Confluence of Building Information for Design, Construction and Management of Buildings

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Professionals who are involved in design, construction and occupancy phases of a building not only generate information that must eventually be used by other building professionals, but also they themselves must use data and informationprovided by others such as product manufacturers, planning departments, etc. The integration of information and data through all phases of the life cycle of a building is important as it impacts the work done by a large number of constituents in the building industry. Seamless integration of such information has been a bigger concern for those who are downstream users of the data generated by the architect as he/she designs a building. Such downstream users can range from structural engineers to construction managers, from facility managers to building asset managers. More recently, the considerable increase in the design and operationof intelligent buildings that incorporate a very wide range of technologies has rendered this coordination more important than ever.

1. Introduction

While in the past, the integration of building data/information has been mostly seen as a matter of data exchange between different AEC software and design professionals, more recently it has become apparent that without the full coordination of how information is coded, created and conveyed, it is not possible to create a fully seamless, integrated data and information exchange system. Furthermore, how this coding is done has become a major concern for all parties involved, since simply providing an information-coding mechanism such as a CAD standard proved itself to be greatly insufficient on two grounds: the manual creation of such a coding led to multiple versions of the coded information, since each office or agency tended to utilize its own unique system; secondly such a coding system did not necessarily serve to integrate the underlying data so that they can be seamlessly transferred to a downstream user such as a facility manager. Therefore, not only the confluence of building information has become necessary, but also standardization of the way building information is translated to data has become essential. This article builds a framework regarding the stages of the design process that require such a confluence of information and data, summarizes a few of the past efforts, and then brings some of the very recent efforts that attempt to integrate both data and information through the life cycle of a building to the attention of the reader.

Here, it is critical to make a distinction between data and information, and pay attention to the fact that standardizing one does not necessarily translate to the standardization of the other. Newer paradigms such as XML frameworks are aimed at seamlessly integrating information structures with data structures, but this again hinges on the assumption that there is an agreed upon framework for the coding of information which can then automatically translate to a data structure (during parsing of an XML code, this translation is not necessarily always done as seamlessly as one hopes that it would be, since the flexibility provided by the XML coding software can lead to more than one type of data structure. Here we have almost come full circle, as in the past, the interreliance of one on the other has not been fully understood and explored. However, the XML framework itself is forcing all parties involved to address this issue more explicitly.) Clearly other efforts, such as the Industry Foundation Classes (IFC) developed by the Industry Alliance for Interoperability (IAI) [1] recognizes the need to translate information standards to data standards and addresses both issues simultaneously.

The efforts to integrate and standardize data/information used by building professionals have intensified considerably during the past 5–7 years. In these efforts, the building industry started leading the way as well as non-profit organizations like CABA (Continental Automated Buildings Association) who published the Technology Roadmap (TRM) for Intelligent

Building Technologies in December 2002 [2], and FiaTech, which is, in their own words, a "non-profit consortium focused on fast-track development and deployment of technologies to substantially improve how capital projects and facilities are *designed*, *engineered*, *built and maintained*" [3] and have more recently published the "Capital Projects Technology Roadmap" [4] .

In late April 2004, a congress assembled by the American Institute of Architects in Washington DC brought together major players in the industry to discuss how data and information can better be integrated for the design, construction and use phases of a building. Invited panelists, including the author of this paper, discussed different methods of developing industry wide standards for the exchange of data and information. Representatives of AEC software companies such as Autodesk, Bentley and ArchiCAD, construction industry representatives such as the Construction Specifications Institute (CSI), Industry Alliance for Interoperability (IAI), National Institute of Building Sciences (NIBS), General Services Administration (GSA), Code Officials Association and technology integration organizations such as CABA and FiaTech were participants of this congress.

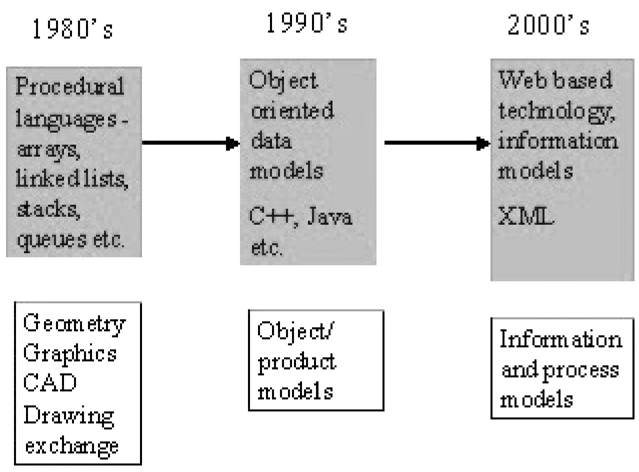
One must also mention many major architectural firms who use computer technology very creatively and in doing so, have come to the conclusion that seamless integration of data and information through all phases of the design process including the construction phase was essential for the most effective use of technology. It is not coincidental that, within the last two years, Frank Gehry Associates has launched a software company that is already revolutionizing the way we think technology should be used in the design/construction cycle of a building [5]. This effort does not currently include the use phase.

Currently, there seems to be a transition to the notion that the totality of the building must be considered from the very beginning, as indicated by Frank Gehry's approach to design [6] to the Whole Building movement [7] and the Capital Projects Technology Roadmap [8] developed by Fiatech. This is clearly a paradigm shift from piecemeal integration to wholesale integration of building data and information. One of the main implications of this approach for architectural firms is in the area of design communication, since, in the future, representation of buildings in 3-D will be the norm rather than the exception.

2. Evolution of the integration efforts

The evolution of standardization efforts cannot be separated from the phases of the life cycle of a building (Fig. 1):

- 1980's – efforts to develop graphics file exchange standards (such as IGES, and defacto DXF) as well as CAD drawing standards/conventions for *design communication* purposes.



► Figure 1. From data modeling to building information modeling

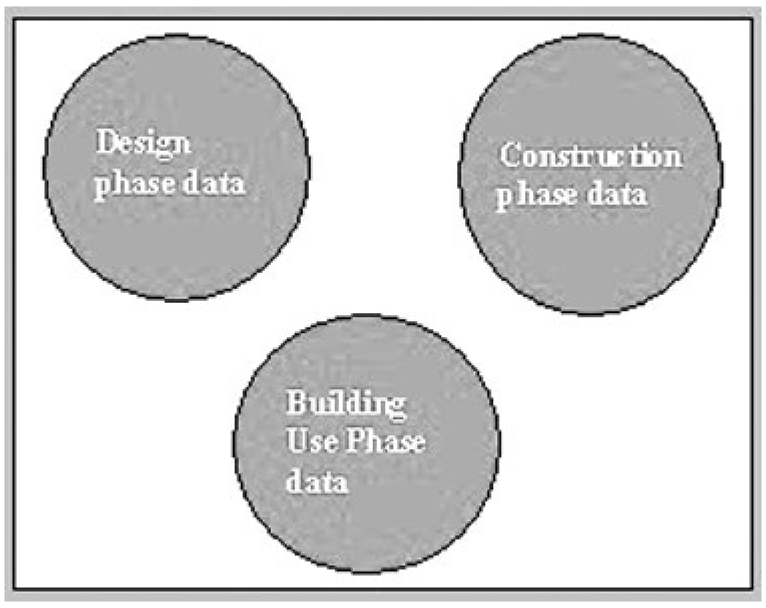
- 1990's – efforts to develop product information exchange standards, such as STEP, IFC for *design analysis* purposes.
- 2000's – efforts to standardize across *all three phases* of the life cycle of a building, namely design, construction and use phases (including the standardization of building information and AEC business processes.)
- 2005 – *Total Building* Movement – generate seamlessly integrated data and information within a jointly agreed upon framework that is based on an information coding system that reflects not only design "project" information and related design/construction processes but also "facility" information and related management processes.

The evolution of integration efforts is closely tied to the development of standards to share data, since when drafting software came about, people soon realized that without a standard data structure (mostly manifesting itself as an issue of "drawing data file structure"), it was not possible to exchange electronic information effectively. This not only led to efforts to standardize graphics file structures, but also led to efforts to develop (CAD) drawing standards/conventions. The latter was clearly more in the category of information coding, but it primarily addressed the information regarding the designed object during the design phase of a building. Construction and use phases as well as the design and business processes used by building professionals were not addressed, unlike the current efforts that focus on the integration of Building Information Management (BIM) systems. .

Historically, the AEC industry has been plagued by disconnects between data/information generated by a variety building professionals. What this author calls "the great information disconnect" (Fig. 2) has clearly been between:

- Design phase data and information (Project phase)
- Construction phase data and information (Project Phase)
- Building Use phase data and information (Facility Phase)

It is not accidental that those who complain about the lack of seamless integration of information the most are those who are at the downstream receiving end of design information such as facility managers, building asset managers, enterprise resource managers, etc., in short those who are involved with the use phase of a building. Historically the disconnect between the "project" data/information versus the "facility" data/information has been the greatest. Among the participants of the AIA congress mentioned above, the most organized and the most vocal group were those who were involved with the use phase of a building (building as a "facility") followed by those involved with the construction phase of buildings. Architects were seen as increasingly having the responsibility to provide design information that can be used by others in the AEC/FM industry sequence.



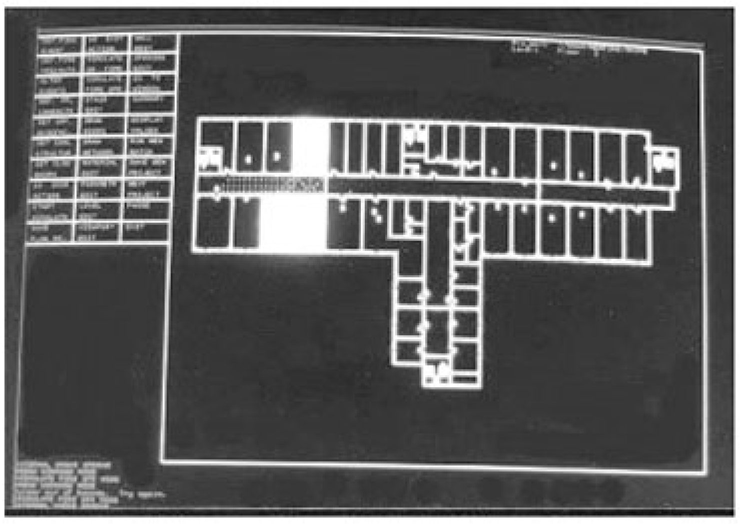
◀ Figure 2. The great information disconnect

2.1 Design Phase Integration

Design phase includes "information disconnects" between design communication, design analysis and design project management. Architectural and engineering design communication/representation has always been an important aspect of architectural education and practice, since without that neither can the architect describe the nature of the design he/she has in mind, nor can the engineer/construction professional understand how to construct/build the proposed design. Unfortunately, data models created as a result of visual representation of designs have rarely been useful in the analysis phase, since these models lack the information needed to describe the complex relationship between building parts or knowledge about how such objects behave in the real world.

Present day blue print conventions were primarily established in the 19th century with the increased industrialization and specialization of the AEC industry. Thus these blue print conventions were established long before CAD and computer based representation became common practice. As with any new technology, conceptually CAD was seen as a continuation of manual drawing/drafting conventions, thus did not explore the potentials of the new digital media such as its ability to seamlessly represent objects in 2-D and 3-D (they can be simply different views of the same object), dynamically linking non-graphic information to objects, the ability to organize/retrieve building related information with ease that is normally not possible by manual methods, and the ability to manage design .

Nevertheless, the blue print conventions that became the foundation for initial CAD systems continue to dominate the way proposed designs are represented in the AEC industry even in the present day, almost 20 years after the first examples of CAD systems were developed [9] [10]. As a result of this, CAD drawing conventions (standard layer names, sheet names/numbers, etc.) still continue to be used to code "project" information [11].



► Figure 3. An early example of software with data structure that allowed design analysis, ArchFire based on CAEADS software data structure [12]

Among these CAD conventions, the following can be named:

- AIA (American Institute of Architects)
- BS1192 (UK)
- ISO 13567 (International Standards Organization)

- NCS – National CAD Standards (US), etc.
- Version 1.0 of the AEC (UK) CAD Standard, released in May 2002

(For a discussion of standardization efforts in the UK, please see [13])

Clearly, the AEC/FM (architecture, engineering, construction/facilities management) industry is no longer only concerned with CAD standards, but is very much concerned about how to seamlessly manage building information (BIM). The possibility of incorporating design analysis (Fig. 3) and design project management information into the totality of the design process shifted the focus of design representation from visual representation/graphics data exchange to information representation and management, as evidenced by the shifting of the focus of commercial CAD systems to information management, examples of which are Architectural Desktop and Revit by AutoDesk [14], ArchiCAD [15], Bentley's MicroStation and ProjectWise [16], AllPlan by Nemetschek [17], etc.

The development of 3D Building information exchange based on XML framework has also attracted the attention of many AEC software companies:

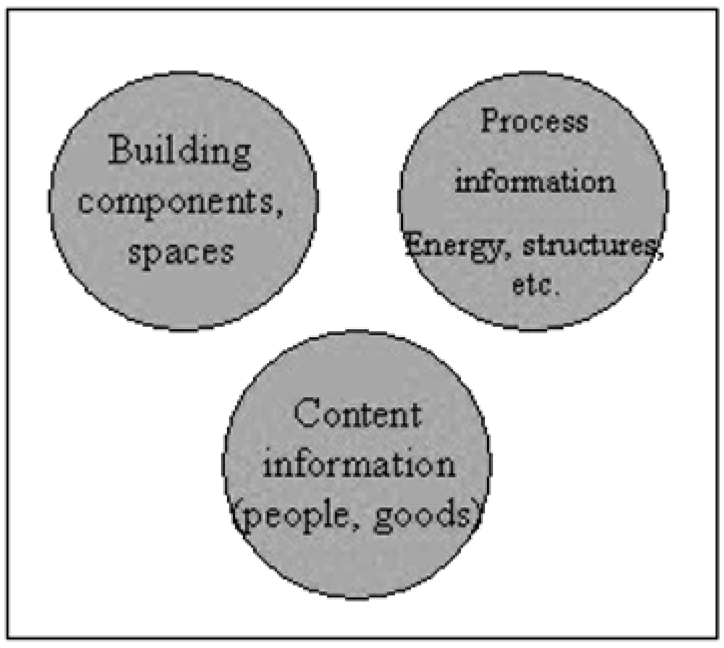
- aecXML (Bentley) – primarily non-graphic data
- IfcXML (Industry Alliance for Interoperability) – primarily graphic data, but also some non-graphic data
- BlisXML (General object relationship builder)
- General 2d/3d CAD/drawing data exchange – DesignXML (Autodesk)

2.2 Design Analysis

Obviously, information representation for design communication purposes is not sufficient for design analysis purposes. New structures are needed. "Information and data modeling disconnects" for design analysis include the disconnect between the information about building components/spaces, building processes (behavior) and building content (Fig. 4). Analysis requires the representation of buildings and their components as objects with unique attributes, behaviors and relationships to each other, and to the whole. Design analysis such as those for:

- Cost analysis
- Energy analysis
- Fire spread models
- Structural analysis models
- Navigation of people, goods, etc. requires very complex information coding and data structures.

Earliest examples of software that can support design analysis through the



► Figure 4. The great disconnect in data needs of the design analysis stage.

representation of architectural elements, relationships, components are:

- CAEADS (University of Michigan and Carnegie Mellon University) – Developed for the US Army Core of Engineers – ~1980–84
- BLAST – energy analysis
- ArchFire – Life safety code analysis

Unfortunately, these early examples remained to be isolated attempts to model data structures for building components and spaces that allow design analysis. Therefore, as represented in Figure 4, a disconnect between data models that will support three different aspects of design analysis remains to this day: namely the disconnect between data models for buildings objects, data models for the analysis process such as energy, fire spread, acoustics, etc, and data structures for content such as furniture, people, goods and materials. Most of the current efforts by ASHRAE [18] and others now focus on the disconnect between the first two. For example, for modeling energy performance of a building, one must not only model its geometry, but also model individual spaces, conglomerate of spaces such as zones, materials for each building component that impact its performance, the size and composition of materials since building components are usually made out of composite materials, etc. Other issues such as heat gain due to content such as people or heat retention due to objects with solid mass must also be a consideration as the energy performance of a building is modeled by using geometry based data model, although traditional mathematical models have been very successful in capturing energy performance of a building as a whole.

Similar issues exist for life cycle analysis where one must calculate the environmental impact of mass and energy flow for each component of a building, making life cycle analysis the most complex and comprehensive of all analysis efforts when it comes to building performance. The latter becomes even more complex when the environmental impact of large sections of towns or new developments must be based on life cycle performance of each individual building unit. Therefore, the disconnect at design analysis stage is one of the most difficult aspects of building data and information modeling for AEC software purposes. Issues such as very large databases, spatial reasoning algorithms, data structures that will easily handle the relationship of objects in 3D space and most importantly a user interface that can build the necessary backend without encumbering the user's time and effort to an unnecessary degree have become very important issues. Furthermore, the inability of analysis software to exchange data and information seamlessly with design communication software became an impediment to the use of such software through all phases of the design process.

- Design Analysis information exchange based on XML framework:
- Landscape/surveying information (subpart of aecXML) – LandXML
- Energy Simulation – enerXML
- Simulation/performance analysis – bmXML (General building model)

A new area that is emerging in design analysis has to do with the security and safety performance analysis of buildings. For this, not only must building information be available, but also information regarding hazardous building contents for emergency response purposes must be available.

To address the great information disconnect in the AEC industry, numerous attempts have been made. Among the collaborative efforts, the most widely known ones are:

- STEP – for exchange of product model data based on an information modeling language (SDAI – standard data access interface)
- IAI – Industry Alliance for Interoperability, compliance with Industry Foundation Classes (IFC) is becoming a standard for most AEC software as well as other specialized analysis software
- National CAD standard – AIA-CSI-NIBS through NIBS' consensus building process

2.3 Construction Phase Disconnects

Data/information disconnects between design and construction phases are causing loss in productivity and seamless transition. Current construction management software typically require the input of most data from scratch, and very complex construction projects such as high rises, sports complexes, hotels, etc. need very versatile tracking and scheduling systems for the thousands of parts and tasks needed for the completion of the building. Seamless integration of data between design communication software such as CAD and 3D modelers and spatial data management software can be infinitely useful as it can save endless hours of data input. In the congress at the American Institute of Architects in April 2004, such downstream users of design data were quite vocal regarding the need for seamless integration of data. Some of the current applications geared towards the construction industry can be listed in the following areas:

- Project scheduling/project management software (propriety format)
- Cost estimating, quantity surveying software (propriety format)
- Cost Analysis – Timberline, Primavera, etc.
- Precast concrete design software
- Steel structure design software

Examples of construction and e-business information exchange systems based on XML framework:

- E-business applications in design- ebXML
- Center for e-business in Construction – citeXML
- Building Construction – bcXML

Among the most creative uses of technology that can seamlessly connect design phase to the construction/manufacturing phase is clearly the parametric approach taken by Frank Gehry's office through the use of CATIA software. According to the companies' WEB site [19]. "Gehry Technologies, LLC (GT) was established in 2002 to provide advanced building delivery technologies to the AEC industries. GT brings the experience of fourteen years in technology and process innovation to its clients, leveraging the very best in digital tools for building design and construction." The platform called Digital ProjectTM is intended to revolutionize management of architectural projects by enhancing 3D collaboration between design and construction teams. Gehry Technologies views three dimensional models of construction information as components of the project contract documentation, thus promoting the integration of 2D and 3D digital models. This is revolutionary, in the sense that 3-D modeling is the first step towards manufacturing of building components, thus is no longer an afterthought or a luxury. Similar 3-D approaches to design communication exist in other software such as ArchiCAD, but not as directly connected to manufacturing. On the other hand, Gehry Technoloigies' effort still clearly targets the "project" rather than the whole continuum of "design project and facility".

Other standardization efforts to cover the full span of design and construction phases have been successfully geared towards pre-cast or premanufactured building components such as steel and pre-cast concrete for obvious reasons. Due to the nature of the manufacturing processes where these elements come in a limited number of sizes and configurations, manufacturers of these building components were able to support an initiative to seamlessly exchange data between design and construction phases [20].

Standardization of the way building materials are specified has been an important concern of the Construction Specifications Institute (CSI) for quite some time. CSI standards such as MasterFormat and Uniformat are now widely used in the industry [21], but are yet to find its way into the design communication software as well as into other data/information integration efforts.

2.4 Use-phase data/information needs

The use-phase of a building poses an important challenge in the sense that building uses and their data/information needs are very varied and different from the data and information needs of the other two phases, namely design and construction. Below are some examples of the areas that require building information at the use phase:

- Facility management (FM)
- Building asset management
- Enterprise resource management
- Real estate management
- Spatial data management, GIS (CAD – GIS interface)

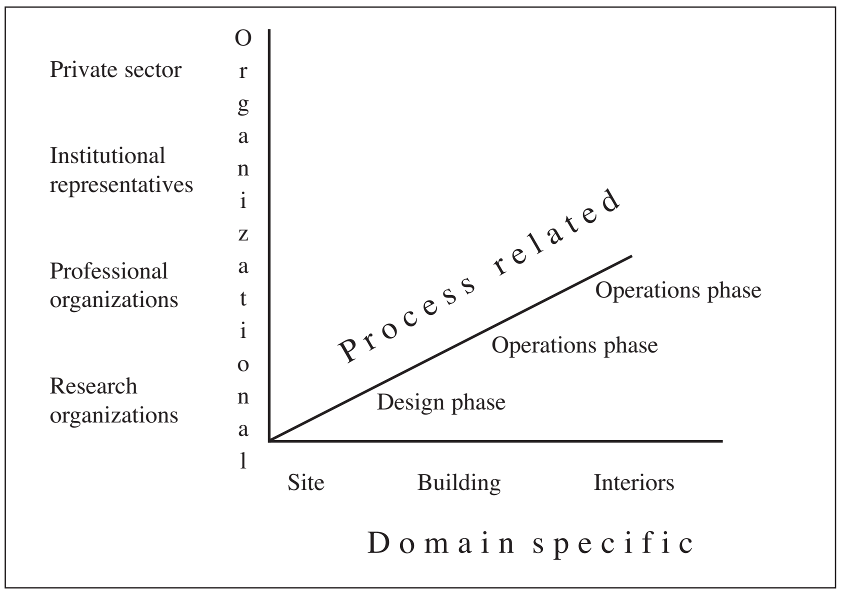
Industry groups such as FiaTech [22] are now gearing towards producing full building information management software and are primarily focusing on the use phase of a building ("facility"). According to this organization's WEB site "The Capital Projects Technology Roadmap (CPTR or the Roadmap) is a cooperative effort of associations, consortia, U.S. 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." [23]. The vision in this roadmap clearly represents the confluence of data and information in a highly automated "project and facility" management continuum integrated across all phases of the facility lifecycle. This is much different than what has been envisioned in the past through product models of buildings as well as through process models for the design process. It aims to revolutionize the project delivery process through an integrated environment that creates data and information for the total building (design "project" and "facility"). Fiatech envisions a system though which all project partners and project functions can instantly and securely "plug together their operations and systems".

On the other hand, technology integrated buildings called "intelligent buildings" are emerging as important users of building information during occupancy/use phase, since such spatial and geometric information as well as component behavior are necessary for effective operation of an intelligent building [24].

Business-to-business software solutions are beginning to become the norm in the business world, thus standardization and seamless information integration in the AEC industry closely relates to the development of B-to-B software solutions. That is why these initiatives are spearheaded by the industry and by AIA rather than by academicians or by governmental agencies, although they are partners in these efforts. Some U.S. governmental agencies such asGeneral Services Administration (GSA) with literally hundreds of thousands of square footage to manage in federally owned buildings has been at the forefront of the data integration efforts, since they are such a major downstream user of design data.

The business to business aspect of the AEC industry can clearly benefit from the confluence of data and information for the total building, since aspects such as integrated, automated procurement & supply networks as well as intelligent & automated construction job sites and intelligent self-maintaining and repairing operational facilities [23] can be envisioned by seamlessly integrating the business processes of different stakeholders. Linking to manufacturers' databases and business processes for new materials, methods, products & equipment is another aspect of this vision. The Capital Projects Roadmap by Fiatech clearly aims to address the business to business coordination and integration of processes, thus is a vision that goes much beyond the process of only sharing data and information. This is a much more all encompassing vision than Gehry Associates', which primarily focuses on an integrated and technology-enabled design and construction project delivery system.

► Figure 5. Issues in standardization



National Institute of Standards and Technologies' Computer Integrated Building Processes Group [25] is a U.S. government agency whose objective is to develop "standard building information models (BIM) facilitating the simulation of building system behavior during adverse events and enable ready access to BIM data by building owners and other parties". This group stresses the national security dimension of gathering building information for simulation purposes, and brings the argument that creating an extensive building information system from early on (i.e. during design phase) can prevent loss of valuable facility information as time passes by while also eliminating the need to duplicate effort by creating building information system for the facility's use phase during the design project and construction phases [26].

This vision takes the building information management (BIM) issue much beyond a single building or project, and sees it as a matter of maintaining a large scale building information system for safety and security purposes. Smaller scale versions of this concept have already been implemented at the local level for many municipalities for emergency response and management purposes. This represents the ultimate confluence of information and data regarding the built environment, since it can cover millions of buildings and large urban areas, as urban population centers of the world grow faster than ever.

5. Overview and issues related to integration

The need for a common data/information model for the full life cycle of the built environment (full range from site to individual building elements) has become urgent with the increased data use by downstream data users. The sheer scale of the building industry and the variety of professions/businesses that contribute to this industry is a challenge in the development of a standard model. Issues in data/information modeling for buildings can be summarized as seen in Figure 5.

There is need for a standard scalable model that can be small enough for simple applications, but robust enough for use for software spanning the whole life cycle of a building, and a model that is based on typical business processes used by businesses in all phases of the life cycle of a building. The adaptability of the standard model to variations in the business models that are employed in the AEC/FM industry is also very important. Organizational aspects of standardization and integration efforts are no doubt very complex.

3.1 Incentives

Progress can only be made if the software industry representatives, U.S. governmental agencies, local administrations such those for cities and counties, architectural firms, engineering consultants and use phase constituents work together to develop and adopt standards in building information modeling. Some of the incentives for such intense level of collaboration are:

- Increased marketability of software that are based on standard data models
- More effective research and development – eliminating the need for reinventing the wheel
- And most importantly, the potential for integrating business processes across multiple phases of the life cycle of a building that can lead to cost savings in document generation for describing buildings. AEC/FM industry has major responsibility to produce documents related to the design, construction and use of a building. Therefore, seamless integration of data can lead to significant cost savings by eliminating the need for duplication of efforts.

3.2 Challenges

Challenges to achieving a uniform building information model that can seamlessly integrate data used by all parties involved in the AEC/FM continuum are numerous.

- Organizational – The very large scale of the AEC industry is a major challenge to achieving standardization. Furthermore very varied constituents such as those in the private AEC industry as well as the institutional and governmental agencies must come together to achieve this. Professional organizations such as the AIA [27] and academia/research representatives can assist in the coordination effort necessary for the development of such standards.
- Intellectual property rights – especially software industry must be willing to go beyond individual propriety formats and data structures.
- The very varied nature of the software needs of the AEC/FM industry as summarized before
- Buy-in from the general AEC/FM community is critical to the wide spread use and adoption of the standards, even after such standards are successfully developed.
- Coming up with a consensus building model is a very important asepct of the process of developing standards. In fact, some of the early efforts are directed towards the development of processes for consensus building such as the congress held at AIA heandquarters in April 2004.
- Addressing international/global aspects of building information modeling is critical within the current environment of the AEC/FM industry that is becoming increasingly global. Large companies as

well as governmental agencies now own building assets throughout the world, and keeping track of these is a critical part of their enterprise.
- Coordination of the standards developed in the U.S. with world wide constituents.
- Architectural community buy-in is important since this is where the initial building information is generated that will have to be transferred to downstream information users.
- Accreditation and licensing agencies can help facilitate the wide spread adoption of these standards by including knowledge/understanding of building information standards as part of the competency requirements.

In spite of the challenges, the opportunities for collaboration and coordination are abound, and the AEC/FM industry is very much willing to embrace these opportunities. The constitutents of the industry very well know that in this era of globalization and e-business environment, their future may depend on their success in developing a seamless environment that can facilitate fundamental business-to-business transactions. Other industries have long embraced such practices, and it is time for the largest industry in the world in terms of real assets, to embrace similar business practices.

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