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Integration of Building CAD/CAE Systems

Intégration des systèmes de CAO/IAO dans le bâtiment

Integration von CAD/CAE-Systemen im Hochbau

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SUMMARY

CAD/CAE systems are an essential tool in the building design process. Although offering powerful mathematical models and sophisticated graphical capabilities to the designer they are not actually improving the design process model itself and the diffusion on expertise throughout the industry. It is necessary to create an integration environment developed around an open and expandable data base able to handle the building design conceptual objects and its data structure and organization. The objectives of this research project are presented in this paper.

RÉSUMÉ

Les systèmes de conception et ingénierie assistées par ordinateur constituent un outil devenu indispensable dans l'établissement des projets de bâtiments. Bien qu'ils fournissent au concepteur un modèle mathématique superpuissant et des possibilités graphiques des plus sophistiquées, ils ne sont pas encore à même d'améliorer le processus d'étude et la propagation des connaissances dans la branche concernée. Afin de développer une banque de données ouverte et extensible, il est nécessaire de créer un environnement d'intégration qui puisse permettre de faire fonctionner les objets conceptionnels du bâtiment, tout comme leur structure et organisation des données. Cet article présente un projet actuel de recherche dans cette direction, dont les objectifs sont largement explicités.

ZUSAMMENFASSUNG

CAD/CAE-Systeme sind ein unverzichtbares Werkzeug im Gebäudeentwurf. Obwohl sie dem Architekten leistungsstarke mathematische Modelle und ausgefeilte graphische Möglichkeiten an die Hand geben, verbessern sie nicht wirklich den Entwurfsprozess und die Wissensverbreitung in der Branche. Es ist nötig, um eine offene und ausbaufähige Datenbank eine Integrationsumgebung zu schaffen, die die konzeptionellen Gebäudeentwurfsobjekte, ihre Datenstruktur und -organisation handzuhaben gestattet. Der Beitrag behandelt ein Forschungsprojekt in dieser Richtung, dessen Ziele erläutert werden.

1 INTRODUCTION

Construction projects are developed in three consecutive parts: design, planning and construction. The first phase, that of design, represents only 10% of the total project cost but it decides on the remaining 90%. It is therefore critical to improve the performance on the construction design cycle, not only to reduce its direct costs but also, and more important, to enhance the quality of the decisions made in this phase which affect the construction itself and its life-time performance.

Computer aided design (CAD) and computer aided engineering (CAE). Although offering powerful mathematical models and sophisticated graphical capabilities to the designer they are not actually improving the design process model itself and the diffusion of expertise throughout the industry. They are a reflection of the fragmentation of many building design disciplines and their specialization. An architectural system does not communicate with a structural system and vice versa, which means that at least 50% of the information and other work has to be done again. This results in poor decisions and down grade performance of the final construction.

It is necessary to create an integration environment developed around an open and expandable database, able to handle the building design conceptual objects and its data structure and organization. The current research is directed to this integration, stating that the low and declining productivity of construction industry compared with that of manufacturing industry is due to the lack of coordination among the different experts who serve the building design process. This project will cover buildings as well as prestressed bridge construction, although the present paper will only deal with building construction. The aim is to create an open integration environment for computer aided building design consisting of a well documented building design process model; a reliable conceptual model of the building entity clearly defining the building objects hierarchically and the corresponding data structures; a database management system reflecting the conceptual models and dealing with objects rather than data; and common principles for user interface which meet the specific needs of building design.

This should improve the quality of the decision-making of the building designer, the overall productivity of the building design process, the management of the building construction, the cost performance ratio, the cost of the actual construction and the building maintenance and repair cycles.

2 THE BUILDING DESIGN (BD) PROCESS

Construction of Buildings has attracted the attention of mankind since the beginning of civilization. Regardless of the status of science and technology throughout history, man constructed various buildings, some of which are still standing, as witness to the wisdom, the will and the power of the ancients.

In every case and without any exception, three main phases were applied in the construction of a building. There was always, first, a Design Phase where the needs, the form and the materials of the construction were defined. Then, a construction Planning Phase had to be accomplished, in order to manage the available resources, the design requirements and the time limits. Finally, there followed the actual Construction Phase to materialize the Building according to the design and the resources. The only difference, throughout the ages, has been the supporting technology.

The Egyptian Pyramids were designed by inspired, "empty-handed" engineers and were constructed by people, rock and some primitive tools and mechanics, taking many years, for each one, to be completed. Today's New York Skyscrapers are designed and scheduled by computerized engineers and constructed by people using sophisticated materials and Robots, taking only a few months to build.

There is a close interaction between the three phases of the construction process. The Construction Planning may alter the designer`s decisions and always imposes minor or major modifications to the initial plan. The construction of the Building provides the designer with feedback information which may cause him to alter minor design details or update the initial design with last-minute, on-site changes. The latter is extremely important for the maintenance cycle and the repair program of the Building, and it would be a great benefit if the documentation of the final construction could be stored in detail, integrated, updated, easily accessible and retrievable.

The BD process can be divided into 10 main, distinct phases, each one of which is served by completely different traditions, sciences, methodologies, disciplines, expertise and practices. A listing of the BD activities, in a reasonable sequence can be:

1. Building Specifications
2. Landscape Architecture
3. Urban/Environmental Design
4. Architectural Design
5. Civil Engineering
   . Structural Design
   . Structural Analysis
6. Energy Engineering
   . Insulation
   . Heating
   . Air Conditioning
7. Facility Engineering
   . Electrical
   . Plumbing
   . Piping
   . Under-Piping
8. Sound Engineering
9. Interior space design / Decoration
10. Material selection and Bill of Materials

The BD process is basically sequential but also includes a lot of iterations and interactions between its various activities. Being sequential means that an activity has to be completed first, before the next activity can be developed. Although iterations may occur, the model has to follow the sequential path and run, every time, from top to bottom, in order to pass the changes made to the next activity.

3 PROBLEMS OF THE BD PROCESS

The previously mentioned list of BD activities could be shorter or longer, depending on the view and the emphasis placed by the given approach to the subject. But, short or long, the items are sequentially developed and successively processed. This results in a set of problems.

One serious problem arising from this sequential nature of the BD activities is that the decisions taken in one activity impose serious limitations on the next, in such a way, that there is little or no room for decision- making in the last stages of the BD process.

Usually supported by independent computer systems, this sequential hierarchy of activities faces serious limitations from the conflicting decisions and/or from the non-compatibility of the supporting systems.

A second problem is lack of sensitivity. In everyday practice, the BD process is more or less a one-way process. The iterations and the interactions may occur only when facing dead-ends.

It is common to see an Architect who disregards some critical client's requirements in favour of the aesthetic, a Civil Engineer who ignores the functionality of the interior space in favour of the stability of the buildings, or a Facility Engineer who constrained limited by the previous two, "reconstructs" the building in order to find the "critical path" for the piping.

The cost, the time and the effort required to review any previous design step, in order to improve the performance of the next steps, is rarely undertaken. On the other hand, this "one-way" of the process is strongly fostered by the wide distribution and fragmentation of the expertise throughout the Building Design industry. The cost of coordinating individual experts who are trying to maximize their own performance, is always against the optimization of the final result. And all these without referring to the degree of the competition between the experts, that reduces even more the quality of the final design.

Even when supported by computer systems, a true sensitivity analysis (recurring "what if" capability) is rarely found in DB systems. Computers may improve the decision review capabilities of a designer, but in reflecting the fragmentation of the expertise, they too are specialized as well. The systems, being dedicated, cannot communicate, thus causing a lot of re-creation and re-processing of common information.

Being sequential, the BD process deals with common extended information which, in most cases, is recreated in each step. It is estimated that an Architect needs at least 25% of the Civil Engineer's information, while the Civil Engineer uses 50% of the Architectural information for his/her design, information that already lies in the blueprints of the Architect and the Structural Designer. Another problem is that the wide experience gained from the numerous construction projects by the many experts of the industry is presently stored in the personal memory of the experts who may comunicate and deliver a part of it to newcomer experts, in the form of on the job or on-site advices or University courses. This is not the best way of saving information.

A lot of expertise "dies" because there is no way for it to be stored permanently. Finding a way of storing this expertise will be a blessing.

4 STATE-OF-THE-ART

Architectural, Civil Engineering and Construction (AEC) computer applications, are among the oldest and represent a major application area because of the sheer size of the projects involved. (Approx. 478 billion ECUs were invested in construction during 1990, in Europe).

As previously stated, the Building Design process is performed today by a multi-disciplinary and rather sequential set of highly fragmented and specialized expert activities. The existing computer applications imitate, in general, the same fragmented scheme, satisfying particular expert needs but ignoring the high degree of work duplication, cumulatively generated along the sequence of the successive Building Design activities.

The CAD (D for Drafting , not for Design) Systems available, being general purpose drafting tools, though impressive with their capabilities in visual outputs (3D shading models, plots,etc.), cannot deal with the features of the building objects (walls, columns, pipes, etc), while the mathematical modelling and simulation applications (FEM, BEM, etc.) are too specialized and poor in drawing capabilities to provide the final construction blueprints.

The existing integration of AEC systems is mainly based on the data exchanges between systems, used by the different Building Design actors, using either standard neutral file-formats or conversion schemes translating data from one system to another. Still, this technology deals only with graphics which, though essential, cover only a small part of the Building object.

An acceptable degree of integration of Building Design disciplines is provided only by specialized, private, closed architecture and rather expensive integrated environments, on Minis or on Workstations (ex. INTERGRAPH AEC family of applications on VAX and PC based MicroStation).

Considering that the low and declining productivity of the construction industry, compared to that of Manufacturing industry, is due to the lack of coordination (read : integration) between the "islands of expertise" that serve the Building Design process, current rese. rch is re-directed towards open integration of AEC applications.

There are already some initiatives that promote the idea of open integration in the AEC industry worth mention, such as CIFE (Center for Integrated Facility Engineering) of Stanford University (USA), CIB Working Commission 78 (Conseil International du Batiment), the RATAS project from VTT (Finland), the CAD/CAM Data Exchange Technology Centre, Leeds (UK), the AEC Systems series of conferences, and the work done at the Instituto Eduardo Torroja, Madrid (Spain), to mention a few.

5 ADVANTAGES OF INTEGRATION

Open Integration is defined as the act or process of making different complementary systems behave, though modular, as one.

Integration is not the merging of systems but rather a cooperation and coordination of systems directed towards a synergetic result.

Integration may overcome most of the previously mentioned problems of the BD process improving not only the performance of the process itself but also the quality of the final construction with considerable tangible and non-tangible benefits.

Through Integration, and without violating the basic flow of the BD process, the decisions taken in any stage could be evaluated in a very short time under multiple-criteria incorporated, at the beginning of the process, by the different actors. Integration then will play the role of the "manager" , who is now absent among the many "islands of expertise" of a BD project.

The cost of revising the decision will be more cost effective, compared to the benefits of improving the cost and the quality of the Building. The iterations and the interactions will be feasible, as the systems communicate automatically, transferring the required data from one system to another, in a very short time. The "what if" analysis and the design alternatives may become every day practice, while the experts will recognize their own potentials and drawbacks on the "mirror" of the display, looking at or reading the combined results of their decisions.

All Building data would be kept in the same format and in some cases in the same mass storage. The information would be passed from one expert to another through a diskette, if they were independently, or through an access call, if the experts are linked together on a Network or a Multi-User system. The time saved may then be invested in exploring better construction alternatives and in more-timely responses to deadlines and bids.

Integration alone cannot ensure intelligent storage of information, but it can lead the way to achieving this. Integrated environments can and should be linked with AI and Expert systems to analyze the information gathered and transform it into rules, statistic and case studies, for the benefit of the younger experts.

There may be many alternative solutions applicable to the BD process productivity problems.

We think that integration should be promoted through their research effort rather than Segmentation (Specialization), as the first appears to be a more justifiable and challenging solution for the BD process problems. In our opinion, integration respects and absorbs, from each individual system, its unique view, while it coordinates and directs all the outcome to one final, multi-aspect concept or result. Through systems integration the designer could run up and down, among any group of activities, even from top to bottom and bottom-up, as much as he/she feels it is necessary in order to spot a more efficient and less conflicting resolution before any final, no-way-back decision. With integration "What if ..." would then be feasible, while "What's best ..." would sound a lower-risk adventure.

6 INTEGRATION STEPS

Training of a company's staff in multi-disciplinary systems is not at all a productive investment, due to the increased turnover, especially in expert jobs. Trusting human ability not to make errors in transferring information from one system to another often proves to be an unforgivable mistake. On the other hand, independent experts are always too busy to learn to use more than one system.

A "first degree of integration" is based upon data exchange techniques that may export data from one application and input them to another. This method is more or less the common practice of the software industry.

By-passing the particularities of the different data structures of each application, these data-exchange files transfer limited and essential information only. IGES, STEP and DXF-files are some of the methodologies used for the exchange of graphics data between CAD systems. Any possible logic or feature of the object described cannot be transferred to another CAD environment through this method.

Developing a special data-exchange file format, for the building entity, would overcome this restriction. This methodology is already applied in well-known products such as Moldflow, ANSYS etc. The problem of such methods is the flexibility and upgradability in case of incorporating new systems using different data structures.

A second step to integration consists of making the systems talk the same language through a common database, in this case, the "key" to integration is a common database containing virtually all building-object data structures. Every distinct system joining this database will create, store and retrieve only a part of the multi-dimensional features of the Building objects, the information the system is made to deal with. For example, a CADrafting system could create and display only the geometric data of a column or a wall, while a mathematical modeling system could calculate and attach the stress applied on these elements.

At present, the Instituto E. Torroja is carrying out a research program which is aimed at establishing the basic principles of a data model to describe construction, using concepts such as objects, attributes and relations focusing on the design phase and proposing a model for the design process as well. Different existing data base systems such as relational D.B. and hypermedia will be studied, paying special attention to object oriented D.B. which is considered to be the best solution on future.

The third step should be adding a comprehensive user interface. The question to be discussed here is wheter the users, already accustomed to certain systems or environments, would prefer a new special purpose user interface instead of their own good old shell and change their habits in favour of the integration.

The answer is "no, not yet". We have concluded that the users are not ready to accept any changes in their habits, unless someone could prove that substantial benefits could be derived from a possible integration of their systems.

A common user interface will not substantially improve the overall performance of the BD process because the different systems are used by different experts. Unification of user interfaces could benefit only integrated environments (ex. Large companies covering a wide range of BD activities) but again, only in terms of common know-how, training and maintenance. Even in these environments the different disciplines are also carried out by different experts.

7 CONCLUSIONS

AEC CADesign systems, using "real-object" concepts, features and parametrics are not yet found in the market. The Design phase, also called the Concept phase, is where most of the major decisions about style, materials performance and energy consumption takes place. These decisions have the greatest impact on overall Building cost and marketability, and require the most sophisticated design tools. During this phase a variety of alternatives may be explored with the aid of performance simulation and cost-estimating models.

Most CADrafting systems are not well suited to conceptual design tasks. However, given enough support, one may be able to overcome the tools' inherent clumsiness, and turn them into cost-effective aids, by integrating the various disciplines and technologies able to support the conceptual design phase.

This requires the involvement of databases dealing with objects and cost-estimating databases, Spreadsheet programs to analyze cost data, critical path scheduling programs to develop and redefine schedules and decision milestones, solid-modelling dealing with Building object attributes, surface-modelling tools for the definition of complex plate surface, finite element analysis tools to evaluate stress and heat transfer, personal modelling aids which let Engineers develop "quick and dirty" mathematical models of engineering systems, drafting and animation tools for development of layouts and interior details and many other technologies capable to enhancing the decisions made by the Building designers.

Such systems are being developed separately or are increasingly migrating from mainframes to the Workstation and Personal Computer levels, driven by a major downward trend in the cost of desk-top intelligence and a corresponding upward trend in performance. At the same time as the Workstation CAD revolution is progressing, AI and Expert Systems technologies are changing the expectations of users in AEC area.

If future conceptual CADesign systems can combine the visual glamour which only graphics can achieve, with the intelligence of the decision support systems, then they will ultimately offer the greatest potential in both Building Design productivity and actual construction improvement. Making the right decision in selecting design and construction alternatives, the designer could save considerable design time and results in more durable, marketable and cost-effective construction.

The next maturity step of the Building Design systems' integration will allow a higher degree of integration with the actual Construction systems, that is integration of Application Software, NC machines and Construction Robots.

Now, one of the first objectives should be to create an Integration Environment for Computer Aided Building Design (BD) systems, consisting of:

- a well documented Building Design process Model.
- a reliable conceptual Model of the Building entity, clearly defining the building objects' hierarchy and the corresponding data structures.
- a database management system reflecting the conceptual Model, dealing with objects rather than data.
- common principles for an industrial user interface, meeting the specific needs of the Building designer.

This should improve:

- the quality of the decision-making of the Building designers
- the overall productivity of the BD process
- the management of the BD projects
- the cost/performance ratio and the quality of the actual construction
- the Building maintenance and repair cycles.

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