BUILDING INFORMATION MODELING TECHNOLOGY FOR FULLY INTEGRATED DESIGN AND CONSTRUCTION

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INTRODUCTION

This paper explores the recent global developments in software and software protocols for Building Information Modeling (BIM) as a tool for fully integrated design and construction. Building Information Modeling is a still emerging technology that has yet to reach its anything close to its full potential. However the technology can already clearly demonstrate its overall benefits in terms of coordinated design, shorter design & construction schedules, significant cost reductions, job site safety improvements and even more sustainable construction programs.

As discussed in this paper, there is a significant amount of work being done worldwide **on software tool & protocol developments** by governmental agencies, non-profit and research organizations, as well as commercial entities, to facilitate and promote BIM technology. Also discussed are the **application software developments** currently underway. The good news is that many, if not most, of these developments are IFC compliant. However there still are many barriers to successful and commercial application.

Clearly BIM modeling has gained wider acceptance in the past two years, particularly in the architectural design side of the profession, but we are far from a fully integrated design process. Research into engineering firms specifically for information related to their experience with Building Information Modeling Programs (i.e. Bentley Microstation, Tri Forma, Factory CAD, Catia, Autodesk Revit, Graphisoft ArchiCAD, etc.) as design and construction tools, does show wider application today. But while we have seen a few companies fully integrate structural design and analysis programs into those architectural models, we have yet to find many companies that are able to demonstrate BIM model tie-ins that can fully integrate HVAC related design programs (such as Load Calculation Programs, Pipe and Duct Sizing Programs, Building Energy Modeling/Analysis Programs - DOE-2, EnergyPlus, BLAST, IBLAST, TRACE 700, etc.).

We have also yet to find many companies that have integrated Building Owning, Operations and Maintenance Programs for Facilities Management. Similarly we have yet to find many companies able to fully integrate natural day lighting design programs (such as Superlite 1.01, LUMEN , doe 2.1 or Radiance 3.4 or illumination design programs such as Autolux, AG132, esp Vision, Autodesk Lightscape, Lightcalc +Art or ALADAN) into BIM models. Yet the spatial planning, modeling and orientation technology imbedded in 3D, 4D & 5D models would seem a logical input data base for such programs and the recipient of the output.

Despite this, the tremendous opportunities for improved efficiency by integration of the design and construction process will continue to drive the technology forward.

OVERVIEW OF BUILDING INFORMATION TECHNOLOGY

The ultimate goal of Building Information Modeling is to assemble a single data base of fully integrated and interoperable information that can be used seamlessly and sequentially by all members of the design and construction team and ultimately by owners/operators throughout a facility's life cycle. The desired result is a BIM model where three dimensional (3D) graphical imaging carries real-time (i.e. immediate and dynamic access) data, and where every line and every object carries real-life intelligent physical and performance data.

The modeling technology can start with direct data transfer from the design calculation software into graphic layouts (for systems such as structural steel, fire protection or other modular elements). Alternatively it can utilize the graphic layouts as direct input to load calculations (such as pipe sizing, duct sizing, etc). Modeling programs can also link to specifications and to manufacturers web sites for data input. Either way, building information modeling technology already extends into fully integrated 4D modeling (adding the fourth time dimension for scheduling or sequencing using programs such as Primavera) and 5D modeling (adding the fifth dimension of cost for estimating and budget control (using programs such as Timberline). The building design development can continue with the provision of automatic bills of material and generation of automatic shop drawings for everything from structural steel to sheet metal duct fabrication, to fire protection and piping fabrication, to electrical cabling and bus duct layouts, etc.

CURRENT TOOL AND SOFTWARE PROTOCOL DEVELOPMENTS

A major key to the success of these efforts is establishing common software protocols. The International Alliance for Interoperability (IAI) at www.iai-na.org. has developed models to address this issue. IAI is a council of the National Institute of Building Sciences (NIBS) at www.nibs.org . The mission of IAI can be found on their Web site, which also provides information on programmable language XML data models for information transfer between disparate software packages (as an example, aecXML is a framework for using an eXtensible Markup Language standard specifically related to technology in architecture, engineering and construction). They also offer comprehensive, intelligent and universal data models through Industry Foundation Classes (IFCs) to IFC.XML2 ISO 10303-28, which incorporate HVAC schemas compatible with ifcXML - IFC2X3 code (ISO 10303-11), as well as data elements that represent entire portions of a building or system. These are used to assemble computer-readable models of the facility that contain all of the information on the parts and their relationship (ISO/PAS 16739). Table 1 Identifies HVAC schema being developed under IAI Project BS-8.

Table 1 - IFC HVAC Extension Under IAI Project BS-8

<table>
<tr><td colspan="2">The main objective of BS-8 was to extend the IFC data model with schema needed to fully support the modeling and simulation of HVAC components and systems. The pragmatic goal was to enable rich data exchange among the various building simulation tools in use today and in the future.</td></tr>
<tr><th>General Data</th><th>IFC HVAC extension schema for support of building energy performance simulation</th></tr>
<tr><td>
General and performance specifications of
materials
General specifications of HVAC and other
simulation related equipment, systems and
furnishings
Performance specifications for the above.
</td><td>
Dynamic load estimation
HVAC design
HVAC equipment selection
Measurement and verification (HVAC view)
Building performance metrics (HVAC view)
HVAC system and equipment commissioning
HVAC system and equipment retrofit
HVAC system and equipment physical layout
HVAC system and equipment product data
(catalogues, external data bases).
</td></tr>
<tr><th>Downstream applications</th><th>Processes that are partially supported by IFC HVAC extensions</th></tr>
<tr><td>
Other HVAC (design) applications
Other building energy performance simulation
tools (such as air-flow models)
Cost estimating applications
Commissioning tools
Building operations and maintenance software
Code-checking applications
Software that serves utility companies
Many other types of applications that use HVAC
definitions.
</td><td>
Energy code compliance
Interference checking
Cost estimating
HVAC construction documents
Construction and installation
Procurement
Maintenance
Operations
Fault detection and diagnostics
Emergency response
Accessibility
Utility billing and cost allocation
</td></tr>
</table>

Even more importantly, IAI's international Council has established the European Integrated Project "InPro" "Open Information Environment for Knowledge Based Collaborative Processes throughout the Life Cycle of a Building"- European Project No. 026716-2.

The US National Institute of Building Sciences (NIBS) has created the National Building Information Model Standard, under their Facility Information Council. The first Version 1.0 is now available for review on their web site www.facilityinformationcouncil.org/. This is in addition to the work being done by the Building Enclosure & Environment Council and the Facility Maintenance & Operations Council. NIBS is working with IAI to develop an overall integrated program developing and expanding IFC component values under the umbrella "building SMART"- www.iai-na.org/bsmart/ . buildingSMART = BIM + IFC and combines BIM technology with Information for the Construction (IFC) global ISO Standard. Target date for the first version was the end of 2006. The annual buildingSMART Conference brings all facets of the industry together to advance the science.

As their web site indicates *"**buildingSMART** is the dynamic and seamless exchange of accurate, useful information on the built environment among all members of the building community throughout the lifecycle of a facility. **buildingSMART** is simply a smarter process for managing the project lifecycle."*

The mission of the National BIM Standard Project Committee as identified in their charter is to improve the performance of facilities over their full life-cycle by fostering a common, standard and integrated life-cycle information model for the A/E/C & FM industry. This information model will allow for the free flow of graphic and non-graphic information among all parties to the process of creating and sustaining the built environment, and will work to coordinate U.S. efforts with related activities taking place internationally.

Of related interest the National Institute for Science and Technology NIST Advanced Technology Program (www.nist.gov/atp) and Standard Reference Data programs (www.nist.gov/srd) are also very supportive of industry research and development in this area. Capital facilities industry cfiXML at www.cfixml.org is a cooperative effort of ePlant Data www.eplantdata.com ; DIPPR a chemical industries alliance and FIATECH are also developing manufacturing industries standard XMLs.
Of particular interest is the work being done by the FIATECH (a non profit consortium supported by NIST and established by the Construction Industry Institute) towards fully integrated and automated design and construction technologies. Their Capital Projects Technology Roadmap (CPTR) www.fiatech.org/projects/roadmap/cptri.htm or www.construction-institute.org/FIATECH addresses many of the critical issues facing the industry. The Projects Technology Roadmap is a cooperative effort of associations, consortia, government agencies, and industry, working together to accelerate the deployment of emerging and new technologies that will revolutionize the capabilities of the capital projects industry. This initiative, led by FIATECH, is open to all stakeholders who are committed to the future success of the capital projects industry. The Capital Projects Technology Roadmap presents their strategy for the capital projects industry in **"Developing a consensus vision for the capital projects industry and a unifying initiative to achieve the vision"**. Table 2 indicates the planned components of project development.

Table No.2 – FIATECH Capital Projects Technology Roadmap

www.fiatech.org/projects/roadmap/jobsite.html

1. Scenario-based Project Planning
2. Automated Design
3. Integrated, Automated Procurement & Supply Network
4. Intelligent & Automated Construction Job Site
5. Intelligent Self-maintaining and Repairing Operational Facility
6. Real-time Project and Facility Management, Coordination and Control
7. New Materials, Methods, Products & Equipment
8. Technology- & Knowledge-enabled Workforce
9. Lifecycle Data Management & Information Integration

The Internet Standard published by the World Wide Web Consortium www.w3.org offers interoperable technologies for information, commerce, communication and collective understanding. WWW recently released XML schema 1.1 Structures for XML documents. Still further tool technology includes Unified Building Modeling Language UML www.omg.org for specifying, visualizing and constructing the artifacts of software systems and SOLIBRI IFC Optimizer and model checker www.solibri.com for more effective data storage and transmission.

CURRENT COMMERCIAL APPLICATION SOFTWARE DEVELOPMENTS

The first challenge facing private and commercial enterprises in developing integrated information modeling is the reality of the limited size of the marketplace. Unlike basic office software where a word processing program may sell tens of millions of copies, building modeling programs (of far greater sophistication) may sell only a few thousand. The second challenge facing the industry is developing a commonality of program protocols that enable free exchange of data between disparate software systems. These are becoming incredibly complex. Here, the work being done by NIBS and IAI to develop an overall integrated program under the umbrella "building SMART" shows great promise in combining BIM technology with Information for the Construction (IFC) global ISO Standards to ISO/PAS 16793.

One of the biggest recent advances has been the development of open meld protocols that allow the integration of disparate software programs. An example of this is NavisWorks "Jetstream" © 3D Design Review at www.navisworks.com , that has the ability to manage, view and integrate disparate software programs providing real time navigation, collaborative communication and presentation of 3D & 4D Building Information Models.

Certainly the European community, particularly, and to some extent Australia, are further ahead of the USA in the widespread application of BIM. Europe is heavily committed to development of integrated building design technology with extensive work being done in the UK, Norway, Sweden, Finland, Germany and the Netherlands. Programs include Integrated IT Solutions by Nemetschek, NA noiXML whose Vector Works Fundamentals are architectural building programs that can plug into AutoCAD and CATIA, Landmark for site planning and Spotlight for lighting design. (Nemetscheck - Allplan, www.allplan.co.uk/ for architectural design and modeling software). Data Design Systems www.dds-bspco.uk/ has developed mechanical and electrical IFC compliant file systems. Meanwhile Zeit + Raum develops virtual building information models. TELKA develops structural programs. Obermeyer has project model orientated software. Octager has access an viewing technology. Mensch Machine has software for MEP CAD application. Graphisoft www.graphisoft.com ArchCAD 10 encompasses architectural design software and virtual building solutions, which will allow input of files into Energy Plus. Meanwhile EPM Technology, Norway has developed an IFC Model Server to share project model data.

Two of the major players in the architectural/engineering end of building design and modeling are Bentley and Autodesk. Both are collaborating with the buildingSMART initiative.

Bentley Solutions at www.bentley.com has Microstation and Intergraph as the primary products for building design, construction and operation. Recent enhancements include interface with gbXML for energy analysis using Trace 700 and tie into pipe and duct sizing, the latter using ddXML. Their suite of products include Tri Forma as an extension of

Microstation for 3D solid mass modeling geared to plant design. Other products under development include Bentley autoPIPE, Bentley Piping and Bentley HVAC. Also under development is Bentley Facilities for building owners and operators.

Autodesk at www.autodesk.com building solutions include AutoCAD www.autocad.com and Autodesk Revit (Building – Architectural; Structure – Structural Design; Systems Plus – MEP and Buzzsaw – Project Management Tools). Autodesk Building Systems (ABS) and Autodesk Desktop (ADT) are BIM compatible packages. ABS provides the special definition by analyzing CAD layouts identifying internal and external loads orientation, thermal zones etc. It can export to load calculations software such as TRACE and input results back to ABS It can also use the input data from TRACE for auto sizing and scheduling VAV boxes. http:/usaautodesk.com/adsk/servlet/index?siteID=123112&id=6861179

In 2006 Oracle launched a new collaborative Building Information Management Platform (CBIM) at the IAI Building Smart Conference in Munich. The Oracle CBIM www.oracle.com/openworld initiative provides a web accessed enterprise collaboration platform, which makes building information available to architects, project managers, building contractors, subcontractors, operators and facilities management firms from a single source. Oracle is working with Graphisoft to fully integrate building modeling tools with design collaboration, visualization, life cycle management and other applications.

There are even players like the Mayo Foundation (under the Mayo Clinic) are developing Mayo Graphical Integrated Computer Aided Design using MagiCAD software. MagiCAD developed by Program Oy of Sweden is IFC compliant and is used widely in Scandanavia and aimed primarily at duct design and equipment manufacturing, but including HVAC, piping and electrical design and application software (Running on an AutoCAD platform). These have the ability to feed data into Energy Plus using Olof Grandlund/LBNL developed BS Pro Com server middleware (with IFC based 3D RIM).

International Building Performance Simulation Association IBPSA www.ibpsa.org , a non profit organization, is developing building performance simulation specifically aimed at HVAC equipment, air flow in buildings, energy usage, as well as visual and acoustical environments. The annual SIM conference promotes building sustainability and performance through simulation.

Green Building Studio www.greenbuildingstudio.com offers open gbXML schema for direct data exchange offering web based building energy analysis tools integrating data from the BIM into DOE-2, BLAST, TRACE 700, EnergyPlus 1.4, etc. and exporting the results back into the BIM.

Examples of leading edge software for manufacturing and the factory floor are Pro E[6], Factory CAD[7], while for the plant facilities, Unix-based Catia at www.catia.ibm.com. , CC Plant, Tri Forma, Tri-Plan, Bentley Plant Solutions[6], Speedicon , digiPLANT, and autoPLANT, lead the way. These programs can now tackle the more complex elements of equipment layout, HVAC&R design and layout, including piping, sheet metal, equipment, and electrical services. They also are geared to support the complete life cycle from design through construction to operation and maintenance.

Other technologies are emerging, such Ansys CFX 5 computational fluid dynamic software allowing air flow simulation under laminar and turbulent states. Of even greater interest is the development of laser scanning of existing buildings and sites. Programs such as Cyra Technologies www.cyra.com and Leica Geosystems HDS Inc. www.leica-geosystems.com – can record site and as-built conditions and do geospatial imaging and engineering surveys while creating a database file that can be integrated into the building model. Disto laser scanning of existing buildings is tied to USD-M2 www.usdm2.co.uk .

Another interesting development is the work being done by the International Code Council. ICC has unveiled SMART Codes – an interoperable, automated code compliance checking system for checking compliance with the 2006 International Energy Conservation Code. This automatic checking system can yield an inspection check list or provide a 3D virtual walkthrough that tags non-compliant building components.

For a listing of current building systems related software it is worth visiting www.energytoolsdirectory.gov/

BARRIERS TO SUCCESS

The U.S. National Institute of Standards and Technology (NIST) recently published a study that identified and estimated the efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability among computer-aided design, engineering, and software systems. Although the focus of the study is on capital facilities-commercial/institutional buildings and industrial facilities - it benefits key stakeholders throughout the construction industry. This study - the conception, design, and publicity of which FIATECH was a strong and early contributor to - is based on an earlier report also done by NIST of the cost of interoperability in the U.S. automobile supply chain.

NIST GCR 04-867 estimates the cost of inadequate interoperability in the U.S. capital facilities industry conservatively to be $15.8 billion per year. These cost impacts are of interest to owners and operators of capital facilities; design, construction, operation and maintenance, and other providers of professional services in the capital facilities industry; and public- and private-sector research organizations engaged in developing interoperability solutions.

The construction industry itself is highly fragmented between design disciplines, construction trades, and material suppliers, with wide disparities in operational practices and technological development. Even large engineering companies that would, seemingly, have the resources to apply BIM technology are themselves often internally fragmented by multiple offices and operating divisions. As a result the design and construction industry significantly lags behind other industries (such as manufacturing, petro-chemical and aircraft) in exploiting technological advances.

Unlike the manufacturing industry, with its repetitive mass production processes that allows development of operational techniques to improve efficiency and reduce waste, the construction industry handles one of a kind building programs that are each uniquely designed and developed. It is a dichotomy that the very diversity and fragmentation in the industry, which could more fully benefit from BIM modeling technology, also hinders its development and acceptance. A Construction Industry Institute (CII) study indicates that the level of waste experienced in the manufacturing industry typically averages around 28% while that of the construction industry averages around 57%. Similarly the value added component of manufacturing averages 62%, while that of the construction industry is only 10%. (value added being defined as that component of design or construction team labor and cost that directly adds value for the client) . But it is this very disparity and the industry fragmentation that provides design and construction with such tremendous opportunities for improvement.

ISSUES AND BENEFITS

Of course development and use of all of this technology does not come without cost. Experience on large industrial projects ($75 to $150 million) indicates that currently the added design cost represents a 5% to 10% premium on the Architect-Engineers (A-E) fees (or roughly 0.25% to 0.5% on construction cost). The A-E cost premium can be quite a bit higher on smaller projects. More than offsetting this are all of the cost savings outlined above. Immediate savings of 3% to 7 ½ % have already been seen through improved coordination and reduced conflicts. (The Construction Industry Institute www.construction-institute.org/ analysis indicated a potential of 7% for this element alone). This can only increase as more trades come on board and BIM capabilities, such as shop drawings and quantity take-offs, are realized. Increased use of shop fabrication and elimination of waste is, itself, expected to produce savings of at least 7½ % to 10%. Recent experience in the construction of major automotive plants shows that it is possible to eliminate 20% sheet metal waste, develop programs 15% to 25% faster, reduce RFIs by 50%, eliminate 25% of all change orders and reduce construction cost by 4% to 10%. The greatest potential savings may come from the application of value added and lean construction techniques that BIM enables. Regardless, in the interim, A-Es must convince owners that this added investment justifies increased fees.

Table No.3 – Benefits of Building Information Modeling

• Provide visualization of project • Build fundamental intelligence into drawings • Provide a single database of information to meet the needs of all parties. • A valuable project management tool • Improve issue tracking process • Provide seamless flow of information • Provide automated bills of material Reduce the bidding time and effort • Automatically provide shop drawings • Facilitate off-site prefabrication • Simplify material ordering and site management • Improve field coordination and significantly reduce interferences • Reduce change orders • Save cost and time at every phase of design and construction • Provide owner with live/intelligent file records Provide electronic links for service and maintenance Facilitate peak building performance throughout a facilities life cycle

BIM can already demonstrate all of the individual elements listed in Table No.3. However it cannot yet achieve all of these benefits incrementally without separate interface. The interoperability of software components is still not there, requiring separate and distinct input and output data. Successful widespread implementation of BIM for fully integrated design, depends upon the ability of architects and engineers, as a design team, to be able to easily input and exchange data. The key then is for the integrated system to be able to continually and dynamically model the building and all of its systems, through daily and seasonal operational cycles. This then allows the “what if” scenarios to be played out utilizing different systems and components and allow them to be evaluated on a first cost, operating cost and life cycle cost basis. We are far from that point.

CONCLUSION

There is no question that the information technology required for these processes is very complex and quite difficult to implement and is straining the limits of designers' current hardware, software, and even staff capabilities. Much more work needs to be done to enable the technology to be applied on a day to day basis and we are still far from having an interoperable system that can enable fully integrated system design. The greatest opportunity lies with fully integrated multi-disciplinary A-Es practices and where BIM integration is being done as a continuum of the design process as well as the construction process.

Building Information Modeling is clearly gaining considerable momentum as the technology evolves and greater interoperability occurs between disparate software systems. The rapidly emerging goals of green building/sustainable design, towards net zero-energy buildings, coupled that with goals for carbon dioxide emissions reduction, will require "whole building" fully integrated design and construction as a dynamic process. BIM can help provide that integration.