eventually lead to perceived failure in the BIM process.
- Life-cycle information management should not involve the indiscriminate accumulation of information and redoing BIM work may be an effective strategy for distinguishing high value from low-value information.

This kind of analysis can also provide useful guidance to project teams, including:

- Defining the proper balance between drafting and modeling.
- Strategies for BIM planning that maximize the efficient use of information and avoid wasteful maintenance of low-value information.

REFERENCES

[1] Engelbart, D., (1962). Augmenting Human Intellect: A Conceptual Framework, Summary Report AFOSR-3223, Menlo Park, CA: Stanford Research Institute.

[2] Gliek, J., (2011). *The Information*, New York, NY: Pantheon.

[3] Eastman, C., Teicholz, P., Sacks, R., and Liston, K. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, Hobeken, NJ: John Wiley & Sons.

[4] Jernigan, F., (2007). *Big BIM little bim*, Salisbury, MD: 4Site Press.

[5] NBIMS, (2007). National BIM Standard – United States, Version 1, Part 1, Washington, D.C.: National Institute of Building Sciences.

[6] AIA National and AIA California Council, (2007). Integrated Project Delivery: A Guide, Washington, D.C.: American Institute of Architects.

[7] DIKW, Wikepedia: http://en.wikipedia.org/wiki/DIKW.

[8] AIA, AIA Document E202 - 2008, Building Information Modeling Protocol Exhibit, Washington, D.C.: American Institute of Architects.

[9] Computer Integrated Construction Research Program, (2009). BIM Project Execution Planning Guide – Version 1.0, University Park, PA: Pennsylvania State University.

[10] Autodesk, (2010). Autodesk BIM Deployment Plan, San Rafael, CA: Autodesk, Inc.

[11] VA Office of Construction and Facilities Management, (2010). The VA BIM Guide, Washington, D.C.: Department of Veterans Affairs.

[12] Gallaher, M., O'Connor, A., Dettbarn, J., and Gilday, L., (2004). Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry, Report, Gaithersburg, MD: National Institute of Standards and Technology.

[13] Architectural/Engineering Productivity Committee, (2004). Collaboration, Integrated Information and the Project Lifecycle in Building Design, Construction and Operation, Report, Cincinnati, OH: Construction Users Roundtable.