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THE QUEST FOR INTEGRATED DESIGN SYSTEM: A BRIEF SURVEY OF PAST AND CURRENT EFFORTS

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Improving the overall quality of buildings is the main motivation behind the development of computer aided technologies in the Architecture-Engineering- Construction (AEC) industry. A seamless design and evaluation environment has been envisioned by researchers since the early days of computational design but the integrated design system has been elusive for the last 30 years. With the recent focus on environmental sustainability, topics in building performance are gaining importance at many educational institutions. However, the lack of a proper computational environment for integrated design is a major hurdle for both students and professionals. This paper will summarize the history of integrated design research and thus hopes to help educators plan for multi-disciplinary coursework.

INTRODUCTION

The architect's role in building procurement is becoming increasingly prominent as advances in information technology (IT) are streamlining the industry. Design is now a well coordinated team effort involving experts of various disciplines. Engineers, facility managers, consultants and architects all work together. Architects are the natural leaders of these teams. However, to be able to carry out their role, architects need to be better informed about the various disciplines they will communicate with.

Issues such as global climate change and energy crises have been critical in the rising interest in environmental sustainability and ecological design. Building design and construction processes are going "green". They are being reorganized to focus on building performance. Designs are evaluated according to performance criteria that are slowly finding their place in building code. An example is United States Green Building Council's Leadership in Energy and Environmental Design (LEED) program (USGBC, 2002). This voluntary rating system has been adopted by British

Columbia as LEED-BC and Vancouver municipality now requires its civic buildings larger than 500 m^2 to be designed to earn a LEED-BC Gold rating.

INITIATIVES AT EDUCATIONAL INSTITUTIONS

Architects need to be well versed in performance criteria used by other disciplines in the AEC industry. If, during the early stages of design, architects make design decisions well aware of their impact on performance criteria, at later stages, a more effective collaboration with engineers becomes possible. For this reason, introducing Integrated Design principles to architecture students is becoming a priority. Recently, multi-disciplinary projects, at both graduate and undergraduate levels, are being offered at many schools.

An example at the graduate level exists at Stanford University. Fischer and Kam have collaborated with the Finnish National Technology Agency (TEKES) on Product Model and Fourth Dimension project (Fischer and Kam, 2002). Students were involved in the design and construction of an auditorium at the Helsinki University of Technology with the PM4D methodology. An example at the undergraduate level is at New South Wales University. Plume and Mitchell coordinated a Multi-Disciplinary Studio (Plume and Mitchell, 2005). Students from architecture, interior design, landscape architecture, mechanical engineering, environmental engineering, construction management and computer aided design departments worked with architects on a project that is to be built. Teams involved in such projects all have concluded that the major problem lies with the fact that technologies for facilitating the data flow among the various required software are promising, yet still not mature enough. They point to the lack of interoperability among software.

There are various competing approaches to solving this problem of interoperability for the AEC industry. Planning a multi-disciplinary studio needs to start with deciding what technologies to use. The next section provides a historical perspective to the research in this area.

INTEROPERABILITY RESEARCH IN THE BUILDING INDUSTRY

The consensus in the building industry towards achieving high performance is providing a major motivation for solving interoperability issues related to information technologies. Yet, the progress so far has been slow.

Design environments architects use should be able to provide performance evaluation starting with the early stages of design. However, current computer aided design (CAD) tools have been developed for rapid input of design descriptions and output as drawings and realistic visualizations in three dimensions. Tools geared for performance evaluation are not integrated with these CAD environments. However, even during the early days of CAD research, the “digital assistants” envisioned by researchers had integrated design capabilities and were acting as consultants to architects.

Goal: Integrated Design System

The “Architecture Machine” Negroponte described in 1970 was in fact very similar to today’s laptops (Negroponte, 1970). It was portable and looked like a notebook. The Machine was able to accept three dimensional input. In his book, Negroponte described dialogues between the Machine and the architect that was continuously guided by the designer creativity. While most of his predictions have been realized and even outdated, the grand vision of Negroponte and his colleagues such as Coon and Sutherland still seems to be far away.

The Architecture Machine was to embody three essential capabilities:

1. *Generation*. An environment for rapid design manipulation.

2. *Evaluation*. Knowledge on various aspects of architectural design.

3. *Adaptation*. “Learning” mechanisms.

Significant progress has been achieved separately in all of the three areas above. Design manipulation systems have been evolving with CAD systems that started by imitating two dimensional drafting and are today three dimensional component based systems capable of producing realistic visualizations and animations. Evaluation tools on the other hand have been developed by engineers to support their own tasks rather than to communicate results to collaborators. Some tools such as DOE-2 and Lumen Micro have even become industry standards. Research on adaptive capabilities has been carried out under artificial intelligence topics although they have not yet had a direct impact on the building industry.

Schmitt provides an elegant summary: “Knowledge is being gained vertically much more rapidly than horizontally, thus creating the impression of islands of knowledge that are unable to communicate with each other” (Schmitt, 1991). Integrated Design Systems attempt to combine generation and evaluation capabilities and thus provide a solution for this problem known as “Islands of Automation”. The work of many research groups who have tried alternative approaches have focused on two areas.

Product Modeling-Buildings are the products of the design process. As such we need a common representation for buildings to be able to communicate design information across software. Over the years many computational models were developed based on various product modeling methodologies.

Software Architecture-Analyzing the requirements for all the tools to be integrated, choosing a communication framework, and deciding on technologies to be employed are critical in defining the level of integration to be achieved. While some efforts chose to create one all-inclusive system, others aimed to facilitate automatic translations among independent applications.

Early Efforts

Efforts in the 1970s all were aimed towards paving the way to the integrated design system. In the United Kingdom, while Bijl worked on SSHA, a housing design system (Bijl and Shawcross, 1975), Hoskins developed OXSYS (Hoskins, 1973), and Meager created Harness (Meager, 1973), both for hospital design. OXSYS was later commercialized as BDS. Eastman who started his work with BDS, later developed the GLIDE language (Eastman and Henrion, 1977).

1980s started with Borkin’s ArchModel project (Borkin et al., 1981) that defined a database for building representations. Later Fenves was solving design problems by breaking it into subtasks within the IBDE (Integrated Building Design Environment) system (Fenves et al., 1989).

While these systems were all developed for architects, general purpose CAD systems were evolving rapidly and vendors were in search of data exchange standards among the competing tools. General purpose formats like IGES, DXF, SAT paved the way for PDES (USA) and ISO-STEP (Europe) standards. Especially STEP was accepted widely following its success in automotive and aerospace industries.

STEP

STEP(Standards for the Exchange of Product model data) was developed as a general, industry-neutral set of standards for all engineering data (ISO 10303). In order to contain enough information to cover a product's entire life cycle, from design to analysis, manufacture, quality control testing, inspection and product support functions, STEP tries to cover geometry, topology, tolerances, relationships, attributes, assemblies, configuration and more. STEP defines a modeling methodology as well as data communication methods.

STEP, is made up of a growing series of "Parts", each a standard on its own. STEP documentation can be organized into five main categories:

1. Description Methods: Parts in this category define the EXPRESS product modeling language.

2. Implementation Methods: This set of parts defines how to access the data modeled in EXPRESS. For Example, Part 21 defines the format for writing data to a flat text file. This format is known as the STEP Physical File (SPF) format. Furthermore, parts that define data access from languages such as C++ or Java also fall under this category.

3. Conformance Testing Methodology: Explicit conformance requirements for application protocols.

4 Integrated Generic Resources: These parts define generic libraries for building application protocols. Geometric entities are one example (Part 42).

5. Application Protocols: Industry specific product data.

1990s

In the 1990s while STEP was employed widely in Europe, research efforts in the U.S.A. mostly avoided this standard. Pohl developed ICADS and AEDOT systems that applied geometry interpretation on drawings and passed design information to expert systems for evaluation (Pohl et al., 1992). A multi-institutional effort supported by the US Army was the ACL project that aimed to define a common representation and facilitate communication among independent "agents" (Khedro et al., 1995; Flemming et al., 1996). Eastman who focused on data exchange between different representations, developed EDM and EDM-2 product modeling and database languages for modeling representations that can evolve over time (Eastman et al., 1995). Papamichael worked on the BDA system that employed a "meta-model", an extendible modeling framework (Papamichael, 1999). Mahdavi developed the SEMPER system with an empirical approach to a common representation , as well as S2 that supported collaboration taking advantage of distributed computing technologies (Mahdavi, 1996). Flemming, while creating a modular infrastructure for SEED to allow different interfaces to be used in different stages of design, explored representations that allow information from earlier stages of design to be carried over to the later stages (Flemming and Woodbury 1995).

European efforts mostly chose to employ STEP technologies. The RATAS project that aimed to widen the acceptance of product models in the AEC industry, immediately adopted the STEP standard (Bjork, 1995). Gielingh combined STEP models with object oriented methodologies and tried to establish a data exchange platform over CORBA (Common Object Request Broker Architecture) (OMG, 1999) with the PISA project for steel structures (Gielingh et al., 1996). The PISA system set an example for many efforts that followed. In similar fashion, Böhms' ATLAS project set an example with its large product model that was broken down into layers (Böhms and Storer, 1993).

Maybe the largest effort in the AEC industry was the COMBINE project (Augenbroe, 1995).

Under Augenbroe's coordination, COMBINE was a mutli-national effort that was carried out in two phases. In the first phase, COMBINE I, an Integrated Data Model (IDM) was developed. The second phase, COMBINE II, tried to make use of this IDM within an Integrated Building Design System (IBDS) where the IDM was kept in a central database and individual design tools extracted the information they required. The design tools in this IBDS were stand-alone tools. IBDS only facilitated the export of design information for these tools. The project building on the experience of projects like ATLAS and PISA achieved a certain success, however, the IDM was too complicated to be employed in practice.

The importance of establishing a common building representation for use as a data exchange standard was recognized throughout the AEC industry in the second half of 1990s. Led by Autodesk, a large group of companies formed the International Alliance for Interoperability (IAI) and immediately started developing the Industry Foundation Classes (IFC) (IAI, 2006). Today, IFC is still under development and is the most widely implemented effort.

One of the first systems based on IFC was Marir's OSCONCAD (Marir et al., 1998) that focused on construction planning, process management and cost analysis. IFC were far from answering the needs of other performance analysis applications. Since its onset, IFC development has been able to release various versions (1.5, 2.0, 2x2, and 2x3).Built on STEP technologies, IFC, with each release has expanded to cover more domain requirements.

Current Research

IFC is a technology that is almost ten years old. Although, it has still not been fully accepted, it is the most utilized platform for interoperability. A recent effort is, O'Sullivan and Keane's IFC based user interface for energy simulations of buildings (O'Sullivan and Keane, 2005). Bazjanac has been extending IFC for HVAC systems (Bazjanac, 2004). Nytsch-Geusen and his team integrated a computational fluid dynamics application and an energy simulation tool with a computer aided architectural design (CAAD) environment using IFC (Nytsch-Geusen et al., 2003). These are only some examples to current work based on IFC.

On the other hand, many researchers are critical of IFC. The product model is a large model and cumbersome for many researchers looking to develop simple applications. The STEP technology its based on is not compatible with the development methodologies that are in use. Although an XML version of IFC is available, it comes with some loss in fidelity. But most importantly, the development process IAI follows for IFC is a "top-down" approach. IFC is developed and vendors are asked to follow. Behrman who has voiced these concerns in his report, saw aecXML as a viable alternative (Behrman, 2002). IAI coordinated the development of aecXML as well. This initiative was supposed to follow a "bottom-up" approach and collect models already established in various domains from vendors. However, this initiative was able to collect two schemas out of an initial goal of seven. First is gbXML for energy analysis and second was LandXML for infrastructures.

Recent building performance research continues to improve on the available tools despite the absence of an industry-wide acceptance of a standard building model. Especially new modes of utilization in early design stages are of interest. Malkawi explains:

> "To shift the conventional use of such tools from only analysis to analysis and design aid, a renewed research in utilizing advancements in optimization is underway. This research stems from the idea that digital simulation tools can be used to support performance-driven design using optimization and partial automation" (Malkawi, 2004).

Such tools are mostly developed as plug-ins for a specific CAD tools. Shea is working on eifForm for structural performance optimization that is integrated with Bentley's Generative Components software over XML (Shea et al., 2005). Monks developed methods of optimizing geometry to meet acoustic performance criteria (Monks et al., 2000). Caldas experimented with genetic algorithms in generative systems optimizing lighting and thermal behavior (Caldas and Norford, 2002). Such examples demonstrate very well how the design process can benefit from integration.

PROPRIETARY MODELS

Even with a lack of an interoperability standard, CAD tools that are in use by professionals in the AEC industry continue to evolve. Commercial CAD systems that started with 2D drafting, first incorporated databases, then added 3D modeling capabilities, and later moved to object-oriented, component based platforms that have enabled them to develop their own building representations commonly referred to as Building Information Modeling (BIM). With BIM, CAD systems all claim integration capabilities with analysis tools and are able to export data in IFC and/or gbXML formats.

Most building performance analysis tools in use today are developing IFC and/or aecXML translators. However, these translators can mostly carry data from the design tool to the analysis tool. The results are not sent back into the design environment. This scheme can only support analysis that is performed for verification purposes. It is inadequate for performance based design explorations.

Analysis tools intended for use by architects are rare. One popular example is ECOTECT (Roberts and Marsh, 2001). It combines an intuitive 3D interface with multiple simulation applications (solar, thermal comfort, energy, lighting, acoustics, cost estimation). It is capable of reading the gbXML format and is able to communicate with ArchiCAD. Although the simulation algorithms are not preferred by practicing engineers, it's most valuable in educational settings allowing students to explore the impact of design decisions on performance criteria.

CHALLENGES FOR EDUCATION

The Integrated Design System is still distant. Therefore, as architecture students are educated with a focus on integrated design, they should be prepared to tackle the challenges that await them. In the absence of a proper design environment, some steps that educational institutions can take today are the following:

- Students should be encouraged to use the most recent BIM based CAAD systems. These systems are ready for data exchange standards.
- Courses on Building Physics and Building Performance should introduce computational analysis tools and encourage students to evaluate designs with regard to performance criteria.
- Multi-disciplinary studios should be planned and carried out where students make design decisions in collaboration with students from other departments.

At the graduate level, research should take into account the necessity to integrate design manipulation environments with prediction and evaluation capabilities. ESTARA (Educational Simulation Tool for Architectural Room Acoustics), currently under development at Balıkesir University, is an example. ESTARA is intended for use mostly in educational settings to introduce basic concepts in room acoustics. It will provide capabilities for comparing various calculation methods and sound propagation paradigms as well as an interface to support parametric studies to communicate the impact of various design decisions on performance indicators. Instead of developing its own interface, ESTARA will use the IFC platform and allow students to use ArchiCAD or any other IFC 2x2 compliant CAD system they are familiar with (İlal and Macit, 2007). This approach prevents students from having to learn a new interface and focus on acoustics as well as providing an opportunity for researchers to explore the use of the recent ifcXML schema.

CONCLUSION

While integration has been the subject of many development efforts over the past thirty years, an acceptable scheme was never produced either by academic researchers or by commercial CAD vendors. However, the recent trend towards ‘green design’ has finally created a strong momentum and everyone involved in the building industry now recognize the necessity of interoperability among software. Multi-disciplinary design teams demand better collaboration platforms.

Multiple challenges exist for educational institutions. While graduate level research needs to provide clues on how next generation tools should meet the demand for interoperability, undergraduate curriculum should be updated to prepare students for their role as leaders of integrated design teams. Successful architects will be the ones able to think across disciplines and are ready for teamwork. The ultimate goal of achieving high performance in buildings is possible only through integrated design approaches that consider various systems (structural, lighting, telecommunication, HVAC, controls, facades, interiors) as integral parts of spaces, and aims to provide flexible, adaptable, environmentally sustainable spaces. A multi-disciplinary understanding should penetrate all levels of architectural education.

REFERENCES

AUGENBROE, G. (1995) COMBINE 2, Final Report, CEC-JOULE program, Brussels, http://dutcu15.tudelft.nl/~combine/.

BAZJANAC, V. (2004) Building Energy Performance Simulation as Part of Interoperable Software Environments, *Building and Environment* (39) 879-83.

BEHRMAN, W. (2002) Best Practices for the Development and Use of XML Data Interchange Standards, Center for Integrated Facility Engineering (CIFE) Technical Report #131, July 2002.

BIJL, A., SHAWCROSS, G. (1975) Housing Site Layout System, *Computer-Aided Design*, 7 (1) 2-10.

BJORK, B.C. (1995) Requirements and Information Structures for Building Product Models, *VTT Technical Research Centre of Finland Research Report*, Publication 245.

BÖHMS, H.M., STORER, G. (1993) Architecture, Methodology and Tools for Computer Integrated Large Scale Engineering (ATLAS) - Methodology for Open Systems Integration, ESPRIT 7280, Technical report, TNO, Delft, The Netherlands.

BORKIN, H., McINTOSH, J., McINTOSH, P.(1981) ARCH:Model: A Geometric Modeling Relational Database System, *ARCH: Model User's Manual*, Architectural Research Laboratory, University of Michigan, Ann Arbor, Michigan.

CALDAS, L.G., NORFORD, L.K. (2002) A Design Optimization Tool Based on a Genetic Algorithm, *Automation in Construction*, 11(2) 173-84.

EASTMAN, C.M., HENRION, M. (1977) GLIDE: A Language for Design Information Systems, *SIGGRAPH'77 Proceedings of Computer Graphics*, 11 (2) 24-33.

EASTMAN, C.M., JENG, T-S., ASSAL, H., CHO, M. and CHASE, S. (1995) EDM-2 *Reference Manual*, Center for Design and Computation, UCLA.

FENVES, S. J., FLEMMING, U., HENDRICKSON, C., MAHER, M.L., SCHMITT, G. (1989) An Integrated Software Environment for Building Design and Construction, *CIFE Symposium Proceedings*, March 1989.

FISCHER, M., KAM, C. (2002) *CIFE Technical Report Number 143: PM4D Final Report*, Stanford: CIFE, Stanford University.

FLEMMING, U., WOODBURY, R. (1995) Software Environment to Support Early Phases in Building Design (SEED), Overview, *Journal of Architectural Engineering*, v: 1; 147-52.

FLEMMING, U., AYGEN, Z., SNYDER, J., TSAI, J. (1996) A2: An Architectural Agent in a Collaborative Engineering Environment, *Technical Report EDRC-48-38-96*, *Engineering Design and Research Center*, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA.

GIELINGH, W., LOS, R., LUITEN, B. (1996) The PISA Project, a Survey on STEP. Shaker, Aachen.

HOSKINS, E.M. (1973) *Computer Aids in System Building, Computer-Aided Design*, J. Vlietstra and R. Weilinga (eds.) North-Holland Press, NY; 127-40.

ILAL, M.E., MACIT, S. (2007) Integration of an Acoustic Simulation Tool with CAAD Environments using ifcXML, Enterprise Interoperability II, *3rd International Conference on Interoperability for Enterprise Software and Applications*, Madeira, Portugal; 807-10.

IAI (2006) Industry Foundation Classes IFC2x Edition 3, http://www.iaiinternational.org/Model/R2x3_final/ index.htm.

KHEDRO, T., CASE, M., FLEMMING, U., GENESERETH, M., LOGCHER, R., PEDERSEN, C., SNYDER, J., SRIRAM, R., TEICHOLZ, P. (1995) Development of Multi-Institutional Testbed for Collaborative Facility Engineering Infrastructure, *Computing in Civil Engineering, v: 2* (Proceedings of the Second Congress held in conjunction with the A/E/C Systems '95, Atlanta, Georgia, June 5-8) American Society of Civil Engineers, New York; 1308-15.

MAHDAVI, A.(1996) SEMPER: A New Computational Environment for Simulation-based Building Design Assistance, *Energy and Mass Flows in the Life Cycle of Buildings (Proceedings of the 1996 International Symposium of CIB W67)* Vienna, Austria; 467-72.

MALKAWI, A.M. (2004) Developments in Environmental Performance Simulation, *Automation in Construction*, v: 13 (4) 437-45.

MARIR, F., AOUAD, G., COOPER, G. (1998) OSCONCAD: A Model-based CAD System Integrated with Computer Applications, *Itcon*, v: 3; 25-43.

MEAGER, M.A. (1973) The Application of Computer Aids to Hospital Building, *Computer-Aided Design*, J. Vlietstra and R. Weilinga (eds.) North-Holland Press, NY; 424-53.

MONKS, M., OH, B.M., DORSEY, J. (2000) Audioptimization: goal-based acoustic design, Computer Graphics and Applications, *IEEE Journal*, v: 20 (3) 76–90.

NEGROPONTE N. (1970) *The Architecture Machine*, MIT Press, Cambridge, MA.

NYTSCH-GEUSEN, C., KLEMPIN, C., NUNEZ VON VOIGT, J., RADLER, J. (2003) Integration of CAAD, Thermal Building Simulation and CFD by Using The IFC Data Exchange Format, Eighth International IBPSA, Eindhoven, Netherlands; 967-74.

OMG (1999) The Common Object Request Broker: Architecture and Specification, *Object Management Group Formal Documentation,* Formal/1999-10-07.

O'SULLIVAN, B., KEANE, M. (2005) Specification of an IFC Based Intelligent Graphical User Interface to Support Building Energy Simulation. IBPSA 2005, Montreal, Canada; 875-82.

PAPAMICHAEL, K. (1999) Application of information technologies in building design decisions, *Building Research and Information*, v: 27(1) 20-34.

PLUME, J., MITCHELL, J. (2005) A Multi–Disciplinary Design Studio using a Shared IFC Building Model *Martens*, (Proceedings of the

11th International CAAD Futures Conference) Vienna University of Technology, Vienna, Austria.

POHL, J., LA PORTA, J., POHL, K.J., SNYDER, J. (1992) AEDOT Prototype (1.1): An Implementation of the ICADS Model, *Technical Report CADRU-07-92*, CAD Research Unit, Design Institute, School of Architecture and Environmental Design, Cal Poly, San Luis Obispo, California, USA.

ROBERTS A., MARSH, A. (2001) Ecotect: Environmental Prediction in Architectural Education, in eCAADe; 342-7.

SCHMITT, G. (1991) Computer Aided Architectural Design Futures. Computer Aided Architectural Design Futures: Education, Research, Applications, *CAAD Futures 1991 Conference Proceedings*, Zurich, Switzerland; 9-16.

SHEA, K., AISH R., GOURTOVAIA, M. (2005) Towards Integrated Performance-driven Generative Design Tools, Automation in Construction, v: 14 (2) 253-64.

U.S. GREEN BUILDING COUNCIL (2002) Leadership in Energy and Environmental Design Green Building Rating System, Version 2.0. [Electronic Version] Retrieved December 9, 2002, http://www.usgbc.org/Docs/LEEDdocs/LEED_RS_v2-1.pdf.

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BÜTÜNLEŞİK TASARIM SİSTEMİ ARAYIŞI: GEÇMİŞTEN GÜNÜMÜZE GİRİŞİMLERE TOPLU BİR BAKIŞ

Mimarların daha “kaliteli” binaları daha kısa sürede tasarlamalarına yardımcı olmak yapım sektörüne yönelik geliştirilen bilgisayar destekli teknolojilerin ana hedefidir. Mimarların tasarımlarını sadece çizmek değil, yapım sektöründe var olan uzmanlık alanlarının bakış açılarıyla değerlendirmeyi de destekleyen bir Bütünleşik Tasarım Sistemi yaratmak için son 30 yıldır yapılan bütün çalışmalar sonuçsuz kalmıştır. Son yıllarda çevreci yaklaşımların önem kazanmasıyla beraber eğitim kurumlarında bina başarımı konularına ağırlık verilmesi zorunlu olmuştur. Fakat öğrenci çalışmalarını destekleyecek yeterli bir bilgi teknolojisi altyapısı halen yoktur. Bu yazıda, geçmişten günümüze bu alanda yapılan çalışmalar tanıtılarak bütünleşik tasarım yaklaşımlarını desteklemek isteyen eğitimcilerin onları bekleyen sorunları daha iyi tanımaları hedeflenmiştir.