Technical Challenges for Integrated Design and Delivery Solutions in Civil and Building Engineering

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Abstract

Integrated Design and Delivery Solutions (IDDS) are defined by CIB as follows: "*Integrated Design and Delivery Solutions use collaborative work processes and enhanced skills, with integrated data, information, and knowledge management to minimize structural and process inefficiencies and to enhance the value delivered during design, build, and operation, and across projects*." (CIB, 2009). Conceptually, the development of an extensible infrastructure for IDDS appears to be a straight-forward matter, made difficult by the sheer size of the information needs of the domain. To that extent, there are few current implementations in existence, and the majority of those that do exist are bespoke developments which support a restricted number of processes and analyses.

This paper characterizes the variety of technical challenges which are faced by those delivering on the promise of integrated design and delivery solutions. Alongside each of these challenges it identifies current approaches to supporting IDDS, both at a commercial level, and from the viewpoint of researchers working on future improvements to the IDDS ideal.

Keywords: Integrated design and delivery solutions, IT future, Interoperability.

1 Introduction

The CIB (International Council for Research and Innovation in Building and Construction) comprises approximately 500 member organisations and manages over 50 task groups and working commissions on all major aspects of building and construction. Over the past decade it has developed a range of high-level priority themes that cut across the very specific nature of the working commissions, and draws on the synergies of experts across all of CIB. IDDS is the latest of the priority themes developed by CIB to help drive a global change in research and collaboration internationally.

In developing the IDDS theme the CIB recognises three major aspects that form the core viewpoints for a successful IDDS. These aspects are: the technological viewpoint of tools and techniques which can support IDDS; the processes which are impacted and improved by the adoption of IDDS; and the people who must interact with technologies to accomplish the necessary processes in a project. While the process and people aspects are vital to the successful development of IDDS, they fall outside of the scope of this paper and will not be explicitly considered here.

Currently, there are very few integrated solutions available in the marketplace, and those that do exist are of limited scope. Typical solutions proffered by major CAD vendors tightly couple a small set of software tools covering a limited set of processes and analyses. These software tools are often not the set in use by the partner organisations that come together for any one project, and integrating the software tools of preference is time-consuming and usually not practical for just a single project.

Open standard-based approaches to achieve interoperability for a selected set of processes and domains are in existence. These come in the form of STEP, IFC, etc data standards, although their limited uptake means that their penetration into the IDDS space is also limited.

Current approaches to IDDS are inadequate, with numerous issues still to be addressed. For IDDS to become commonplace the technology needs to be ubiquitous and mostly invisible. Approaches to integration and interoperability should not require highly specialised knowledge of data models, data transport formats, and collaboration technologies. To be successful these details need to be hidden from the users view, as we see with successful technologies such as email. The remainder of this paper considers the suite of technical tiers that form an IDDS and then discusses the progress and challenges for each of the major tiers to progress to this state.

2 IDDS technical tiers

To focus on the necessary technical needs of an IDDS, we consider the range of technologies in a layered fashion as shown in Figure 1.

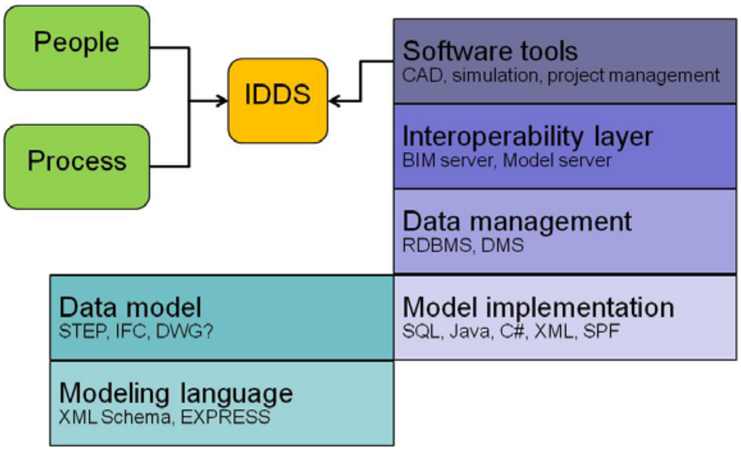

Figure 1. IDDS technical tiers (Amor, 2009).

At the lowest level in this model we identify abstract aspects of modeling as specified in one of many popular modeling languages. Of particular interest to the A/E/C-FM industries is the EXPRESS data modeling language, and the more modern and less specialized XML Schema language.

Through the use of such modeling languages, domain experts are able to develop and agree upon domain specific data models. This is the work undertaken by groups such as ISO and IAI for A/E/C-FM domains.

Once data models are specified and agreed, implementers make choices about how the data model is implemented through deployment in a particular programming language or data description language. These languages have different strengths and weaknesses, and hence different choices suit particular implementations to a greater or lesser degree.

Data management choices determine where data resides in an IDDS, and again provide for differing levels of support for particular operations on the data for a project.

The interoperability layer provides the range of services that enables software tools to share data across the IDDS and ensure the semantic integrity of the data as it moves from user to user and process to process.

Finally, software tools provide the particular functionality that enables users to action a particular process in the design and delivery of a project.

3 Data models

3.1 Data model progress

Decades of development effort have seen a range of significant data models developed for A/E/C-FM domains from both commercial vendors and the standards community (Eastman, 1999). The largest of these data models exist in commercial CAD systems, especially those which offer a BIM platform, and in the standards arena. For example, the latest version of the open IFC data model has over 600 class definitions (IAI, 2009).

3.2 Data model challenges

The further development of these data models to have greater coverage of the A/E/C-FM domain becomes an increasingly difficult task. Current models are sufficient for the particular processes which form the basis of their development, but to extend further requires significant expertise from modellers who need to understand the existing models as well as the new domains which must be woven into the current data model structure. As with any software development process, additions require an increasing effort as the system grows in size and the likelihood of unintended consequences increases (Sommerville, 2006). Testing the model's correctness becomes more complex and costly, which affects both modellers and the eventual implementers of data models.

Decisions on the level of modelling required in data models does not seem to be explicitly addressed to date, aside from the pragmatic requirements of particular processes. In comparison with the over 15,000 distinct products found in comprehensive classification systems, the 600 classes in today's open data models would indicate a significant gulf in required modelling. It is also not clear the extent to which an individual data model should cover A/E/C-FM domains. A single monolithic data model is not considered feasible (Amor and Faraj, 2001), and significant data models exist, or are in development, for domains such as infrastructure, GIS, plant, furniture, etc. Where, and how, interfaces to these models are made is not currently considered. The utility of agile data representations is still on the research agenda (Christiansson et al., 2008; Yurchyshyna et al., 2007; Grilo et al., 2007), reflecting the success that agile standards tend to have in the marketplace (e.g., HTML, XML, etc).

The development of process specific sub-views of an underlying comprehensive data model (e.g., Model View Definitions (MVD) in IFC) seems instrumental in the management of data model complexity, implementation costs, testing costs, and in reducing the impact of extensions to the underlying data model. However, this is also a major undertaking and it is significant that only one sub-view has currently been developed by the IAI for the IFC data model.

4 Data management

4.1 Data management progress

The management of data for individual design tools and CAD packages is an area which receives considerable attention from developers of those packages. Representations and storage structures are chosen to ease the process of accessing required data, and to minimize the amount of data to be transferred between applications. This approach also works well where several applications utilize the same optimized representation of building information (e.g., a DWG file).

4.2 Data management challenges

Utilizing standard data models introduces significant data management issues. In particular, the data files for these models are of a significant size. This is partially due to the requirements to create complete and consistent data against the standard data model, which often requires significantly more data than preferred by a software tool. The size is also due to plain text representations, such as XML or SPF, used to encode the data. With data files currently reaching hundreds of megabytes, the transportation and storage of evolving project descriptions is a bottleneck in IDDS.

There is also a significant overhead in processing standard data files of this size into, and out of, the internal representation required by every software tool. This impacts as both a computationally costly process to handle the millions of objects which need to be mapped, and also a potentially error-prone process depending on the sophistication of the mapping specification utilised by the software tool. It is unsurprising that many software tools drop data which is not required for their analyses when processing such data files, though this creates issues further down-stream when a modified data model needs to be supplied to another application. Sophisticated transactional approaches to access and modify data over the long transaction times (see Gray and Reuter, 1993) in A/E/C-FM need to become a standard part of an IDDS.

Alongside research and development for transactional issues there are also many softer data management issues which require standard approaches. These include management of ownership information for data to protect intellectual property rights, inclusion of provenance information, notification and management of change propagation, and archiving of data models. New forms of data will also impact on data management, especially when real-time information (e.g., sensor data, video feeds, etc) is tracked alongside the evolving project data (Soibelman et al., 2008).

5 Interoperability

5.1 Interoperability progress

Currently there exist small groupings of interoperating applications in a tightly coupled environment. These groupings tend to form around a particular CAD system and link together applications covering major processes within A/E/C-FM (Eastman et al., 2008). There are also demonstrations of such approaches centred around open data standards with a wider grouping of software tools.

5.2 Interoperability challenges

Ensuring the correctness of project information within an interoperable environment provides significant challenges for A/E/C-FM. The problems obvious in Figure 2 are fairly typical of the issues found even in the software tools from major companies with large development and testing teams. It is a challenge which is unlikely to have a perfect solution, as with any software development with complex requirements it is not possible to guarantee the correctness of the resultant system (Sommerville, 2006). The specification of mappings between 600 classes and the internal structure of the representation of a software tool has large and complex requirements.

Improving interoperability in A/E/C-FM is a major research goal for researchers in this domain (Gursel et al., 2009; Wang et al., 2009; Ball et al., 2008; Amor et al., 2007; Lipman, 2006; Ma et al., 2006; Pazlar and Turk, 2006), and it is clear that new approaches to managing conformance testing are possible, and will be required, to ensure confidence in IDDS. It is also clear that the stringency of conformance testing for certification needs to be balanced against the cost to implementers of significant conformance testing regimes.

The majority of research and commercial IDDS approaches utilise a star configuration with a central repository for project data. While such an approach simplifies a number of interoperability issues it does not suit the structures in A/E/C-FM. The development of federated approaches would increase the flexibility of IDDS, and resolve a number of data management issues such as ownership of data.

Support for knowledge management is evolving in our industries (Kazi and Wolf, 2006) but have not reached particularly sophisticated levels. Management of knowledge (e.g., design intent) at all the levels required, such as individually, for particular processes, for an individual project, for a company, and at an industry or country level are not possible with current approaches

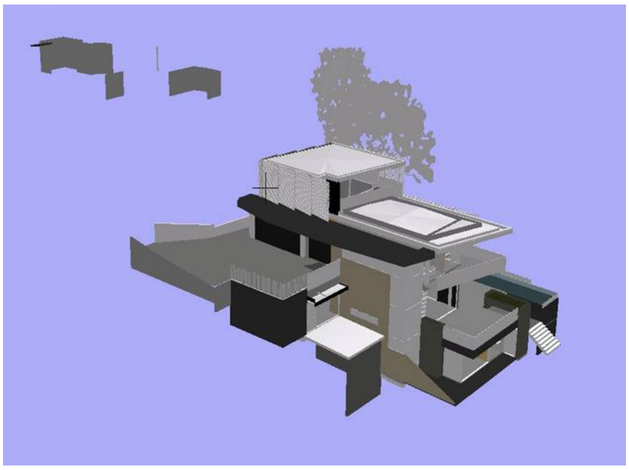

Figure 2. Poor interoperability due to incorrect mappings.

6 Software tools

6.1 Software tool progress

The A/E/C-FM industries are well served by software applications addressing various national markets and the wide range of processes in the industry (over 4,500 individual software tools were identified by Turk and Cerovšek (2000)). Collision detection and simulation is now a standard process in design stages of projects. The use of 4D tools and 5D (cost) simulation is becoming common and parametric CAD is available to the mass market.

6.2 Software tool challenges

With Autodesk estimating a person year's effort to implement a complete interface to standard data models such as IFC it is clear that the impact on an industry with over 4,500 software tools is astronomical. Identifying methods to support interoperability with less overhead will be necessary to reach the majority of software tools in the industry.

Bridging the gap between results provided by simulation tools and the real-life performance of a constructed facility is an ongoing research issue. To ensure greater benefit and utility from the powerful simulation tools available will require new approaches to resolve the gaps seen today.

Greater emphasis on human-computer interaction in our software tools has the potential to increase productivity, reduce error rates, and enable greater collaboration and communication in an IDDS.

7 Conclusions

In choosing to move towards IDDS as an approach for the A/E/C-FM industries there are a range of issues which impact on the people in the industry, the processes they undertake over a project, and the technologies that support them. There is obvious support for many of the core areas identified when considering the range of technologies required for IDDS. However, it is also clear that the technologies in place today are only the first incarnation of what will be required in the future. For each layer in the technology stack required for IDDS there are significant challenges to be addressed before we can claim to have reached the level of support required by the people and processes in this industry.

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