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Barriers to the Adoption of Building Information Modeling in the Building Industry

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Abstract

The productivity and economic benefits of building information modeling (BIM) to the global building industry are widely acknowledged and increasingly well understood. Further, the technology to implement BIM is readily available and rapidly maturing. Yet despite the obvious benefits and readiness of BIM software, BIM adoption has been slower than anticipated. Why?

Fragmentation and calcified processes inhibit widespread change in the building industry. Digital technology, and particularly the integrative use of BIM during the building lifecycle, can catalyze change as the industry moves towards new approaches. However, technology alone is insufficient.

This paper suggests that the barriers to wider adoption of BIM in the building industry extend well beyond the oft-cited relationships between software applications. Data interoperability between applications is frequently heralded as the prescription to many building industry ills and we agree that lack of interoperability is one significant point of friction. However, interoperability is neither the singular nor most important factor impeding BIM adoption and the general use of digital tools in design and construction. Here we posit three interrelated barriers to BIM adoption:

(1) The need for well-defined ***transactional business process models***;

(2) the requirement that digital design data be ***computable***; and, finally,

(3) the need for well-developed practical strategies for the purposeful ***exchange of meaningful information*** between the many tools applied to industry processes today.

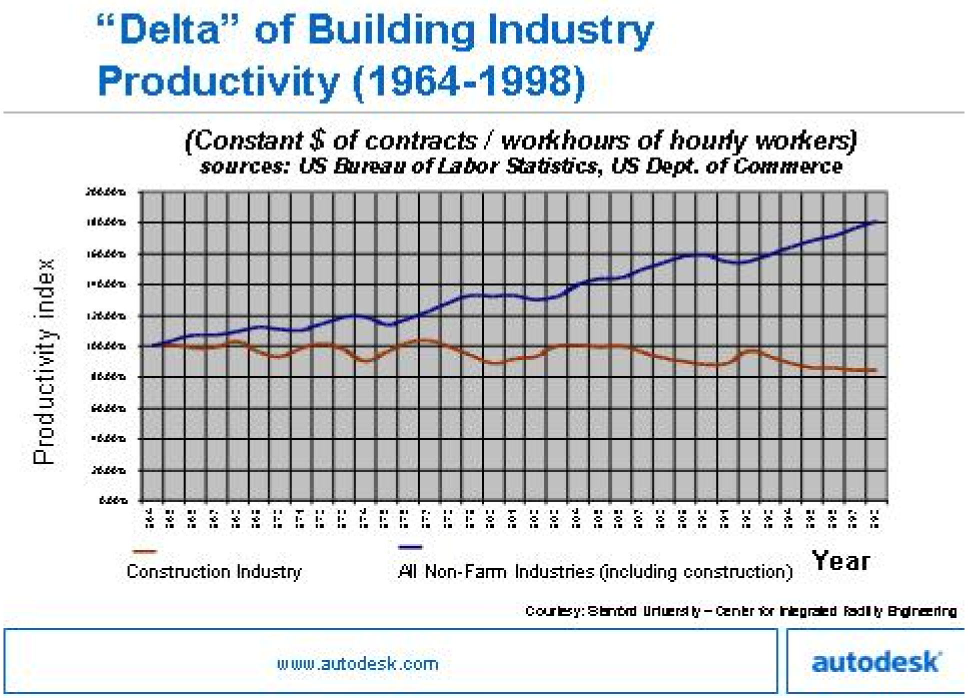
We conclude with suggestions for how the industry will be influenced to adopt building information modeling.

BARRIERS TO THE ADOPTION OF BUILDING INFORMATION MODELING IN THE BUILDING INDUSTRY

Table of Contents

Background

The building industry is a well-known latecomer to the productivity advantages offered by technology. Manufacturing, agriculture, and finance, like most modern enterprises, have embraced information technology for competitive gain, efficiency, and new approaches. The construction enterprise has yet to fully realize similar benefits, and the results are discouraging. The diagram below, from Stanford University's Center for Integrated Facility Engineering (CIFE) illustrates the productivity of U.S. construction relative to all non-farm industries over a period of thirty-four years. Productivity in all other industries has almost doubled in the period while construction productivity has declined slightly. Thus, construction has not only lagged other sectors of the U.S. economy in productivity, it has deteriorated over a thirty-four year period. Although the data presented is for the United States, we believe a similar analysis of construction productivity on a global basis would show similar trends.



A typical building project today, produced in silos of design, fabrication, construction, and operation, consumes vast resources with extraordinary inefficiency.[1] Investment in technology in the worldwide building economy lags the similarly sized manufacturing industry by almost six-fold.[2] The diagram above vividly illustrates the results and their consequences for growth in the construction industry. Facing global competitive pressures on every front, automobile, airplane, electronics, and consumer goods manufacturers turned long ago to model-based digital design processes based on data that supported engineering analysis, bill-of-material generation, cost modeling, production planning, supply-chain integration, and eventually computer-driven fabrication on the factory floor. As globalization and economic integration increases, the construction industry will soon be faced with similar competitive pressures.[3]

These lessons from manufacturing are gaining currency with today's architects, engineers and contractors, but very slowly.[4] Unlike the integrated supply chain of the manufacturing industry —a continuous team of designers, suppliers, fabricators and distributors (think of the array of companies that seamlessly work together to bring you your automobile)—building project teams rarely work together more than once. Their efforts are focused on the realization of a single, unique product: a building that will only be produced once.[5] And most

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[1] For further info, see www.m4i.org
[2] These computations were based on 2000 data.
[3] Early indications of trends toward globalization include recent increases in the number U.S. architectural and engineering firms sending construction document drafting offshore, as well as the steel and cement pricing crises precipitated by the Chinese construction boom of 2004.
[4] Stephen Kiernan and James Timberlake, in their book Refabricating Architecture, describe some of these lessons and their application.
[5] Buildings are often constructed with a high (and increasing) percentage of manufactured components. Further, some studies show that up to 75% of the "content" going into a typical building design is identical, according to research done by the Movement for Innovation (www.m4i.org). While each

methods of building project delivery are optimized for least cost and least exposure to each player in the process, to the detriment of the overall result. Legal, insurance, and financial systems have reinforced this focus on least cost and exposure and calcified inefficient delivery practices. Ultimately, building owners bear the brunt of these inefficiencies as the party most impacted by construction errors, broken schedules, and budgets, as well as high long-term operational and maintenance costs.

The use of digital tools within the building process has been focused on discrete, disjoint, and unrelated tasks such as drawing generation, visualization, cost estimating, or construction administration bookkeeping.[6] "Episodic implementation" of this array of tools is a result of the disconnected nature of the design-to-build process, and its traditional reliance on paper-based data transactions. While discrete analog elements of this process are being replaced by digital data exchange—accelerated by the ever-increasing speed of desktop processors, networks, and the Internet—there are few protocols that establish the inherent relationship of digital information between adjacent processes in the industry. The array and deployment of digital tools is thus considered to be fragmentary, and users demand tighter connections, generally under the rubric of "seamless data interoperability."

To remedy poor productivity and anemic growth, the building industry must address the underlying issues described above. The solutions are not purely technical problems that will be achieved by a broad consensus among software vendors (like the employer of the authors), imposition by standards making bodies, or use of a single set of tools to support design/build/operate. The desire for deeply interoperable tools with completely exchangeable data is a consequence of more important issues that are precedent to achieving good interoperability. In fact the technical hurdles to achieving these process relationships are far lower than the related business process integration goals.

Three Barriers to Building Information Modeling

The three barriers to BIM adoption that we posit must be addressed directly and in balance are transactional business process evolution, computability of digital design information, and meaningful data interoperability. Solving the challenge to one barrier alone will not accelerate BIM adoption. The following analysis addresses each such barrier, in order of priority, and suggests paths to resolution.

1. Transactional Business Process Evolution

The array of technologies available to today's designer or constructor creates process possibilities that far exceed norms of practice and well-understood business protocols. Not unlike today's doctors, whose tools create circumstances that exceed ethical definitions of care, few players in today's partially digital design-to-build process are on sure footing. Consider the following examples:

> **Digital backgrounds**
>
> During the contract negotiation between a design architect and an architect of record on a large project, the architect of record insists that her fee structure (and profit) depend entirely on receiving coordinated digital schematic and design development background files from the design firm, which will be used as backgrounds for the construction and permitting documents.

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building is unique, the underlying components, design methodologies, and construction processes are often replicated from project to project.

6 Tools such as AutoCAD®, Autodesk® VIZ, Microsoft® Excel, or Primavera® Expedition are typical examples.

Discipline coordination

The mechanical engineer on a small office building project receives DWG-based backgrounds from the architect for his construction documents. Finding insufficient headroom on the lobby level for air distribution, he increases the floor-to-floor height between Floors 1 and 2 on the architectural backgrounds, failing to notify the architect that this was required. During construction, the successful MEP sub-contractor submits a change order citing increased costs of coordinating vertical ducts runs sized on the erroneous sections that do not connect between architectural and MEP drawing sets.

Digital basis for shop drawings

After award of the construction contract during a hard-bid “design-bid-build” project, the structural engineer receives an RFI from the steel fabricator requesting digital structural drawings. After she refuses to submit the drawings, citing lack of payment and any liability protection, she receives a demand letter from the project owner accusing her of “being uncooperative” and insisting that she transmit “all of the drawings immediately without further delay to the project.”

Design delegation and fabrication

In order to construct a complex curtainwall that will enclose the lobby of a project, the architect provides his digital construction documents, including extensive 3D data that was used to create the resulting documents (not represented in the permit set), to the fabricator, who, after engineering verification of the performance specification provided by the design team and shop drawings, proceeds to fabrication and installation. The curtainwall is completed at 75% of the original target budget. Immediately after occupancy a strong wind storm destroys a large portion of the wall, and several people are injured.

Digital record drawings

At the conclusion of construction, and in accordance with the Owner-Architect agreement, the owner receives copies of the architect’s conformed, digital record drawings and incorporates them into his campus-wide facilities management system. Years later during the bidding of a routine maintenance construction project (and before the expiration of the statute of limitations) a serious dimensional error is discovered resulting in a large cost overrun on the maintenance project. The owner files an E&O claim against the architect.

These imaginary examples begin to describe the uncharted territory that lies ahead for the building industry. In the near future, we will have to answer the following:

- What is the relationship between design intent represented in preliminary design and the responsibility for signing and sealing the final design “documents”? Will the “signed and sealed” documents of today be replaced by their digital equivalents at the building department?
- What is the design team’s additional obligation for coordination when integrated information—such as a set of construction documents—becomes fluid and malleable as a natural result of design document production?
- What is the definition of AE instruments of service as digital expectations rise? How do designers reach a professional standard when that standard is defined by analog-based processes historically memorialized on paper? When designers are traditionally compensated (and insured) for

"rendering professional judgment" how is value assigned to (and payment received for) data, and for how long?

- When design and fabrication data are inextricably intertwined, how are the duties and responsibilities of the parties allocated? The risks and associated rewards?
- What is the predicted lifespan of digital design information? How are its downstream uses anticipated, and how are its creators compensated? Are there parallels in the ongoing responsibility for building performance and the underlying data that created the design?

In each of the examples, BIM would ease the flow of information and connect processes, but not solve the business challenges. The inherent integration of design data in a model-based design-to-build process eliminates numerous potential conflicts, but addresses none of the underlying lack of basic business process integration. Without such integration, the processes themselves (and therefore the supporting tools and their data) will fail to properly mature; they lack clearly delineated work flow and data interactions.[7] Ironically, paper-based protocols provided clear lines of business process that are now blurred by fluid digital information.

Each relationship in the building supply chain is defined by a set of obligations, risks, and rewards. Before the digital future can be fully realized and true process integration (including interoperability) achieved, these basic business terms must be defined across the enterprise:

Obligations

What tasks will each participant perform? What deliverables are required to achieve those tasks? What information must be generated and specifically exchanged in order to meet these responsibilities?[8] Defining the specific data exchanges will both circumscribe responsibilities and reduce the enormous task of allowing all participants in the design to "interoperate" with all the data.

Risks

As data relationships are established, the discrete boundaries of responsibility are also going to blur, and this will require new ways to allocate risk. When the originator of a given piece of design information can not be definitively determined, how is risk assigned? A more pointed question might be, how is it fairly shared? Should design decisions be tracked to their precise originators in order to assign risk, or does an "open information project"[9] imply equally shared responsibility?

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[7] The most successful software applications both support and augment well-defined work processes and deliverables. Better definitions of both will accelerate correct development by vendors of these solutions. The recent efforts of the AIA's Large Firm Roundtable CIO Group to create such definitions are a good example of such an approach.

[8] A key characteristic of the definition of obligations includes defining the excerpted data that one information author owes another user of design data. Each process does not require the complete subset of all information created by every other process. For example, the electrical engineer, when designing the emergency lighting system, need not know the color or type of the carpets within the same room.

[9] "Open information project" is a term originated by Carl Galiota, FAIA, the technical leader for SOM's Freedom Tower project. He uses it to describe an approach to data integration where all design information produced on the project—irrespective of origin—is depicted in the building information model that is the central design document.

Rewards

With shared risks, shared rewards must follow. If a BIM-based construction process is inherently more efficient and productive, the incentives for integrating data and risk must be driven by compensation. Some of the savings realized by the owner must be spent during design and construction to achieve the more cost-effective end. Eventually, market forces will establish new baselines of compensation, and likely new models for payment.[10] Until then, how are digital deliverables to be valued as instruments of service that persist through the building's lifecycle? Rewards are, in our view, the primary driver in the adoption of any technology; effectiveness, in and of itself, does not drive business behavior.

Each of these key business issues, defined in parallel, must be connected to the proposition of BIM before widespread adoption will occur.

Early adopters of BIM approaches suggest how some, but not all, of the questions posed above will be answered. Model-based technologies today are frequently deployed in projects that are highly collaborative, and where the design team has agreed to fully integrate information from all sources during design including the constructor who is frequently at the table at the onset of the project. In such situations, risk is by definition distributed across the entire design team.[11] And that team frequently includes the Owner, who joins the fray by using the model as a design decision-making tool. As the value of such approaches becomes apparent by more coordinated design and projects constructed on schedule and below budget, designers who offer BIM-based design strategies will command larger fees and commensurate risk distribution in their contracts.

2. Computability of Digital Design Information

Digital design data exist in a variety of forms, many of which are not computable. At first glance, this seems like a nonsensical statement. How can data be both digital and non-computable? If data is digital, is it not by definition "computable"? The answer is yes and no. A computer can operate on any digital data – but the kind of computations the computer can do depend upon the semantic information expressed by that data.

Consider building a financial model as an illuminating example. One could create the financial model using a word processor, incorporating its table functions. This would involve creating tabular entries for all of the financial items – neatly aligning rows and columns. However, most word processing applications do not do computations within tables, requiring the author to do all of the calculations manually. If a number is changed, all affected cells would need to be manually recalculated and their new values re-entered in the table. This would be an extremely laborious and error-prone approach.

In contrast, one could create the financial model using a spreadsheet. The spreadsheet version might look identical to the word processor version, but the spreadsheet model contains numerical values, relationships, and sophisticated calculations. A changed value creates automatically recomputed results. Iterations are easy, and desirable. The spreadsheet maintains the integrity of the model and the relationships contained therein. While both the word processor table and the spreadsheet model have similar presentations,

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[10] For example, traditional fixed fee arrangements, where all players in the construction process are driven by considerations of least cost, might be replaced with performance-based compensation from baseline objectives. In Australia, the Project Alliance delivery method uses this, amongst other methods, to change behavior.

[11] For example, SOM's Freedom Tower project is characterized by both a Revit®-based BIM design process and as an "open information project" by the designers involved.

there is a fundamental difference between the two. The spreadsheet model is computable whereas the word processor representation is not, even though both are digital data.

The building industry, for the most part, has adopted the word processor approach to documenting building designs over the past 20 years. Computer-aided design (CAD) tools have been primarily used to create electronic drawings of buildings. In these drawings, buildings are depicted by abstract graphical representations such as lines, arcs, circles, and polygons. These representations are meaningful when read by humans, but contain little information that can be used for purposes other than plotting a drawing.[12] Even the 3D models some have used for visualization purposes are little more than three-dimensional drawings. In most of these applications the computer has no implicit knowledge of building elements such as doors, walls, windows, roofs, HVAC equipment, furnishings, and columns. These are represented by graphical elements that, at best, are tagged with a label indicating their type. Further, complex systems such as structural grids, HVAC networks, and plumbing, are represented by graphical elements and their fundamental relationships, topology, and functions are unknown to the computer. Design information that flows through the building process for most buildings today is documented using pictorial data, not computable information.

The historical reasons for this situation are partially technological. Early computer applications that mimicked the drafting process were enormously successful in improving productivity for architects and engineers. Sophisticated building information modeling systems – the building industry's version of the spreadsheet – were rare. However, now technology is no longer the issue. Sophisticated building information modeling systems are available, but their adoption has been slow. Why?

One easy explanation is simply inertia and resistance to changing process, but we believe there is a more fundamental issue – designers and decision-makers do not fully grasp this notion of computable data and the limitations of the data created by their present systems and approaches.[13]

The state of practice in most firms is to create pictorial, non-computable data. However, the presumption is that the data is computable. It is quite common to attempt to use design data for analysis, cost estimating, or even visualization and find that the data – although it looks computable, is actually a collection of pictorial elements. For the most part, humans look at the data, interpret it, and transfer it to new applications for additional analysis. This process is both wasteful and error prone.[14]

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[12] While it may be technically possible to imbue such graphical information with computable characteristics (such as calculating area from the geometry of an enclosure) the graphics themselves carry no inferable information and are thus not computable.

[13] One of the authors recalls a meeting with a large retail client 20 years ago. Our firm was designing a new headquarters for the client and a senior executive met with us to describe his vision for use of computer-aided design in the new building. He spoke of moving people, furniture, and equipment around his building and having the databases automatically update. He told us of his plans for retail stores in which we could move displays in the computer and have inventory databases update automatically. The retailers own IT staff was present and they kept giving us sidelong glances. They understood that we were producing pictures that lacked the computable information that was necessary to implement the executive's vision.

[14] The U.S. National Institute of Standards and Technology (NIST) recently published a report titled Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry. This report rigorously identifies $15.8B in waste in the U.S. building industry". The symptoms identified in the report are absolutely correct. It is a useful contribution to understanding where waste and inefficiency occur in the US building industry. However, the report attributes all of this waste and inefficiency to

This phenomenon is not unique to the building industry. For all of its documented productivity gains, only about 10% of the manufacturing industry has moved from pictorial to computable models of products. In manufacturing, computable product models are used for structural and thermal analysis, machining, and resource planning. However, the benefits of these uses are only realized in a minority of firms. In our industry the number is far less – we estimate only 2-3% of practitioners really understand this issue and have embraced BIM as a path to computable design information. Further, this issue is precisely the issue facing developers of the world wide web. While much of the information on the web presently is representational in nature, there is now a great deal of work underway to create a "semantic web" using techniques such as XML in which the information on the web becomes computable.

Before the industry can move to meaningful BIM adoption, the need for computable information must be understood and the industry's mindset must shift from pictures to information models. This is a shift that all industries experience. Once the value of a computable database is recognized – and computable databases are created for buildings – new forms of value can be unleashed.

3. Meaningful Data Interoperability

Once business process and computability are resolved, the final prerequisite for BIM adoption is making the resulting data accessible to the relevant parties involved in the building process. There are a great many design tools, and more importantly, other applications that operate on design data and provide analytical insight. This is not necessarily a bad thing, since it is both unhealthy and unlikely that any one BIM system can or should provide all of the capabilities necessary to address and solve the diversity and breadth of design and analysis problems in the building industry. Monolithic data models and software applications that try to do everything often fail to do anything well, and we find that purpose-built and focused data models and applications often meet customer needs far better. Innovation is likely to proceed more quickly with purpose-built and loosely coupled applications than with large, interconnected, and interdependent applications. To facilitate this progression, sharing meaningful design information between applications is essential.

This idea of sharing design information is often called "interoperability," an imprecise term used in several different and ambiguous ways. Some proponents of interoperability suggest creating a master database[15] that contains all knowledge about the building. Applications will operate upon the resulting model and extract and deposit information meaningful to them. This is the way many transaction-oriented business information IT applications such as accounting systems, airline reservation systems, and inventory control systems work. The approach works well when the data is well-defined, repetitious, and transactional in nature. However it has not proven to be a practical strategy for computable design information for two important reasons, one technical in nature, and the other connected to our earlier comments about lack of underlying business protocols.

Technically, because there are so few computable building design models in existence, it is difficult to create one representation that works for every application. Further, the level of complexity of such model-based data is much higher than in a transaction-focused database system. Attempts to define data models up front often fail because they do not account for the ways applications actually use information, and the diversity of applications often makes it difficult to define the needed data. So attempting to define a universal building model prior to implementation within real applications will likely result in a "least common denominator" that fails to satisfy anybody's needs, or a model schema that is so complex as to be impossible to

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only one of the causal factors "poor interoperability". Unfortunately the diagnosis is incomplete and fails to address either business processes or the lack of computable design information.

[15] Sometimes called a "model-server"

implement. Finally, the process of developing such models is long, arduous, and political – thus making it costly and ultimately suboptimal.

Second, the discontinuities of obligation, risk, and reward discussed earlier suggest that one large database with unfettered access is incompatible with current fragmented building industry structure. Controls on the kind of information flowing from one participant to another are needed to address the business realities of the industry, and these controls will evolve carefully over time. Further, the technical mechanisms to support these controls will need to evolve in parallel. For these reasons, the technical issues in managing controls on design information are far more daunting than those found in managing transactional databases.

A second strategy can be found in the work of the International Alliance for Interoperability (IAI), and in particular the "Industry Foundation Classes" (IFC).[16] IFCs are intended to be a platform-independent geometric and data definition for the exchange of information across various AEC applications. As such, they are a "top down" attempt to create a holistic computable standard for AEC information. Their early success can be found in the most clearly defined computable problem—the exchange of graphical information between adjacent authoring applications. The IFC model may, over time, evolve to the point where it will transmit defined computable information. But presently, both transactional business processes and lack of defined computable data in the building industry limit their utility for this purpose. We believe that such efforts would be enhanced by emphasis on establishing standard business protocols as well as computable information, in addition to interoperable data standards.

Thus, a more practical strategy is one we call ***meaningful interoperability***, comprised of purpose-built conduits from one application to another that achieve a particular task. A good example is Green Building XML (gbXML). gbXML is a simple XML-based protocol to transfer building model data from a BIM application to an energy analysis application. It represents precisely the information that needs to be transferred in a way that is both easy for the BIM application to produce and for the analysis application to consume. Because the data moves on demand, for a specific purpose, the owners of the data are assured that it meets their obligation/risk/reward criteria.

Interoperability is best achieved when there is a demonstrated need and a specific transactional problem to be solved. gbXML was developed using a simple data transfer protocol, purpose-built for a particular use, to meet a specific business need. As such, it was developed quickly and inexpensively. We believe this is the prototype for one type of meaningful data interoperability and a process that is more likely to lead to the ability to share information widely amongst a variety of design and analysis applications.

In the world of e-commerce on the Web, the emerging concept of web services takes this approach. It uses very lightweight, purpose-built XML protocols allow two collaborating web sites to communicate, creating essentially a "loose coalition" of applications that communicate efficiently. This approach clearly demonstrates our concept of "meaningful interoperability."

Breaking Adoption Barriers

The fragmented nature of the construction industry precludes widespread change of any kind, particularly to design tools that are based on the traditions of paper. The transition to BIM-based paradigms will be a greater shift than that of paper to computer-aided drafting, as it

[16] Autodesk, the employer of the authors, was a founding member of the IAI and continues to participate today in their activities, as well as produce IFC-compliant software. For more information, see www.iai.org.

entails a change in both tools and process, as described above. The broad range of industry practice, local customs, varied standards of care and product performance combined with the disaggregated building supply chain suggest that a broad change to business practices that support computable, interoperable models is a long way away. Having identified the barriers, what are the accelerators?

While the efficacy of BIM solutions to increase productivity and accuracy while reducing design cycles is acknowledged, we believe none of these characteristics will, in and of themselves, move the industry to model-based design. As with the change to CAD decades ago, external influences like owner demand and changes to risk/reward ratios will be the primary factors. A small number of firms, seeing a potential competitive differentiation, will drive early adoption. Getting BIM to the mainstream will be the result of these bigger forces.

We thus see the problem in two dimensions, which we will characterize here as “horizontal”—changes or influences to the building industry as a whole, and “vertical” – changes that are focused on solving particular problems in the design-to-operate continuum. Some combination of factors affecting each will begin to dissolve current barriers to BIM adoption. We summarize below some of the more important approaches affecting this change.

Horizontal influences and strategies

Reducing waste

Recognizing the inherent waste and inefficiency of the construction process today, owners will insist that traditional design/fabricate/build/operate silos break down. Globalization may bring new competitors into the building industry thus providing an impetus for change. Approaches for delivery of projects will become more integrated, and design information will flow more freely across process barriers. BIM is the most effective source of such information.

A current example: use of “design-assist” delivery, where design documents are considered “complete” after design development, and detailed technical design occurs during shop drawing preparation in collaboration with fabricators and suppliers.

Balancing risk and reward

Acknowledging that traditional allocations of risk in construction create both waste and an ineffective process ultimately reflected in the cost of the resulting building, owners will demand new, shared risk models where multiple disciplines contribute to the creation of design data that is the genesis of construction. Risk will be ascribed to the design-to-construct team as a whole, and its members will be compensated accordingly. Sharing information thus becomes the best risk management strategy, and BIM authoring offers the highest quality, sharable data.

A current example: complex infrastructure projects, where risks are unknown and high, are being built in Australia using a delivery approach called “project alliance,” where all design and construction team members share equally the risks and rewards of success (and failure) with the owner.

Constructing complex buildings

Obligated to construct increasingly complex, intricate, and customized buildings whose genesis is based on digital design strategies, contractors and fabricators will devise ever-more effective means to meet schedule and budget objectives of owners. Construction planning and management will be supported by digital tools that simulate, track and evaluate construction progress. Central to such analysis is the representation of the building itself, the building information model.

A current example: in order to construct the enormously complex Disney Concert Hall in Los Angeles, the construction team used a virtual simulation of the construction project, studying installation sequence and construction inside a video "cave" that projected images from a digital model of the project.

Vertical influences and strategies

Creating a sustainable environment

Determined to reduce the deleterious effect of construction and building operation on the environment, all participants in the building industry will strive towards sustainable projects. Evaluating sustainable design strategies is heavily dependent on analysis, simulation of alternatives, and detailed quantitative evaluation of building materials, components and performance.

A current example: designers using modeling tools that generate gbXML can quickly evaluate the energy performance of their projects by posting the XML file to an Internet-based analysis engine which reports immediately on energy consumption and other characteristics. The analysis can iterate with the design.

Fabricating from digital information

Leveraging the inherent advantages of computer-driven fabrication, constructors will consume digital design information that will supplant traditional paper-based drawings and consume a version of that information from its original source, the building information model at the core of the design process itself.

A current example: most exterior curtainwall systems today are being constructed from computer controlled fabrication systems driven by digital information. In the case of complex, curved walls featured on modern skyscrapers, the source of the generative geometry is the original designer's CAD model.

Managing the building through its lifecycle

Working to manage the cost of building operation through the building lifecycle,[17] owners will demand that information created during design persist through construction into facilities management. Performance criteria for design deliverable will include their use during facilities operation. BIM-based building descriptions are the most robust, the most data-rich, and the most adaptable to FM solutions.

A current example: a large corporation, after discovering that it had constructed additional office space despite having vacancy factors of 30% or more in other locations on its corporate campus, created a digital facilities management database that tracks occupancy, space allocation, and assets.

There is no single factor that will drive the industry to new BIM approaches. But each of the factors above, influencing individual decisions as each building project coalesces, will gradually push construction to truly modern processes based on BIM. Individual firms or projects, wishing to attack one of the problems described below, will turn to BIM as its best hope for addressing them effectively.

Conclusion

[17] Building operation cost to its owner is generally acknowledged to be between four and ten times the total original construction cost of the building.

We believe that a combination of factors are currently inhibiting the building industry from more productive, efficient uses of technology in the form of building information modeling, and we have described here the conditions under which we believe that change will commence. If we are to make progress in BIM adoption, the dialog around productivity in the building industry must encompass all three of the barriers to adoption we have identified.

We conclude here with some final observations and predictions about the changes to occur over the next five to ten years:

- It is unlikely that building information will reside in a single, consolidated source information model. Industry process will commence from a loosely connected coalition of information models that support various processes, governed by the principles of computable interoperability defined here.
- Risk and responsibility will be managed and filtered by connection protocols between these models, whose authors will maintain ownership, and whose data will be distributed via interoperable conduits that support specific transactions and filter unnecessary information from transmission. The architect's BIM will be the central, control model at the core of design decision-making, but it will not contain all project information. It will be surrounded by review, approval, and control data transactions. Crude risk-management mechanisms like practice-based liability insurance policies will be replaced with custom-designed, project-based mechanisms that more closely resemble construction bonding.
- Data interaction protocols will define business relationships, and data structures will reflect transactional obligations. These approaches, and the connections between adjacent digital tools, will be systematically refined by repeated use over time.
- Carrier mechanisms—the methods for carrying computable information between applications and processes—may become more important than the data itself, since they will be the basis for risk and reward.

These observations are not a prescription for the future, but rather what we believe will be likely outcomes of the full integration of digital tools, through the use of building information models, in the building industry in years to come.

About the Authors

Phillip G. Bernstein, FAIA is Vice President of Autodesk's Building Solutions Division, the leading provider of technology to the building industry. Prior to joining Autodesk, Bernstein spent 20 years as a practicing architect, most recently as Associate Principal at Cesar Pelli & Associates, where he managed many of the firm's most complex commissions. Bernstein has taught at the Yale School of Architecture as a Lecturer in Professional Practice since 1988. He writes and lectures extensively about practice and technology issues. He received a Bachelor of Arts magna cum laude with Distinction in Architecture in 1979 from Yale University and a Master of Architecture in 1983, also from Yale University. He is a Senior Fellow of the Design Futures Council, a Fellow of the American Institute of Architects, and a member of the AIA National Documents Committee since 1998, where he becomes Chair in 2005.

Jon H. Pittman, AIA is Senior Director of Strategic Research for Autodesk. Pittman is responsible for researching and facilitating the development and integration of external sources of long-term competitive advantage, participating in the development of overall technology strategy, and representing Autodesk externally from a technology and strategy perspective. With over 25 years of experience in the computer-aided design, computer graphics, and internet industries, Pittman has held a variety of business development, product development, and strategy positions at Autodesk, Structural Dynamics Research Corporation (SDRC), Alias|Wavefront, and Hellmuth, Obata, and Kassabaum (HOK) Architects. In addition to the work in the corporate world, Pittman has been an Assistant Professor at Cornell University's Program of Computer Graphics and an instructor in user interface design at Art Center College of Design. Mr. Pittman holds a Bachelor of Architecture and MBA from the University of Cincinnati. He also holds a M.S. in Computer Graphics from Cornell University.