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建设工程信息化导论

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中国建筑工业出版社

Introduction to the Theory and Practice of Building Lifecycle Management

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Introduction

The building industry designs, builds, and operates the built environment. It is responsible for creating the world's fixed physical wealth - buildings, plants, and infrastructure. The building industry is a major contributor to the economy in most developed and developing countries. Construction alone accounts for 10% or more of GDP in most developed countries-significantly more in rapidly developing economies such as China. The Building Industry employs a great many people and consumes a significant percentage of the world's resources. Further, its "products" significantly shape and influence both commercial activities and quality of life. Buildings consume roughly 40% of the world's energy and raw materials[1] on an ongoing basis. The building industry has accomplished astonishing feats such as the Three Gorges Dam, The Freedom Tower, Petronas Towers, Akashi Kaiko Bridge, and the Walt Disney Concert Hall. Despite these accomplishments the building industry is extremely inefficient relative to other industries. Productivity in the building industry has actually fallen over the past 40 years, while it has dramatically increased in all other industries.

There are many causes for this inefficiency-including fragmented industry structure, adversarial relationships, and poor management of information[2]. Unlike other industries, where information technology has driven productivity improvement, the use of information technology within the building industry is rudimentary and has

[1] U. S. Department of Energy, Energy Efficiency and Renewable Energy Network (EREN). Center of Excellence for Sustainable Development, 2003

[2] The "Egan Report", published in the U. K in 1998, identified many of these causes. See http: //www.dti.gov.uk/construction/rethink/report/

largely been used to automate manual processes. While information technology has been used to improve the productivity of individual tasks - particularly in design of the built environment - it has seldom been used to address the more fundamental problem of integrating and communicating across entire processes.

Information technology can be used to dramatically improve the productivity of the building industry - thus bringing it in line with other industries such as manufacturing[1]. Two fundamental and related information technologies can be used to improve building industry productivity:

- ☐ **Building Lifecycle Management (BLM)** - a digital methodology to create, manage, and share information about built capital assets throughout their useful lives - from concept to demolition or reuse.
- ☐ **Building Information Modeling (BIM)** - the creation and use of coordinated, internally consistent information about a building project in design and construction.

These two technologies can work together to ensure that information is shared among participants in the building process - thus reducing ambiguity, information loss, and misunderstandings. Implementation of BLM and BIM goes beyond automating individual tasks - to integrating entire processes in design and construction. Thus it requires a significant change from traditional processes. However, the results of implementing BIM and BLM can significantly improve productivity of the building industry, thus making it both a more competitive industry and one that consistently delivers value to the economy.

In the following pages, we describe building industry inefficiency, look more closely at the causes of such inefficiency, present solutions to address the inefficiency, and suggest goals for productivity improvement. We conclude with a brief roadmap for implementing BLM and BIM. We believe that deployment of BLM and BIM technologies in the building industry will result in productivity gains similar to those enjoyed in the manufacturing industry.

Inefficiency in the Building Industry

Over the past 40 years, in the U. S., most industries have improved their

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[1] Refabricating Architecture, by Stephen Kieran and James Timberlake, McGraw - Hill, 2004, illustrates many of the lessons the building industry can lean from manufacturing.

efficiency dramatically, almost doubling productivity. Figure1[1] shows the productivity increase of all non-farm industries (including construction) in blue and productivity of the construction industry in red. The red line indicates that construction productivity actually declined by about 10% over the same 40 year period that all non-farm industries increased productivity by 80%. Construction has not only failed to increase productivity, but it has actually declined.

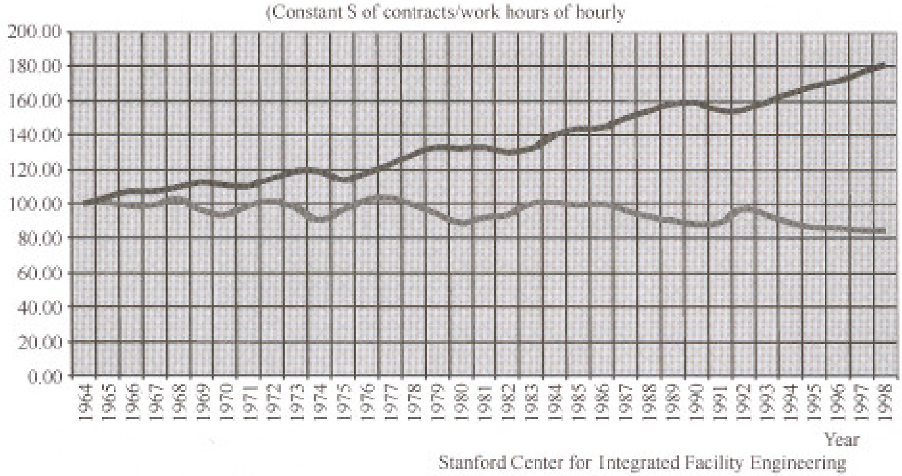

Figure 1: Declining Productivity in the AEC Industry from 1964~1998

Consider the manufacture of automobiles during this 40 year period. Relative to 20 years ago, automobiles today have dramatically greater performance, functionality, fuel efficiency, reliability and durability. At the same time the product has improved, the process of manufacturing an automobile has improved as well. The time to develop a new automobile has gone from 40 months to 15 months[2], quality processes have reduced rework, just-in-time planning has reduced inventory, and the processes employed in manufacture are much more efficient and reliable. The building industry clearly has not kept pace with manufacturing industries - yet many of the issues, processes, and approaches employed in the building industry are similar to manufacturing.

This decline in construction productivity does not appear to be strictly a U.

[1] Sources: US Bureau of Labor Statistics, Us Dept. of Commerce, Compiled by Paul Teicholz, Professor (Emeritus), Stanford University, and former Director of CIFE

[2] The Egan Report.

S. problem - but seems to be a global phenomenon. Studies in the United Kingdom[1] indicate that as much as 30-40% of construction costs are waste due to inefficiency. In early 2005 the U. S. National Institute of Standards and Technology (NIST) released a report detailing about 6% inefficiency due to data interoperability costs alone[2]. These inefficiencies are being reported in the countries with the most advanced construction practices. Anecdotal evidence suggests that these inefficiencies are global in nature. Further, there is growing awareness that many of our buildings are inefficient to operate - particularly in their energy use. This leads to an unnecessary waste of energy and resources over their entire lifecycle. Much like manufacturing in the 1970s and 1980s, there is significant room for improvement in both the product (buildings and infrastructure) and processes (design and construction) employed by the building industry.

In fact, one can easily envision the construction industry taking on many of the characteristics of manufacturing. Presently, a great deal of construction is built on site. However, the manufactured content of buildings is increasing. The industry may be moving from design-build to design-manufacture-assemble. As this occurs, the lessons learned and the techniques employed in manufacturing could well be employed in building.

Information Technology in the Building Industry

The global manufacturing and construction industries are roughly the same size - approximately $US 3T annually on a purchasing power parity (PPP) basis. Manufacturing and the building industry share many similar characteristics, but there is a striking difference in the amount they spend on information technology (IT). As illustrated in Figure 2, The manufacturing industry spends roughly $US 8. 1B annually while the construction industry spends roughly $US 1. 4B on information technology, about 17% of the amount spent in manufacturing[3]. While manufacturing organizations employ sophisticated solid modeling

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[1] The Latham Report. Constructing the Team. Sir Michael Latham. HMSO Department of the Environment. U. K. 1994

[2] Cost Analysis of Inadequate Interoperability in the U. S. Capital Facilities Industry. National Institute of Standards and Technology. U. S. Department of Commerce.

[3] Worldwide IT Spending by Vertical Market 2Q02 Forecast and Analysis, 2001-2006, IDC Research Report, Anne Lu, October, 2002.

techniques, finite element analysis, materials resource planning, product lifecycle management, optimization, scheduling, and other digital techniques to create, manage, and share design information- such uses of IT are relatively rare in the building industry.

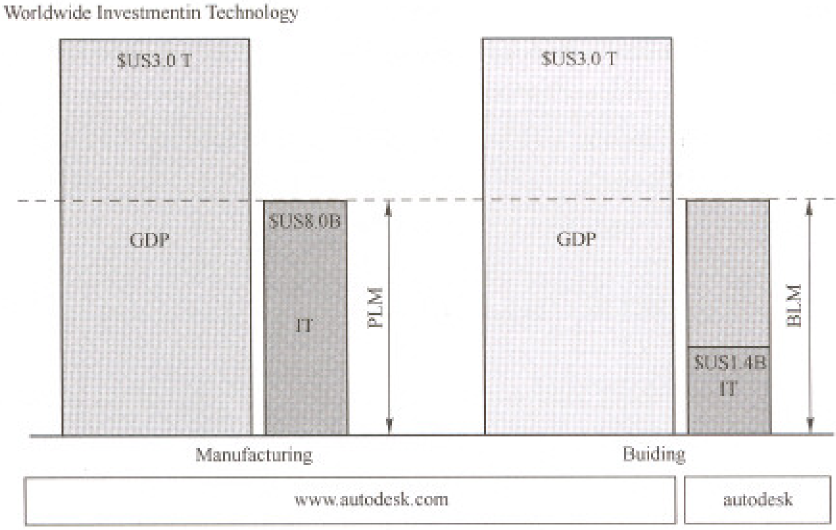

Figure 2 - Relative IT Investment in Manufacturing and the Building Industry

There appears to be a strong correlation between the low productivity of the building industry and its lagging use of information technology. The fragmented industry structure of the building industry contributes to this low productivity because the means of information exchange between the participants is based on technology that is literally thousands of years old - paper. Much of the information is produced in digital form but is exchanged in paper form, thus losing information. The challenge in increasing building industry productivity is to increase IT investment to employ more model-based technology and to use it not only to create information but to manage and share it among all the participants in the building process.

Targets for Improvement

As a catalyst for productivity improvement in the building industry, Stanford's Center for Integrated Facility Engineering (CIFE) has established a set of goals illustrated in Figure 3 as a challenge to their industry partners. The table below illustrates these goals. They are specifically designed to be ambitious, and cannot be reached through incremental change alone. They require significant change and commitment.

	Practice: 2005	Goal: 2015
Schedule	1-6 y Design ~1.5 y Construct Variance 5-100%	1 y Design <.5 y Construct Variance 1-5%
Cost	Variance 5-30%	Variance 1-5%
Function	Large Variance Good? Productivity impact?	Very small variance Great ++ productivity
Safety	Good	Better
Sustainability	Poor	Much Better
Globalization	Some	>= 50% of supply and sales

Figure 3: CIFE Building Industry Practice Goals

The goals identify six dimensions - schedule, cost, function, safety, sustainability, and globalization. For each of these dimensions, metrics for current practice in 2005 are defined and a target to achieve in 2015 is presented. The targets are significantly ambitious that they can only be achieved with dramatic process changes. CIFE believes these kinds of improvement are possible and points to the dramatic improvement in safety in the U. S. over the past 30 years. In the U. S. and other western countries, safety became a priority and through rigorous measurement of safety performance and process improvements safety has now become much better, thus reducing both economic and human costs in construction. The improvements in safety are an example of what can be accomplished by targeting ambitious goals such as those presented above.

We believe that the application of BLM and BIM information technology are necessary elements for the achievement of such goals. As has been seen in many other industries, investment in information technology can measurably improve productivity. To understand the value of these technologies, we will describe the reasons this inefficiency occurs.

Root Causes of Inefficiency

What causes inefficiency in the building industry? We believe there are four fundamental causes:

- ☐ **Fragmented industry structure.** The building industry consists of a large number of small, specialized, interrelated participants. Unlike most manufacturing industries, there is little vertical integration in the building industry. This creates a flexible industry which is able to respond to changing projects and demands. However, it also creates an industry where well-established, but outdated mechanisms and norms of information exchange impede productivity improvement.

- ☐ **Loss of information.** Paper-based mechanisms to transfer information from one participant to another were an appropriate technology many years ago. However, with the advent of digital technology, much more robust information can be created during the design and construction process. Unfortunately, paper - based processes to communicate information are still the norm. Although information is often created digitally, it is still transmitted on paper. Digital information is lost when it is converted to paper for transmittal.
- ☐ **Ambiguous information.** Today's prevalent tools and techniques for creating design information lead to inherently ambiguous project information. Two-dimensional drawings create abstractions of the construction project that are open to interpretation. In this interpretation, misunderstandings and errors can easily occur.
- ☐ **Focus on cost rather than value.** Much of today's building industry focuses on initial cost of construction rather than value created. Since the life of a building or infrastructure project is measured in decades, this is often very short-sighted since spending more initially may result in far lower lifetime costs or may create benefits far in excess of the initial cost.

These factors interrelate to create a system and process with inherent inefficiencies. Even incremental productivity improvements are often difficult to introduce. Dramatic productivity improvement requires changes at the systemic level. However, such changes are difficult to introduce because the industry structure is so fragmented. Such changes require leadership by key industry players, academia, government, and technology providers.

Figure 4 illustrates the loss of information over the project lifecycle using traditional paper-based techniques:

- ☐ In the ***design*** phase, architects and engineers generate a great deal of information about the project, including geometric information, products to be used, analytical information about structural and environmental performance, etc. Much of this information is captured as digital data. However, when the project is sent to a bidder to determine construction cost, the digital information is printed onto paper and is lost to the companies bidding on the project.

- In the ***procurement*** phase, the bidders reconstruct some of the lost information. In particular, they measure and count paper drawings to determine quantities - information that was known when it was digital. At the conclusion of the procurement phase the project is to be built, but once again digital information is lost.
- During the ***construction*** phase, paper-based information is used to build the project. There is little or no capture of information learned during construction and that information is not typically captured digitally nor is it delivered to the owner at completion of the project.
- During the ***operating*** life of the project, new information is learned, but it resides either on paper or in the minds of those maintaining the project. Again, information which was once known and stored digitally is recreated over the life of the project.

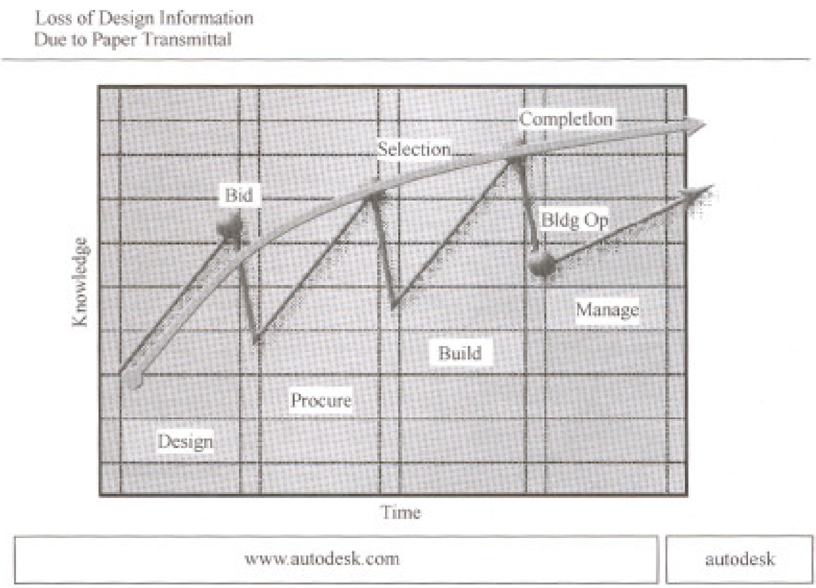

Figure 4: Loss of Information Over The Project Lifecycle

This repeated cycle of creation and loss of information is one of the key causes of poor productivity in the building industry. Many tasks are unnecessarily repeated to reconstruct information that was known at an earlier stage of the process. Digital technology is used to create information, but its transmission and storage revert to paper, thus losing valuable information.

Figure 5 illustrates another driver of productivity in the building industry. Curve # 1 illustrates the ability to impact the project's cost and functional characteristics. This ability is very high at the early stages of the project and low as the project progresses and decisions become literally "cast in concrete". Curve #2 illustrates the cost of design changes—very low early in the project and very high late in the project. Curve #3 illustrates the typical design process and Curve #4 illustrates the desired design process. Curve # 4 moves decision making earlier in the process. This approach was impractical using paper-based processes for design. Manual processes are too inefficient and imprecise to allow early decision making. BLM and BIM tools, on the other hand, have a great deal of expressive power and analytical capability that affords the option of making design decisions earlier in the process when they have higher impact. Thus, use of model - based design tools can positively influence building industry productivity.

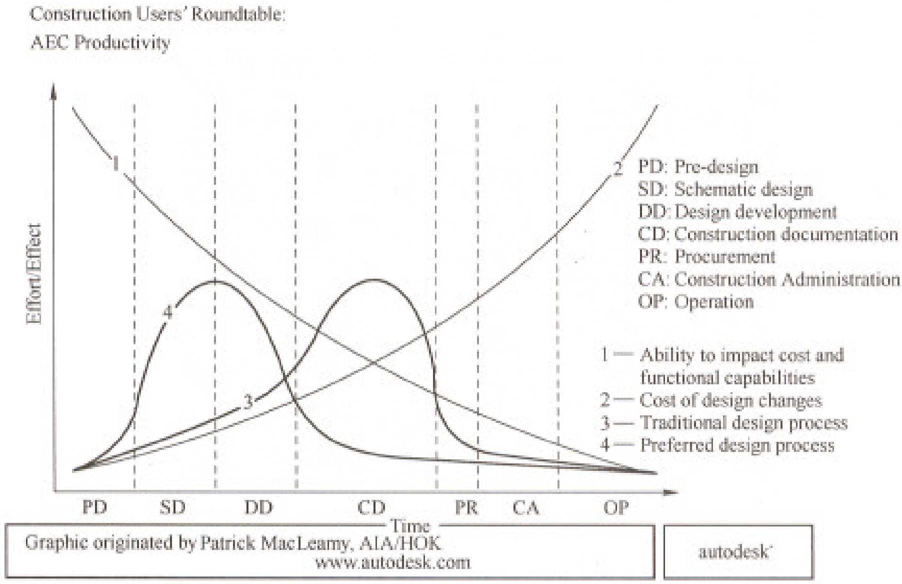

Figure 5 - Impact of Decisions at Various Stages of Project Development

Thus, it is apparent that many of the causes of inefficiency in the building industry are the result of the wrong information reaching the wrong people at the wrong time. To address these inefficiencies requires ***creating*** better information, ***managing*** that information so we know where it is and what it pertains to, and ***sharing*** that information in a timely manner with the participants who need it.

Remedies for Inefficiency

The core remedy for inefficiency in the building industry is to integrate the design-build-manage process. Stanford University's Center for Integrated Facility Engineering (CIFE) defines this as building multi-disciplinary "POP" models that include the:

- ❑ Product—the building or structure
- ❑ Organization—the design, build, and manage team
- ❑ Process—the work processes used to construct the facility.

POP modeling addresses three critical facets of building industry productivity. Modeling each facet and interrelating the models provides insight into issues which impede productivity. Building Information Models (BIM) are analogous to CIFE's Product Models. A Building Information Model contains a complete description of the "product" —i. e. building and facility. This creates a framework which can be used to relate organization and process information. An example of this is "4D Modeling" in which the fourth dimension is time. In 4D modeling, the project schedule is related to the product model. This enables participants in the process to analyze and evaluate construction sequences and alternatives.

Similarly, Building Lifecycle Management (BLM) systems can help model the organization (through roles and access rights) and process (through workflow mechanisms). Thus, the combination of BIM and BLM can support all facets of the project as envisioned in the POP approach.

The POP approach suggests that using information technology to integrate various aspects of the building industry can address the industry's low productivity. The industry can use information technology to:

- ❑ **Create better information**—ensure that information created in the design and construction process is more useful and robust
- ❑ **Manage the information over the lifecycle**—ensure that information is organized and tracked throughout the lifecycle and flows from one phase to another without information loss.

- ☐ **Share information among participants**—ensure that information is available in an appropriate form to all participants in the building process.

Deployment of Building Lifecycle Management (BLM) and Building Information Modeling (BIM) tools in the building industry, while not the only remedy for low productivity in the building industry, can significantly address the industry's productivity problems, assuming sufficient attention is given to IT investment, human resource development and process improvement.

Creating Better Information. Much of the information about a building created during the design process is graphic in nature. It pictorially describes building elements and their geometric relationships, most often in the form of two-dimensional drawings. Because of the difficulty of representing complex three-dimensional facilities in a two-dimensional drawing, drawings are often very abstract representations of the proposed facility. These abstractions are sometimes defined by convention, but are very open to interpretation and introduce significant ambiguity into the communication of information. Further, such pictorial abstractions are often not computable. While a picture is represented in the computer, there is no data structure associated with the picture that indicates the properties and relationships inherent in the element being represented. For example, a door in a pictorial CAD system may not have a representation indicating material, surface, sound transmission properties, thermal transmission properties, associated hardware, fire rating, connection between two spaces, etc. All of these properties and attributes are needed to fully understand the door. All must be represented in the computer for the computer to act upon that data for analysis purposes.

Creating better information requires moving from a drawing-based process to a model-based process, in which the computer contains an information model of the facility to be built. This information model accomplishes two goals—it reduces ambiguity about the facility by offering a more complete and robust description—and it provides a computable database which can be used to perform analysis and more rigorous evaluation prior to construction.

Autodesk Revit™ is an example of a Building Information Modeling tool. Revit is fundamentally built around the notion of a parametric building model. While it creates drawings as output reports, Revit's database is a building model. Thus, Revit ensures information about the building is consistent and coordinated.

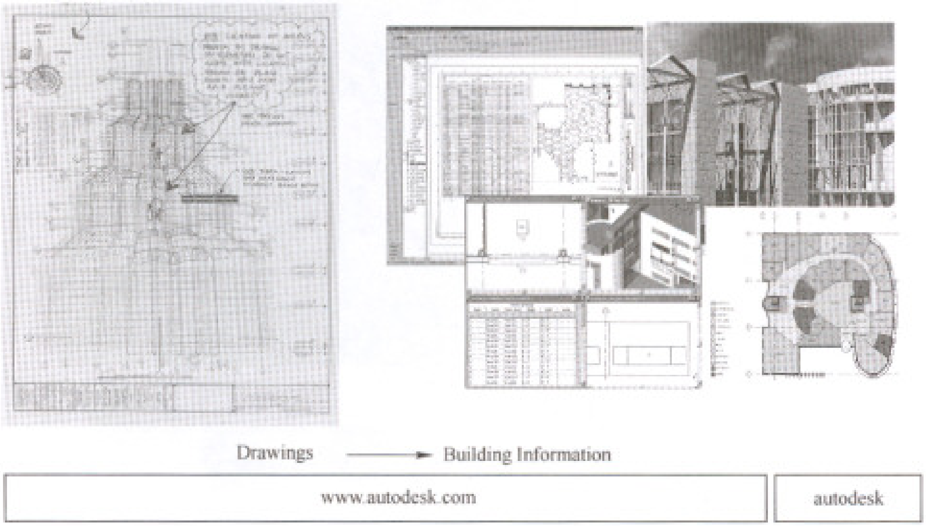

Figure 6: The Goal of Building Information Modeling

It also provides a complete computable representation of the building geometry and function.

Managing Information over the Lifecycle. Managing information about a facility over its lifecycle requires:

- ❑ Creating and keeping information in digital form.
- ❑ Employing mechanisms to store and track the digital data
- ❑ Relating the various pieces of digital information to each other
- ❑ Affording access to the data to participants.

These functions are accomplished by a combination of a Project Information Portal (PIP) such as Buzzsaw that allows all participants to contribute and access information as well as organize the information about a project and a digital data format such as DWF that allows information to be managed and shared in a secure, precise fashion.

A project information portal allows information to be shared among all of the participants in the project but, as importantly, it creates an organizing mechanism for project information and a way to store the information over time.

Sharing Information among the participants. Once the information is in robust digital form and organized into a management scheme, it must be shared amongst the participants. Some participants may be able to use sophisticated computer

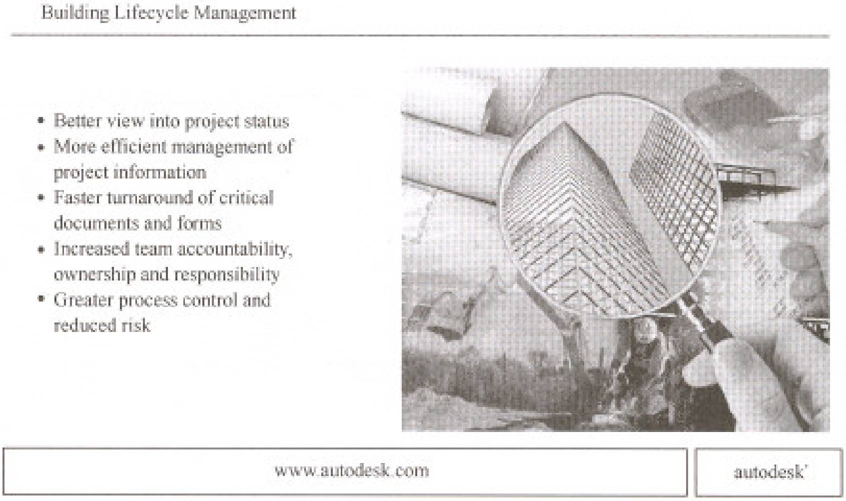

Figure 7: The Role of Building Lifecycle Management

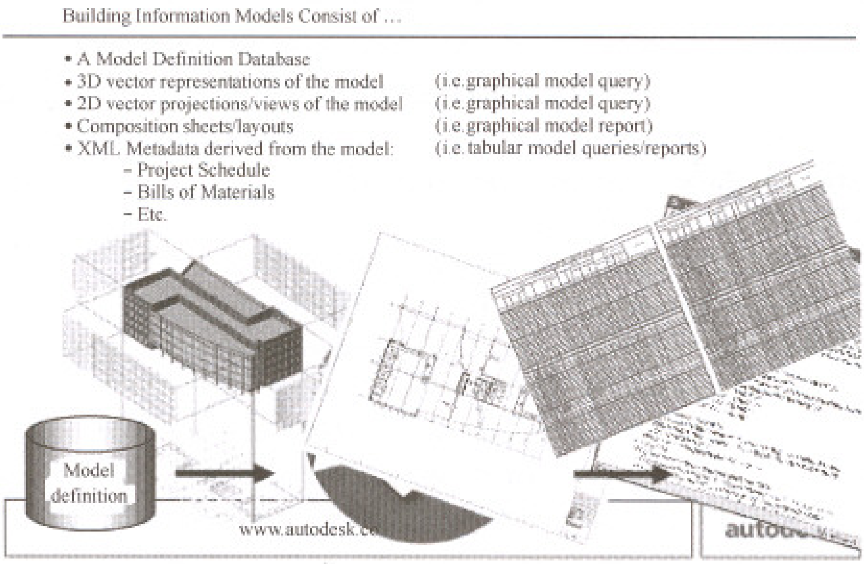

Figure 8: Representations of a Building Information Model

applications to access the data—but many do not have the expertise or desire to do so. What is needed is a simple way to publish the relevant data in digital form and have participants view and make simple comments and corrections to the information. This requires both a data publishing mechanism such as DWF and viewing and markup tools such as found in DWF composer.

Thus, the three elements we have described, ***creating*** robust digital data, ***managing the data over the project lifecycle, and sharing*** data among the participants are the cornerstones of improving productivity in the building process.

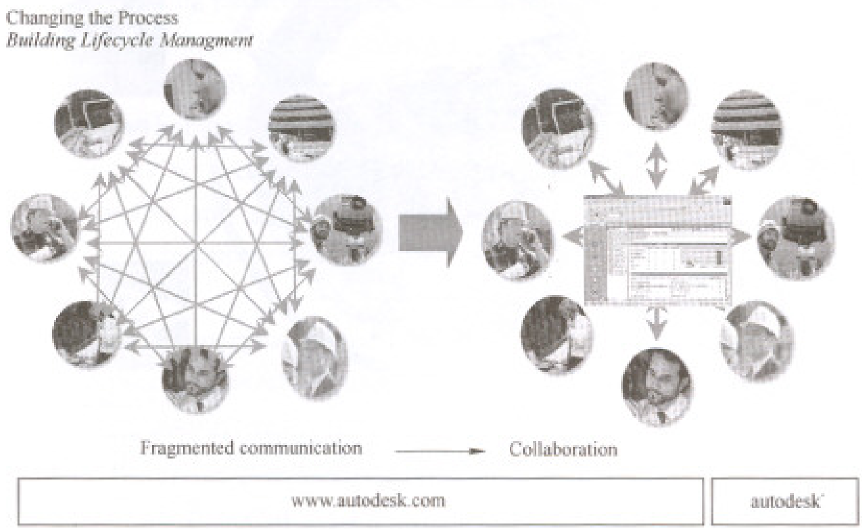

Figure 9: The Goal—Integration of Information and Collaboration in the Building Industry

Ultimately, improved productivity will result from dramatically improved communication and collaboration. While these are organizational and management issues, information technology can support and facilitate changes needed to increase productivity to that of comparable industries.

BIM and BLM Solutions

Autodesk, as a leading software provider to the building industry, offers a comprehensive set of products for BIM and BLM. The Autodesk Building Industry product family is shown in Figure 10.

Autodesk Revit™ is a parametric modeler that ***creates*** a fully-integrated building information model and Civil 3D is an analogous modeling tool for land and civil structures. Buzzsaw is a project information portal that manages a design and construction process, and DWF composer allows participants in the project to share information.

These tools work together to implement a comprehensive BIM and BLM solution. They can also be used independently. However, the true value and

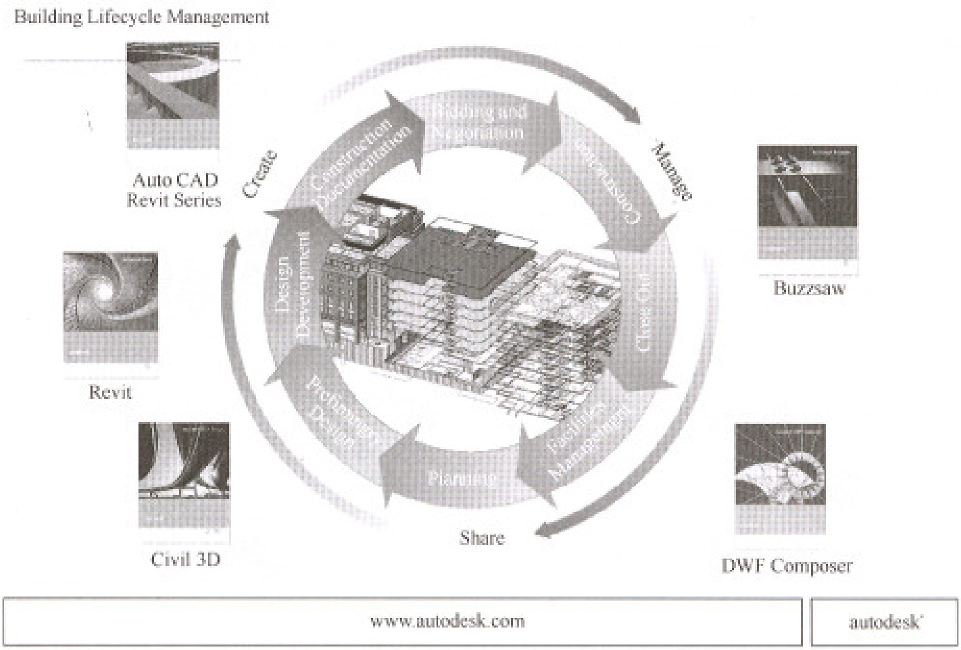

Figure 10: The Autodesk Building Industry Product Family

productivity improvement comes from implementing the comprehensive solution. As the building industry becomes more like manufacturing, tools and techniques used in manufacturing can be applied to the building industry. Autodesk is in a unique position of as a leading provider of tools to both the building and manufacturing industries to leverage knowledge, expertise, and technology to help integrate these two disciplines. Thus, Autodesk has the resources and opportunity to extend BIM and BLM to encompass not only built-in-place construction but manufactured elements as well.

Conclusion

We believe that implementing BIM and BLM is key to productivity improvement in the building industry. Implementing BIM technology to allow users to ***create*** building information models results in better coordinated information and computable information that can be used to form better decisions earlier in the design cycle—when those decisions are both inexpensive and impactful. Further, the rigor of a building information model reduces the likelihood of ambiguity and error, thus minimizing misunderstandings about design intent. The computability of a building information model forms the basis for analysis to help inform design decisions.

Helping participants ***manage*** and ***share*** information over the project lifecyle using BLM technology likewise reduces loss of information and improves communication among participants. BLM technologies focus not on the individual task but rather on integrating the entire process. This helps optimize the work of many players over the life of the project.

Although technology alone is insufficient to improve productivity in the building industry, we believe it is a necessary ingredient. Without the proper information creation and management tools, building industry professionals will never be able to overcome the inefficiencies caused by poor information and coordination.

The building industry is a substantial industry which is ready for change. It has lagged other, comparable industries in productivity. Part of the lag in building industry productivity can be explained by low investment in information technology. Building Lifecycle Management (BLM) and Building Information Modeling (BIM) technologies are now mainstream and can significantly improve productivity. Now is the time to embrace these technologies and drive change to bring the productivity of the building industry—and the profitability of the firms that comprise the industry - up to the standards of comparable industries.