Preparing design to support automation and robotisation in construction

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ABSTRACT: To support automation and robotisation for construction, there are many requirements. A very basic one is the availability of the information about the building or structure to be constructed. The information may include the design of all the specialties in the building. The format of the geometry of the building elements should be in 3D. This can facilitate the construction simulation, planning and scheduling and rehearsal of the construction using robots.
The paper introduces a system only concerns the part of the design that can be tailored to support the automation of the construction process. It is a system that uses 3D as its geometry data format which can integrate all the design in a proper form, supporting composition and decomposition of building elements arbitrarily according to the needs of construction process. It also supports group discussion and decision making.

KEYWORDS: Multidisciplinary design; design integration; design for automation

1. INTRODUCTION

To support automation and robotisation for construction, there are many requirements. A very basic one is the availability of the information about the building or structure to be constructed. The information may include the design of all the specialties of the building or the structure. The format of the geometry of the building elements should be in 3D. This can facilitate the construction simulation, planning, scheduling and rehearsal of the construction if using robots or other automatic machinaries. With all the 3D design information and all other necessary information such as site layout, material storage, access path etc, the robots or other automatic machinery can be planned for collision avoidance and optimization to increase efficiency and reduce error.
The paper introduces a system which only concerns the part of the design that can be tailored to support the automation of the construction process. It is a system that can integrate all the design into a proper form, supporting composition and decomposition of building elements arbitrarily according to the needs of construction process. It also supports group discussion and decision making.
In the current practice in design, it is still far from being satisfied for automation and robotisation. Furthermore, the design process itself is complicated. There are a lot of requirements to reach an efficient, error free design by a geographically spread design team with different specialties. The system we developed is one step forward towards the need of automation and robotisation of the construction.
The system is called M3D [Luo01] which is a first time attempt to provide a higher level integration and communication tool for an architectural design team. The outcome of the system is a complete set of design data and all the related information of the building.
The focus of the system is the integration of architectural design with other specialties such as structural engineering, air-conditioning, energy supply etc. It intends to make early integration to explore design errors at early stages long before the construction. It uses a neutral 3D data format: VRML. It accepts any architectural or engineering design tools that can output VRML, DXF or 3DS format files.
M3D differs from simple application sharing which does not provide concurrent control and authorization of the cooperative design object. Application sharing requires all the partners use exactly the same CAD tool. In contrary, M3D aims at a wide communication between the current CAD tools as it accepts different formats.
M3D has a web based database with all the design project information stored for the use of all the phases of the building lifetime. It has direct interface with the online design editor.
There have been efforts in the construction society to use virtual reality for visualization, performing walk-through of architectural design by animation.

However, the design itself is in 2D. The 3D model is roughly made for visualization only. The construction simulation, automation or robotisation always has the problem to produce the 3D models for its use. Therefore, due to the lack of detail of 3D models and the communication technology to transmit large scale design models, the building models in these applications often look too simple and naive to reach the real need of the industry.

With our system, such problem is automatically solved. The detailed models that can decomposed to whatever level of detail in 3D of the building are there as the center of the information in the system. The designs are in 3D by nature with all the details necessary for error detection and construction. The visualization is only a by-product since the buildings and their supporting elements are already constructed virtually from the very early beginning of the design.

The system applies virtual reality technique to the AEC at a higher level. M3D consortium introduces the 3D design technology for the whole design process from early conceptual design until detail design [Luo 02]. Therefore, it overcomes the problem of the existing VR application to AEC industry which can facilitate the use of automatic machinery in the construction process.

The system has the following features that can support the automation and robotisation of construction:

- 3D Design integration and decomposition from multiple sites connected by communication network – to form a sequence of elements for the handling of atomatic machines.
- Support for cooperative working sessions – to form a working scheme and plan by experts located on different geographic locations.
- Automatic design verification – if adding the robots and machines as scene elements, the collisions can be checked.
- Storage and retrieval of integrated project information
- Full capability of manipulating 3D design information – facilitate the decomposition and reorganization of the building elements according to the need of applying automatic machines.
- Use of VRML, DXF and 3DS to interface with third party CAD tools – easy to cope with geometric models of the objects in the construction sites, robots and other machinery.

2. THE SYSTEM

The system is an application program that runs on PC platforms on each user's site. It is a collaborative tool especially for architectural project integration, on-line discussion, editing and decision making. It supports simultaneous, real-time multiple users cooperative working through low to medium bandwidth and long distance networks. The system can be tailored to the need of construction planning by using automatic machinery. For cooperative information sharing and visualisation, it is platform independent that uses web browser for access [Luo01].

Typically, the system is for a design team for a particular project. The team members can be geographically separated. Each member machine has to install a copy of the application. Each site has the same applications as others. There is no central control of the system for the cooperative working session. Therefore, any member in the system can call for an on-line working session with other members. For information storage, there is a central site which equipped with a database. Figure 1. demonstrates a typical use of the system. When each team has its own design work done at some stage, the chief architect may call for a working session. The team members can connect themselves by an available communication network. They can input their 3D design to the global system from local files or from the central database. All the other members can see the integrated design at the same time. They can manipulate them, modify them during the working session. Upon discussion, some modification may be made and can be agreed by the members and approved by the chief architect.

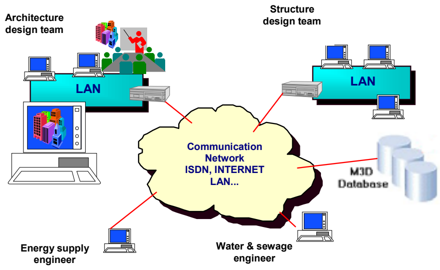

Figure 1. Typical use of the system

For integration and on-line discussion, the VRML is used as the neutral format. It accepts design from CAD softwares for architectural design and other engineering design via VRML such as AutoCAD, MicroStation, 3D studio and others. Standard format DXF or VRML can input directly into the System. Otherwise, they can be converted to VRML using a converter, and stored into database or local files.

3. 3D DESIGN INTEGRATION AND DECOMPOSITION

One of the objectives of the system is to provide a tool to integrate the architectural design with the structure engineering design and all other design projects to form a global design which is ready for construction. However, due to different formats in different CAD tools and many other reasons, there are no integration tools for all the specialties with complete capability for manipulation, modification and visualization of the global design, particularly in a cooperative way.

Actually, such a tool is under wide demand since an iteration of integration – verification - decomposition – integration happens all the time to produce a coherent, compatible and integrated project design. To use robots or other automatic machinery requires a very similar iteration and capacity of manipulation to the building elements.

Based on such high demand, we developed a system with full capability required. All the teams can still design using there own favorite CAD tools. The only requirement is that all the design should be in 3D and follows our recommendation of design procedure and output the VRML format. Our online editor tool can accept input from local files, the database and the remote locations using the web addressing convention URL.

Therefore, each team can use the system to integrate their own design first to form a specialty design. Afterwards, a global design including all the specialties can be formed by using system to work cooperatively. This integration process can be done online during a remote working meeting session or off-line.

As a strong support to integration and decomposition of the building elements in different specialties, the system organizes a global design as a 3D virtual scene with a tree structure. The users can decompose the design again easily in the design iteration for detailed design.

During the working meeting, all the team members work together in a virtual design studio. They can manipulate, visualize the building elements as desired. The decisions made by the whole project can be saved. The integrated design can be decomposed again for further detailed modification by the authors of that part of design. A record will be produced of all the modification of the design for future reference.

The on-line cooperative editing mode is a working session connected by long distance communication network. The participants are able to upload their design for integration, discuss specific design problems, and modify it interactively. The off-line mode can be for the chief architect or project manager to prepare an on-line working session between the members of the team. It can be just a basic stand-alone tool for the architects and engineer.

The system is a multi-site, multi-user environment. A cooperative session can be held between two or more users, located in remote sites.

The system allows concurrent manipulation of the design objects by multiple users. The system has been designed and implemented to be mutual exclusive for modification operations [Galli00]. Selection is the basic mechanism to assure mutual exclusion. This means that once an object is selected by a user, other users in the cooperative working session can not modify it until the object is released by this user. The local and remote selections have different color on the target object. The participants of the working session can easily see which object has been selected by other users.

The editor also allows changing the working bandwidth according to the situation of the network during the session, making it scalable to several network configurations. A multi-user audio conferencing sub-system is also provided by the system [Luo01].

4. COOPERATIVE MANIPULATION OF 3D DESIGN OBJECTS

A team of architects, engineers and designers can work cooperatively during a remote discussion meeting using the system. The system supports on-line modification of the design. The changes made by any user will immediately appear to all the participants in the meeting. Modifying the position, orientation and scale for an object can be interactively dragging or exact numerical specification. The geometry of any single object can also be modified. Common functions in an interactive system, such as undo, and clipboard operations, can be performed. The major editing operations are: scene tree editing, geometric transformations, object editing, light management, material editing, and texture editing etc.

There is a window specially showing the current design tree by names of the components. All the components are organized by specialties. This graphical textual tree can be edited by dragging its nodes around. This makes the decomposition of the design easier. The objects can be selected from the tree using their names. This is proven to be very useful since there are usually large amount of objects in one design 3D scene. Furthermore, this allows the user to select a group of objects by selecting their parent node on the tree.

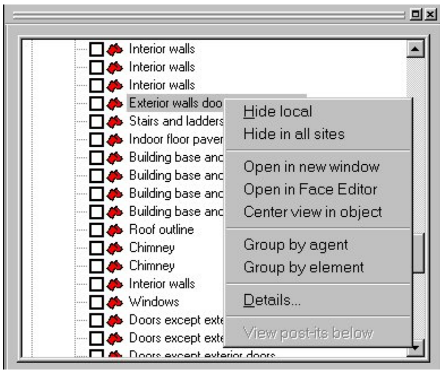

Figure 2. The textual window of the design project

A group of manipulators are provided for the interactive transformation. Dialog box is provided for numerical specifications.
The object editing option in the editing tool allows the user to isolate a particular part of the design and make other modifications on its geometry other than applying transformations.
The system provides the illumination options to the scene for visualisation and lighting test. The material of an object can also be assigned and editable. This can allow the user to specify and modify the material color, roughness, and transparency of the objects for rendering purposes.
A library of textures for the visualization of the architectural objects is provided. The operation of assigning or modifying the texture of an object can be performed locally or cooperatively.

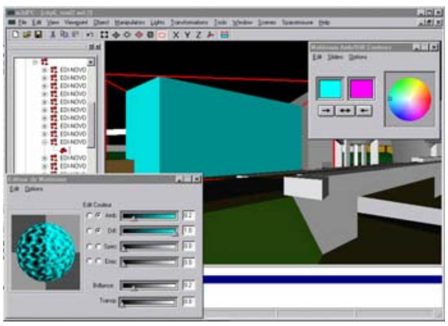

Figure 3. A view of the material editor of the system

5. DESIGN VERIFICATION

According to our study the errors within these iterations can be classified in two cases. [Dias 99]. The first case is the omission of geometry information, which can cause indeterminacy. The second is the contradiction of the geometric information when two or more incompatible elements occupy the same space at the same time. Our system provide a design verification tool which aims at solving the second type of errors.
The specific geometric elements that can be verified include architectural and engineering objects within the same specialty project or from different specialties. For example, the verifier can check different classes of objects belonging only to the structural project, such as columns against beams. It can also verify between classes of objects from different specialties, e.g. columns from structural engineering, against walls from architecture.
With minimum extension, this feature can cope with the need in using automatic machineries in which the conflict in the robot path with the building elements can be checked during the simulation phase.

6. ARCHITECTURAL INFORMATION VISUALIZATION

Designed specially for AEC users, the system has rich options to visualize the architectural 3D design information through our 3D editing tool. The organization of the global design is intuitively visualized by a tree structure in graphics and text form, see ***Figure 2. The textual window of the design project***.
Each individual building element's properties and other information can be visualized as well. An object can be identified by a standard color code in our system. The editor follows the ISO 13567-1,2 standard to code each of the building elements. Object codes can be visible or hidden. Other object properties include the dimension of the object, the material etc.
For on-line interactive discussion and examination of the design, each individual participant can make navigation into the 3D models. Every user is represented on the screen by an avatar. The users can also visualize other participants' views in the cooperative session. A 2D map of the design scene is provided to avoid user's disorientation in navigating in 3D. The user can locate himself to any location in the 2D map of the design while his

3D view will appear on the 3D viewing window. The user can change his position and orientation either on the 2D map or on the 3D viewing window.

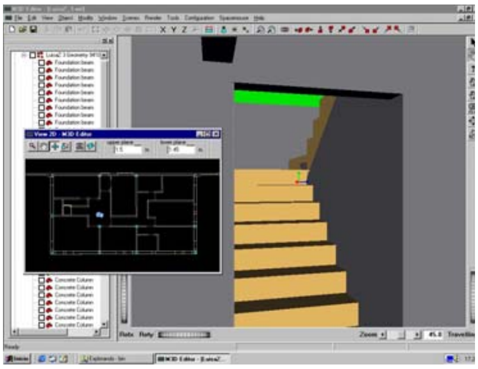

Figure 4. The 2D map

The system supports typical architectural viewing orientations and multiple windows. One can choose the point of view or specify it explicitly. To facilitate the visualization of the focused area, the objects can be hidden or visible. Clipping planes are available for any orientation to visualize the sections of the design. These sections can easily be interactively manipulated.

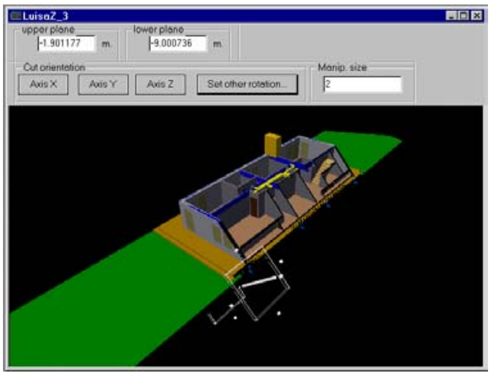

Figure 5. An arbitrary oriented clipping plane of the building

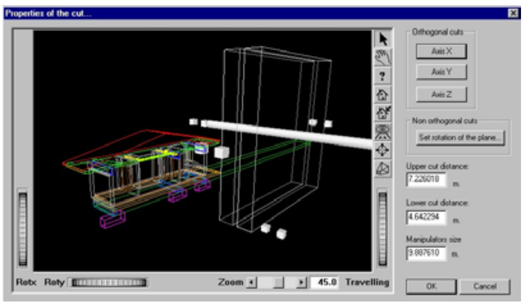

Figure 6. Definition of clipping parameters

A measurement facility is also provided by the editor to give the user an exact knowledge of the dimension and distance of the object.

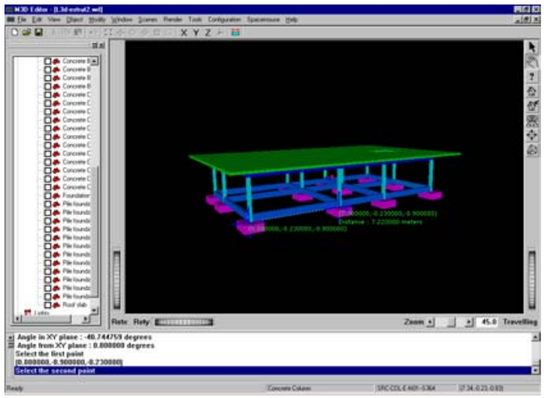

Figure 7. the measurement tool

To improve the communication between the partners in the session, the editor provides support for textual annotations. The users can make a text annotation to any object in the design. Then they can be saved into the database for future reference.

7. STORAGE AND RETRIEVAL OF INTEGRATED DESIGN INFORMATION

As a complete solution to the problem we identified in the architectural production process, an integrated design project information storage and retrieval system has been developed. All information about other phases of the construction process can also be stored in the database. This may include the 3D geometry of all phases in design, the actual status of the project, photographs, preliminary drafts, proprietary CAD application data files, etc.

The advantage of having such an information system is obvious. All the information about a building project is stored from the very first beginning of the design phase. The information and its evolution history are always available for all the phases of the building object if desired. This can avoid duplication errors, wrong use of the design version during the design phase because the information system has the up-to-date unique copy of the design. It will facilitate the construction phase by providing a complete three-dimensional virtually pre-built building far before the construction. This can definitely be used for automation of the construction process [Luo02]. It can serve for maintenance of the building and even for historical archive.

The database can be accessed by a web-browser or within the editing tool. The users can search the design information using the structure of design projects such as design phases, design specialty down to a particular architectural object.

8. INTEGRATION WITH OTHER CAD TOOLS

The system uses the standard VRML so far as the native file format. It can open and insert any design in this format. Almost all modern CAD tools can generate VRML files as output.
This means that the system can adopt whatever input from any CAD tools that output VRML format or via a converter. This is considered to be important since the traditional design needs a bridge to evolve to the new design business process. To provide such a bridge, the system can also accept DXF and 3D Studio files directly. Therefore, the design output from some dominated products such as AutoCAD can be input to the system easily.

9. CONCLUSION AND ACKNOWLEDGEMENT

The paper introduces a design integration system which may be tailored to serve the needs of automation and robotisation of building construction. It organizes all the design project information in a specialty based separation. It can compose and decompose a global architecture design from all the specialty design teams. With further improvement, it can serve for planning and scheduling of the construction process which is essential for the automation and robotisation for construction.

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