CAD Software and Interoperability

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INTRODUCTION

Decisions taken during the conception phases in huge architectural projects influence a lot the cost and the schedule of the building construction. To ease this decision-making, many mock-ups have been used as a project prototype. This prototyping is useful to test and to improve the conception of projects. Nowadays, collaborative sites that appear on the Web greatly improve the flexibility of the framework's actors of a distant project [Aliakseyeu, Martens, Subramanian, Vrouble, & Wesselink, 2001; Balaguer & DeGennaro, 1996; Klinker, Dutoit, Bauer, Bayes, Novak, & Matzke, 2002). Digital mock-ups are used to represent future 3D elements of the final product. Digital mock-ups are known to be often employed in the architectural field. Indeed, the visualization of the future buildings in 3D by architects and engineers is a way to facilitate the testing of the choices, the scheduling of costs and processes, and the completion dates. In the architectural field, all types of activities have developed tools for special prototyping: structural analysis, thermal and fluidic networks, and so forth. Unfortunately, this development is completely chaotic. Sometimes existing tools in the same type of activity cannot exchange information. Moreover, information stored by tools is in most cases bound by a set of files that contain only geometrical descriptions of the building. Not every actor of a project has necessarily the same knowledge as the other actors to understand and to interpret information. Thus, the collaboration between the actors as well as the data interoperability seems to be difficult to evolve without a new kind of tool. The following section presents two examples of platforms using digital mock-ups to handle conception data. The section "Collaborative Web Platform" focuses on our solution through the presentation of the Active3D collaborative platform. The section "Interoperability Demonstration" presents the Active3D platform as a central point of collaboration with the help of use-cases examples. The last section concludes on the work being undertaken.

BACKGROUND

The collaborative work between distant actors on the same project improves the conception of a prototype by reducing the time between each update. A lot of CAD software packages were modified to allow virtual prototyping, but this was done independently of specific project requirements. Unfortunately, most of these solutions do not join together the essential capabilities of interaction and collaboration for the completion of an engineer project. To avoid this problem many projects were suggested. The project Cavalcade (Cavalcade, n.d.) is based on a distributed architecture, allowing several distant teams to collaborate on a conception, to test, to validate, and to exchange documents. Cavalcade provides a visual system of 3D visualization. Contrary to classical ideas on simulation tools, the virtual representation of a prototype concerns only the visual aspect of attributes of which the objects of the building are composed. These attributes are functions like "is a part of a subsystem" and documents like technical files or Web links. The 3D model becomes then a visual interface of information requests. Cavalcade aims to manage conception data. To exchange the models created with the help of CAD software, the developers of this software use specific format files for their requirements. The set of files that forms the conception of the project constitutes the digital mock-up. The 3D model of the conception object is generally integrated in this mock-up and a set of information allows management of the project by itself.

In addition, the organization of the engineering and design department must be reconsidered. To facilitate the pooling of data, a digital mock-up should be installed. The conception work is then immediately possible from the mock-up. Access to the last updated data avoids expensive errors related to the use of data not up to date. The sharing of conception data is obviously a requirement in order to accelerate the conception cycle. Several problems must be taken into account in the conception of a 3D collaborative platform.

The first problem concerns the choice of an information storage structure. There are two kinds of information storing: files and databases. In the field of 3D, the file formats are very numerous. Although the principal information of these files is the geometrical representation in 3D of the objects, each kind of file has its own levels of abstraction. The higher the abstraction level of information is, the more semantics contains the file. This semantics is an additional knowledge on geometrical information, making it possible to re-use in a better way the geometrical file and its definitions. Databases ensure the storage of large quantities of information by structuring and indexing information. In general, the databases carry the subjacent semantics of information which they store. Indeed, the structures which receive information model information that they must contain, therefore these structures form metadata on information. The databases are, thus, of primary importance to organize information so that it becomes possible to search for relevant data in a vast set of information such as a file.

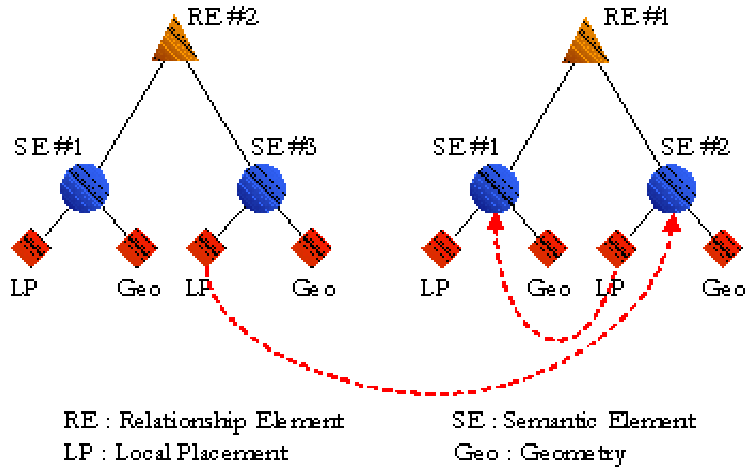
The second problem concerns the definition of an optimized 3D interface that allows a flexible and fast handling of stored information. Certain applications require at the same time a lot of memory and a minimum speed of execution. For instance, the computer-aided design often produces complex 3D geometrical models that have a very large size. Thus, the recurring problem in graphical application is the data visualization. Indeed, with the advent of design techniques, the growth of the volume to be computed is largely higher than the increase of the capacity of the graphic material. Consequently, a phase of optimization is necessary. It is located at the data model and at the data themselves. Many techniques of optimization and acceleration for interactive navigation were developed. These include calculations of visibility (Pearce, Partial, & Day, 2004), geometrical simplification (Hoppe, 1996; Pailot, Merienne, Frachet, & Nevfeu (2003), and the image-based representation (Christopoulos, Gaitatzes, & Papaioannou, 2003; Gortler, He, & Cohen, 1997; Levoy, & Hanrahan, 1996; Mark, McMillan, & Bishop, 1997). All these techniques were combined successfully to render architectural models (Funkhouser, Teller, Sequin, & Khorramabadi, 1996) and urban models (Wonka, Wimmer, & Sillion, 2001). The GigaWalk project is a rendering system that makes it possible to render CAD projects of more than 10 millions of polygons. The most striking example is the design project "DoubleEagle tanker" made up of more than four gigabytes of data, that is to say 82 million triangles and 127 thousand objects. The rate of calculation is 11 to 50 images per second which permits to navigate in real time through the digital mock-up after a time of approximately 40 hours pre-calculation (Baxter, Sud, Govindaraju, & Manocha, 2002). However, there is no perfect system. Each technique has advantages and disadvantages but certain combinations with precise conditions are very effective. These techniques described previously proved their reliability within a static framework, that is, the optimized scene is calculated once for several visualizations. In fact, the pre-computing time before the accessibility of the scene can sometimes take several days. The pre-computing of the optimized scenes is the major problem of all these techniques because if the 3D models evolve during this time then the management of the data synchronization must be taken into account. These synchronizations are not always possible because the complete structure of the scene can sometimes change. Other ways must be explored to allow for the visualization of a 3D scene to evolve during this time. Optimizations are always carried out in comparison to the geometry or the topology of the scene. On the one hand, the nature of the geometrical objects was not taken into account for computing optimization. The nature of the objects, thus, proves to be an undeniable way for research. This nature depends on the scene structuring but if it is limited to geometrical information then only geometrical optimizations are applicable. On the other hand, if information on the nature of the objects is indicated then this information provides a new way of research on the handling of geometrical information and their storage.

COLLABORATIVE WEB PLATFORM

Nowadays, the fundamental needs of all the actors in architectural engineering projects relate to a simple tool which allows a coordinated management of the actions carried out in a project. This tool must allow management of data generated during the lifecycle of the project through a 3D visualization of a digital mock-up and must also allow its access to all project actors through a collaborative Web platform. This section presents the ACTIVe3D-Build platform which makes it possible for the actors of a project, geographically dispersed - from the architect to the plumber - to exchange documents directly in a virtual environment during the lifecycle of a civil engineering project. A 3D visualization makes it possible for the actors to move around the building that is being designed and to obtain information on the objects. This section is divided into three parts. The first part presents the format used to describe the data. The second part deals with the data structuring. The third part presents the division method and exchange of data.

Data format: CAD software used in civil engineering projects models each building element by a set of vectors. In this formalism there is no semantic information on the objects that compose the building. Thus, there is no way to select automatically objects by their nature. To solve these problems the International Alliance for Interoperability (IAI) proposed a standard called IFC (Industrial Foundation Classes – http://www.iai-international.org/) which describes the representation of the objects that can be found in an architectural project. The IFC file format is a model which associates trade semantics with 2D/3D geometry for each element constituting the building. The addition of trade semantics makes it possible to limit the redundancies of information because it identifies instantaneously each element that the building is composed of for a faster

Figure 1. Example of direct and indirect links between several semantic elements



qualification of the building elements. The basic classes of the IFC include the description of the objects and provide a structure permitting the data interoperability between trade applications. For example, an IFC door is not simply a collection of lines and geometrical primitives identified as a door, but it is recognized such as "door" by the machine and has attributes corresponding to its nature. The adoption of this format by all the leaders of software CAD solves the problem of the interoperability of information between the various civil engineering professions.

Data structuring: The choice of the IFC format for the data structuring has many advantages but comprises also certain disadvantages. The study of the IFC shows the complexity of the links between the instances of relational classes and the instances of object classes. On this level there are two types of links between the objects. We call them direct and indirect links. The indirect links are defined by instances of relations, "Relationship Element" (RE: triangles - Figure 1). The direct links are defined by discontinuous red links between the instances of class resources (rhombuses - Figure 1) and an instance of "Semantic Element" classes (SE: circles - Figure 1). These indirect links are relationship elements. The instances of objects in our architecture are semantic elements. The instance resources are the attribute elements like the geometry (Geo) or the local placement (LP) and are structured as hierarchical trees.

These resources are of very diverse nature like the type of materials for a wall or the structural characteristics for a beam. Those are defined in the model IFC but we can also add other types of resource like Word® documents, requests on Web Services (elements of catalogue's suppliers), and so forth. These types of resources are added to the IFC via our structuring model of the IFC for the management of electronic documents. The IFC model defines only one type of direct link between two semantic elements. This link is the placement link used for the definition of the local placement between the graphic elements of scene 2D/3D. In the IFC model this link is called "IfcLocalPlacement". The whole local placement link forms a tree which is the graphic tree scene. Thanks to the definition of their semantics, the nature of the elements makes it possible to choose which elements are relevant for the actors of the project. Consequently, the elements are extracted from the platform only according to the needs.

Figure 2 shows a representation of the trade plumbing view of an IFC file. Figure 3 shows a representation of the architectural trade view. These trade views are textual information from which specific documents can be generated or associated (reports, information of management, etc). In the 3D scene all the geometrical forms defined in IFC trees are converted in the triangular model of surface (Ronfard & Rossignac, 1996). During this conversion, the 3D objects are associated to a GID. This GID is the general identifier used to identify each trade object of an IFC file. The GID is used to combine 3D visualization with the information stored in the database. Thanks to this database and the GID, all types of information can be combined to a trade object of a 3D scene.

Sharing and data exchange: The ACTIVe3D method: The mechanisms of management and handling of IFC files,

Figure 2. A 3D plumbing context view

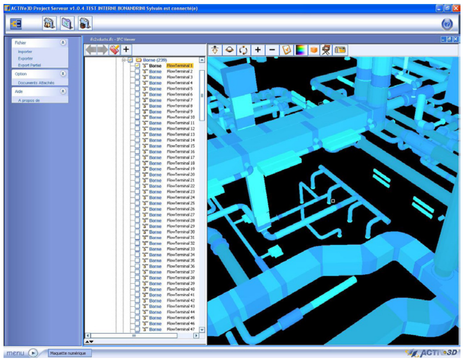
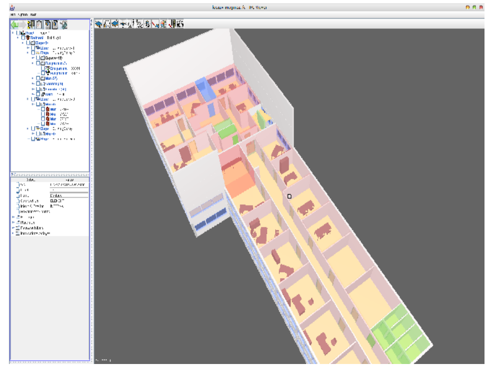


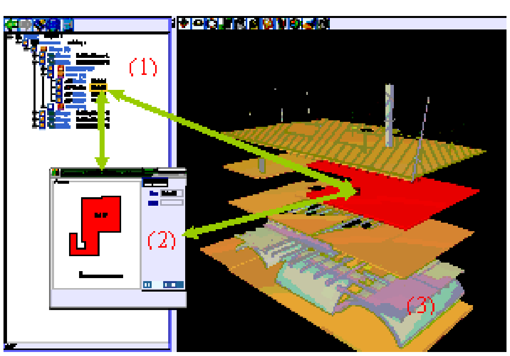
Figure 3. A 3D architectural context view



like the fusion of two files in one, the partial extraction of data from one file, visualization or storing, must take into account the multiple semantic values of the objects, which depend on the context of use. To achieve this goal, we defined a hierarchical structure of context called contextual view. The solution consists in reducing the complexity of a cyclic multiple-context graph in an acyclic mono-context graph.

Figure 4 presents the 3D scene management system which builds a specific user interface made up of a tree of composure (1), a 3D scene (2) and a technical chart (3) on a semantic element of the scene. The navigation between the elements is carried out using hypermedia links which associate a set of semantic elements to a trade object. In this case the trade object is a semantic element "Slab" (Slab - Figure 4). Certain contextual trees are generated dynamically by the system starting from IFC files. Others can be created specifically by the actors to structure their data according to their own format (starting from an IFC file or starting from existing trees).

Figure 4. Snapshot of the 3D scene management system



The principal tree is the geometrical contextual tree which contains the topological relations of the various objects. The resulting 3D scene corresponds to a particular trade view (Kim, Hwang, & Kim, 2002). This view corresponds to the actor trade association. This one is customized by the actor according to his needs, its rights, and the size of the data to be transmitted on the network. Starting from this interface, the actor can update the model while adding, modifying or removing part of the principal tree. The selection can be also carried out through the 3D scene by selecting the 3D objects. The following section shows the services available to the speakers of the project, underlining the collaborative aspect of the processes of the platform.

INTEROPERABILITY DEMONSTRATION

This section shows the use of the ACTIVe3D-Build platform as well as IFC files within the framework of civil engineering projects. In the first part of this section we will see the design phase of a building through actions made by several actors working on different CAD software. The second part of this section presents the technical study phase of the building for the structural and thermal validation of the building being designed.

Phase 1: Conception

The design of a building is divided into four phases. The first phase consists of bringing a ground statement of an old building to the platform. The second phase consists of defining an extension to this building. The third phase carries out the extension and the last phase defines the building's floors raised in the first intervention.

Viz'all: A solution for building statement via a pocket PC: Viz'all® is an automated solution of building statements, associating the use of a laser meter, a pocket PC, and software on a pocket PC. The principle consists in tracing by hand the sketch of the room on the touch screen of a pocket PC. After the connection and the deposit of the statement on the ground, the model of the building is updated and is available for all the other actors of the building restoration project. The other actors of the project can now visualize the building starting from the 3D interface of the ACTIVe3D-Build platform.

ADT, Mock-up enrichment: After the deposit of the ground statement, other actors of the project connect themselves to the platform to retrieve this statement and to enrich the mock-up. For this, the architect defines new spaces by using ADT (Autodesk Architectural Desktop). Once the architect has finished his updates on the model concerning the future building extension, he adds these new data to the platform.

ARCHICAD, Mock-up enrichment: Following the architect's updating of new spaces in the extension of the building, the engineers of the civil engineering connect themselves to the platform to collect the last information. These engineers work on ArchiCAD® from Graphisoft. When they have completed their work of building design, these new data are added to the digital building mock-up that is designed on the ACTIVe3D-Build platform.

ALLPLAN, Importation of file and finalization of the building: The second part of the project on this building is the rehabilitation of the existing building. For that, a team of engineers manages the design of this part. As the other teams do, this one is connected to the platform to extract information concerning the principal building. This team works with the software AllPlan® from Nemetschek Systems Inc. Once the updates have been carried out, the engineers put this new information on the platform.

Assessment: Thanks to the platform, a set of actors can exchange information about the building being designed and this between various types of CAD software. The IFC 2.x standard is used to format the data sent to each actor. All the data flows forward through the ACTIVe3D-Build platform because it allows each actor to have all data up-to-date, once they were placed on the server. The effectiveness of this exchange process and the centralization of information saves important time. Indeed, the data exchanges take place on a daily basis in design projects. Thus, the waiting for data updates can block the work of another team; therefore, the access to the up-to-date digital mock-up on the platform makes it possible to resolve emergencies more quickly.

Phase 2: Technical Studies

We saw in the previous section that it is possible to add information to the semantic elements of the digital mock-up of the building. This semantic information will be re-used thereafter in the creation processes of new data on the building using calculation software.

RobotBAT, Structural calculation: During the design of a building, the structures, like the beams and the columns, must be validated. Indeed, if the structures are too weak and they do not respect the standards, then the plans must be modified accordingly. RoboBAT is a structure calculation software. This software optimizes and validates the structures according to the national and the European standards about reinforced concrete, wood, steel, aluminium, and so forth. This software is able to import IFC data. Consequently, the structural engineering and design departments can validate information of the digital mock-up being designed on the ACTIVe3D-Build platform. To realize this study, the engineers must connect themselves to the platform and select all the elements concerning the structure. These elements are the walls, the slabs, the beams, etc. For that, they use the definition of the contextual tree "structural analysis".

BBS Slama, Thermal calculation: There are standards for the validation of heat exchanges between building spaces. The thermal module of the software CLIMA-WIN® made by the company "BBS Slama" makes it possible to carry out the calculation of heat loss "Th-D 1991" as well as the lawful coefficients of the buildings according to "ThBât/ThU rules" 2001. This software imports and exports IFC data. This allows to update and to validate the digital mock-up concerning the heat exchange.

Windesc, Calculation of Bill of Quantities: Windesc® is a tool of bill of quantities from the company ATTIC+ which imports IFC files. This software provides reports/ratios and estimates in connection with surfaces of walls, grounds, and so forth. This tool is essential to establish the cost revaluation of the building construction. The reports/ratios and the estimates carried out on the digital mock-up are then added to information concerning the building and the phase of design.

FUTURE TRENDS

CAD Software interoperability is a main issue that was resolved partially by the information system presented. But there still remains a second main issue, which is the semantic coherency between geometries and them semantic definition. Indeed, when users add information in the platform, this can be false. For instance, "a window is in a wall" is correct information but the different geometries can be located in a wrong place. Consequently, the window is not really in the wall. Future trends consist in defining a process to check the semantic coherency.

CONCLUSION

We have presented the importance of interoperability for civil engineering projects and how to manage it. Thus, we have presented the Active3D Web platform which makes it possible to associate semantics, 3D and documents. This method was adapted to the IFC to allow the semantic handling of the building components. Currently, we are developing a module of 3D acquisition connected to the platform to convert a cloud of points into a set of IFC semantic elements. For this, the knowledge contained in the IFC model is used to search 3D objects in a cloud of points.

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KEY TERMS

Building Lifecycle: The lifecycle of a building is articulated in two parts. The first part is about the construction into a civil engineering project. The second part concerns the "use of the building" which deals with facilities management. Currently, these two parts are dissociated in the building management processes. The Teams which are concerned with the processes facilities management are rarely those who have participated in the construction of the building. The facilities management step often begins with a physical analysis of the building to obtain a numerical representation of this building in CAD software. To avoid information loss acquired during the construction of the building, it is necessary to develop a building information system at the beginning of its lifecycle.

CAD: (Computer Aided Design) The use of computer programs and systems to design detailed two- or three-dimensional models of physical objects, such as mechanical parts, buildings, and molecules.

Civil Engineering: Includes the planning, the designing, the construction, and the maintenance of structures and altering geography to suit human needs. Some of the numerous subdivisions are transportation; for instance railroad facilities and highways, hydraulics; like river control, irrigation, swamp draining, water supply, and sewage disposal' and structures by example buildings, bridges, and tunnels.

IAI: The International Alliance for Interoperability founded in 1995 is an organization representing widely diverse constituencies from architects to software companies and building product manufacturers. The members promote effective means of exchanging information among all software platforms and applications serving the AEC+FM community by adopting a single Building Information Model (BIM).

Interoperability: It is the ability of several systems, identical or completely different, to communicate without any ambiguity and to operate together.

ISO: "International Organization for Standardization" is a network of the national standards institutes of 148 countries, on the basis of one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system. ISO is a non-governmental organization. *http://www.iso.org*

Mock-Up: A mock-up is usually a full-sized scale model of a structure which is used for demonstration, study or testing. A digital mockup is a 3D graphical model.