A Multi-Disciplinary Design Studio using a Shared IFC Building Model

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Abstract: This paper reports on a multi-disciplinary building design studio where a shared IFC (Industry Foundation Classes) building model was employed to support a collaborative design process in a studio-teaching environment. This project began with the premise that the efforts over the past decade of the International Alliance for Interoperability (IAI) to develop a genuinely operational building model schema has resulted in a mature technology that is now ready to be applied. This design studio experience sought to test that premise. The paper discusses the background to the idea of design collaboration based on a shared building model, placing this current work within that context. We look at both the nature of design decision-making, as well as the process opportunities afforded by close multi-disciplinary collaboration and rapid feedback from design analysis. Although the work was undertaken in a teaching context, the paper does not discuss the pedagogical issue, but rather concentrates on the operational issues that are encountered when working with a shared building model during a design process. The paper concludes with a statement of the lessons learnt and strategies to be adopted in future projects of this nature.

1 INTRODUCTION

During the past decade, the International Alliance for Interoperability (IAI) has undertaken a worldwide effort to develop a model schema that is able to support a semantically rich representation of a building for use during the life-cycle design and management of a project (IAI 2004). The model schema is defined in the EXPRESS language in accordance with ISO STEP (Standard for the Exchange of Product Data) and has become known as IFC (standing for “Industry Foundation Classes”). In effect, the IFC schema defines a standardised file format that can be used as a mechanism for sharing building information between CAD (computer aided design) systems and an ever-expanding range of design analysis tools. Furthermore, the IFC model schema can be loaded into a STEP model server, providing the opportunity to hold the building model as an object database on a central shared computer and accessible across the Internet as a resource to support collaborative design.

This paper reports on a project in which a shared IFC building model was used as the basis of a multi-disciplinary design studio taught at the University of New South Wales (UNSW), Australia, during the second half of 2004. Our decision to undertake this project was motivated by a recognition that IFC development had reached an important milestone, and it was time to introduce its use into a learning context and begin testing its efficacy as a design support technology. The class was run as a conventional architectural design studio over a 14-week semester (equivalent to 25% of a student's course load) and brought together 23 senior students from a variety of disciplines including architecture, interior architecture, landscape architecture, mechanical and services engineering, statutory planning, environmental sustainability, construction management and design computing.

The aim of this work was to review the efficacy of existing building modelling technology when used in a multi-disciplinary design context. It had three objectives: to examine the impact of using a shared building model in a collaborative design setting; to develop an understanding of the type of information required in a building model in order to support effective design collaboration; and to critique the current IFC standard (Release 2x2), and some of the major applications that support IFC technology. This paper focuses on the last two of those objectives, reporting primarily on the operational issues surrounding the use of a shared building model in a multi-disciplinary design context. Our interest is to consider the scope of the IFC model and to report on our experiences when an attempt was made to use the model to support a design process.

The paper begins with a review of the research context, specifically identifying recent efforts to develop or propose the use of shared building models to support collaborative architectural design processes. It then provides a brief outline of the project sufficient to explain the context of this research. The body of the paper identifies the key issues that emerged from this experience with respect to the nature of the information that can or should be held in a shared building model in order to support effective collaboration within a multi-disciplinary team. The paper concludes with a series of recommendations for further work.

2 RESEARCH CONTEXT

The notion that building design is a multi-disciplinary process involving contributions from an increasingly broad team of specialists is well understood and generally accepted. Thomas Kvan, in a thoughtful discussion of design collaboration, concludes that building design is correctly described as a co-operative process with brief episodes of collaboration where team members come together to resolve issues through negotiation and evaluation (Kvan 2000). He then goes further to argue that it inevitably involves compromise, being very careful to position that as a positive thing since it can often lead to design innovation. In a complementary work, surveying a broad range of research into the nature of design collaboration, Nancy Cheng concludes that "better interfaces for communicating design information and standardized file information and procedures could streamline team interaction (…) they must integrate visualization with building performance and provide useful functionality throughout the building life cycle" (Cheng 2003). It is the contention of this present work that shared building models provide exactly that, and when combined with appropriate work processes, can lead to effective teamwork and significant improvements in the life-cycle management of facilities.

We can trace the history of building modelling back to the earliest days of CAD development, but it has been during the past decade that significant work has been undertaken to understand how such systems can be effectively used to support building design. Three key examples will serve to illustrate those developments, each providing particular insights into issues of design collaboration. Eastman and Jeng are well known for their EDM-2 project, where the central focus was to address the issue of maintaining multiple disciplinary views of a core building model to allow simultaneous access while still maintaining the integrity of the data (Eastman and Jeng 1999). As we will see later in this paper, this was a key issue for us in our project, and raises one of the most critical issues for the on-going development of shared building model technologies. At about the same time, Yehuda Kalay's P3 project was built around a clearly articulated understanding of design collaboration. He pointed to the fragmented nature of the building industry where each specialist has their own view and set of objectives, arguing that design collaboration works best where those same specialists adopt what he called a "super-paradigm", agreeing to a course of action to achieve a common goal for the whole project, rather than narrowly considering their own objectives in isolation (Kalay 1998). The third example is the ID'EST project reported by (Kim, Liebich and Maver 1997). This project demonstrated that a CAD model could be mapped on to a product database implemented using STEP technology so that the data could be analysed by a variety of evaluation tools as a way of testing its design performance. Although that work has been subsequently overtaken by the development of IFC technology, its remains as a significant example of this approach.

Since that pioneering work of the mid-nineties, we have seen the steady emergence of IFC technology, fostered by an international team of researchers determined to promote a building model approach to facility procurement. Perhaps the most significant demonstration of the efficacy of that technology is given in (Fischer and Kam 2002), a report on the HUT-600 auditorium extension project at Helsinki University of Technology, where IFC technology was used to facilitate data exchange among the major design partners in the project. The benefits observed in this project were summed up in these words, "compared to a conventional approach, these relatively seamless data exchange and technology tools substantially expedited design and improved the quality of interdisciplinary collaboration" (Fischer and Kam 2002, 4). Our approach, working with a small multi-disciplinary team of students, seeks to complement such industry-based studies by focusing on specific operational issues.

We are not aware of any other work that has tested the IFC model in the way that we have attempted, but there are several critiques in the literature of the building modelling approach to support collaboration. These are all useful as they highlight specific issues that need to be considered and addressed. Per Galle's list of 10 desirable features of what he terms CMB (Computer Modelling of Buildings) serves as a very valuable starting point in this discussion (Galle 1995). More recently, (Halfawy and Froese 2002) recommend several specific directions for the IFC development, specifically proposing a strategy to incorporate more “intelligence” into the model. Pham and Dawson, though strongly supportive of building modelling as a design technology, point to the complexity of information transfer that occurs in a typical building project and the need to rigorously understand exactly how that information can be captured effectively (Pham and Dawson 2003). Finally, several authors have recognised the importance of managing the decision-making process when diverse experts have conflicting proposals, each suggesting a computer-based tool to support that process (Kam and Fischer 2004, Kalay 1998, Lee and Gilleard 2002).

3 PROJECT OUTLINE

The design task revolved around a 6 level development with about 38 self-care retirement units and a community hall, located on a busy road in an established part of the city. Due to the time limitations, it was considered impractical to begin with a green field and a brief, so the students began with a preliminary design of the building complex (in the form of an ArchiCAD model) that had already received local government development approval. The professional architect who had core responsibility for the design of the building was involved in the Studio, providing a wealth of detailed knowledge about the site and the planning context of this project. Each student adopted a specific role (with a corresponding area of design focus) to be enacted during the studio. These design foci included things like: statutory planning, site management, thermal design, services engineering, acoustic design, lighting, internal fit out, model management, site access, design for disabled access, code checking, life cycle sustainability, etc.

During the initial phase of the project, the students were required to use their expertise and the tools available to critique the proposed building in terms of their specific area of focus, prepare a design audit report, and then add relevant design information to the shared model. This established what we termed the “reference model”, providing a semantically rich representation of the design proposal. The students were then formed into three multi-disciplinary teams and charged with the task of identifying a team design goal, generally centred around a particular part of the project (for example, the community hall, a north-facing apartment, etc). Each team member then had to undertake a design analysis of that part of the proposed building and develop one or more design proposals to be brought back and negotiated with the other team members in order to arrive at an agreed set of design propositions, taking account of the conflicting demands of their individual concerns. These design propositions were then presented in a public forum for the purpose of course assessment. Figure 1 below illustrates all this with one the team’s group process model, showing the disciplinary roles represented in that team and the design process envisaged by that team.

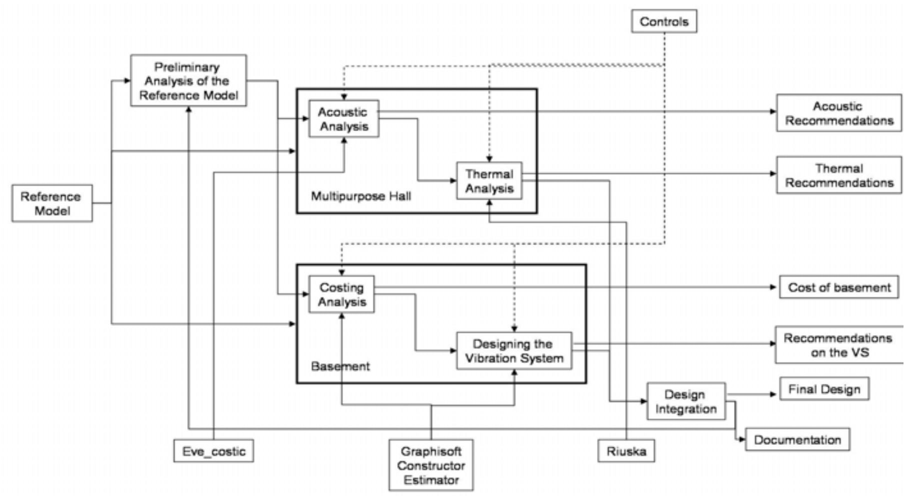

Figure 1 Typical process model developed by a student design team

On a technical level, the studio was supported by an IFC Model Server (provided by EPM Technology). The primary model-editing tool was ArchiCAD. We used a range of IFC viewers in the initial phases to allow the students to visualise the building model, and introduced the Solibri Model Checker (SMC) as a generic tool for doing initial design audits. We negotiated access to a range of design analysis tools covering areas like cost estimation, thermal analysis and services engineering, code checking, life cycle embodied energy calculations, disabled access analysis, lighting and acoustic analysis, and structural analysis (though we have no structural students). A complete list of software contributors is given in the acknowledgements at the end of the paper. Since access was via the Internet, the students had the freedom of working in the studio labs, or from networked laptops within the faculty precinct, or from their homes via standard dial-up or broadband connections.

4 OPERATIONAL ISSUES

While a substantial proportion of architects are apparently now using object model CAD (Geopraxis 2004), the focus of their output is still drawings. Their models are built and optimised for that primary purpose, and are “shared” by traditional 2D layered drawings, while in our multi-disciplinary studio we were sharing the model itself. Therefore, the building model needed to be constructed with collaborative interchange in mind, but more significantly, it was necessary to anticipate the needs of design collaborators. Since our starting point was an ArchiCAD model developed for initial local government development approval, it needed a substantial amount of editing to make it suitable for sharing in a collaborative environment. This process, combined with the need for the students to learn the various applications and become familiar with the concepts of object modelling, took up far more of the studio time than we might have wished. However, in the midst of those delays, there were many things to be learnt about the use of this type of technology to support design collaboration. The purpose of this section is to report those findings. We do so under two broad headings.

4.1 Building Model Issues

The first major issue was the concept of space or "room" definition. The importance of space data cannot be under-estimated as almost every collaborating application depended on the definition of spaces to identify the functional occupancy of the building. Of the applications used in our studio, only life cycle sustainability ignored the direct use of room data. As our source model had none of this defined, it was necessary to set up an additional studio task to enter this data into a revised model. The reference adopted for space definitions was the Singapore Code checking guidelines (as one of our students was using the online ePlan service in Singapore). This required specific room names, and usage coding, not at all satisfactory for concise construction documentation, but comprehensive and well suited to our Studio needs.

A second major issue was the robustness of the geometric model. It lacked a correct designation of storeys (peculiarly, this was missing in the source model even though it was a multi-storey building), a reference survey datum, correct geographical location, and appropriately accurate building elements. Although the model was generally accurate, several wall junctions were out of alignment: there was some debate about how critical that would be, but the more pedantic of us felt compelled to correct them. This raises a general issue with building modelling and the amount of detail that needs to be accurately represented, balanced against the cost of creating that detail.

A third issue was the consistent usage of building model entities: this relates to the semantic integrity of the model. This is a potentially more complex issue as each application has its own unique mapping to the IFC model entities and in this case, where the architect had never intended to use it for IFC based sharing, many problems arose. For example, the ease of use of ArchiCAD's slab tool meant that ifcSlab entities turned up as kitchen furniture.

A fourth, and probably the most important aspect, was the need for building elements to include property data to support specific analysis by the collaborating applications. A basic requirement was that all building elements should have a material specification to allow thermal, acoustic, sustainability or cost performance calculations. This is handled adequately by the standard IFC model, but more specialised data is generally handled in the IFC definitions through property sets (PSETs). An initial surprise was that the Solibri Model Checker (SMC), which is very good at checking for model consistency and spatial clash detection, could not detect PSET data. As the students were using SMC to assess how complete the model was to support their analytical role, this was a significant set back, and they were obliged to import the IFC model into ArchiCAD to check for such data.

An issue arose with some of the applications that required wall objects to have very specific properties assigned to them in order to carry out the analysis. As the source model was very schematic, the students had to go through and carefully define the layered construction of each wall (which were quite complex for some party walls with both fire and acoustic isolation requirements), expecting that would be enough to allow design analysis. However, two exceptions emerged: the cost estimating application required that each element be assigned a “type” (selected for convenience from the Finnish TALO standard); while for the life-cycle sustainability analysis, each element had to be classified with the application’s own classification schema. Contrary to our expectations, those applications were unable to derive that data from the wall construction data in the model, so a level of human judgement and additional entry of property data was needed to support those applications.

4.2 IFC Technology Issues

The most basic issue here was the inconsistency among applications in their support for the current version of IFC: several tools were based on IFC 2.00, two on IFC 2x and the remainder on IFC 2x2. The student version of ArchiCAD had limitations in the export of IFC data, and although since resolved, caused a lot of conversion issues that would have been a major impediment in a real project.

Of greater significance, however, were the mechanisms available for sharing the data using the IFC model server. As a matter of expediency, we decided that our first repository should be the source model divided into sub-models by level. This facilitated the division of the data into more manageable analytical tasks as we were starting to appreciate that it was too large to handle as a complete model (the complete IFC model was 12 Mb, an impediment for students working from home on a dial-up connection, but also surprisingly slow to load in some applications). Breaking it up into separate sub-models also meant that we could update the model concurrently, at least by level, using the small student teams.

The communication with the IFC server was handled by a beta version IFC add-on for ArchiCAD that, in its initial functionality, only permitted the upload and download of complete models. As the Studio developed, a new version was provided to us with increased functionality, providing direct upload and download from the remote repository to ArchiCAD as before, plus new functions to copy both ways between the remote and local repositories. (The local repository is a holding place for each user to manage the native IFC data retrieved from the server.) A major limitation of this interface was that it could not select sub-sets of the data on the fly: although this is a fundamental feature of the server technology, it was not yet implemented in the beta ArchiCAD add-on available to us.

Although the available server technology did not fulfil our expectations, it is that operational concept that offers the greatest promise as well as the most significant development challenges for the future. In such an environment, new data management tasks became paramount: specifically, the need for model access protocols and the versioning of data. This model management requirement is necessary to ensure models are built according to appropriate model building standards, and to define access and editing rights for users to ensure consistency of data. In our Studio, both of these tasks were beyond the capacity of software functionality available to us and beyond our ability, acting as de-facto model managers. This is the area that offers the most exciting challenges for our ongoing efforts.

5 CONCLUSION AND FUTURE WORK

This paper has reported our experience in running a multi-disciplinary design studio using a shared building model hosted on an IFC server. After putting this work into a research context, we have focused this paper on the operational issues that arose in the studio. To conclude this paper, we wish to identify a few key issues that need to be addressed in the short to long-term future, and to speak briefly of our plans for future developments of this project.

The first key issue is the importance of creating a building model that is suitable to support collaborative design. This may seem fairly obvious, but it was surprising to us just how much the existing model had to be re-oriented towards the applications used in the disciplinary analyses. There is a clear need here to systematically define our understanding of what should be modelled, and to develop good practice guidelines for the use of the various object CAD systems that might be used as model editors. This will be an ongoing task as we see the gradual take up of this technology.

The issue of model management becomes a very vexed one. Almost every writer in the field has drawn attention to this problem, but few, with the possible exception of (Eastman and Jeng 1999), have come up with sound strategies to balance the need for concurrent access with maintaining the semantic integrity of the model. It is instructive to note that Per Galle, writing in 1995, saw this as a major dilemma, to the extent of highlighting the fact that Paul Richens had argued this same need more than a decade earlier, exactly 22 years prior to this present conference (Galle 1995, 203). A very simple example here can be used to highlight the extent of this problem: one application may be used to calculate thermal transmittance based on wall construction properties; the value is uploaded to the model, but then the architect changes the wall construction so that calculated value no longer applies. Clearly, a very clever mechanism is required to track the interdependence of object data. However, just as current work practice manages these processes with adequate rigour, it is not at all clear how intelligent and at what granularity we need to make these model-updating mechanisms. For our part, we will be working further to test this in practice and devise model management processes to handle such contingencies.

Another issue that surfaces in this kind of discussion, and will be a focus of our future projects, is the notion of attaching “intentions” to elements in the project model. In a co-operative design environment, there is a need to find a way to convey the intent behind the decisions that have been taken. This has been addressed by several authors (Kalay 1998, Maher, Liew and Gero 2003, Lee and Gilleard 2002) and is linked to the need for rigorous tools to support collaborative decision-making.

Our plan is to continue running this studio course at least once each year, gradually refining our processes and testing new technologies and solutions as they become available. It is expected that the feedback generated by this work will continue to inform the on-going development of the IFC model and the growing range of IFC compliant tools. As an extension of this work, we plan to initiate some industry workshops where a multi-disciplinary team of mid-career professionals are brought together over a 5-day period to tackle a focussed design problem using a shared building model in much the same way as this studio. It is anticipated that experienced professionals will have some very useful insights to share, and so this will become an effective way to complement "real-world" case studies such as the HUT-600 project (Fischer and Kam 2002). We are planning the first of those workshops in the first half of 2005, so there may be some interesting things to report at the conference.

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