A VIRTUAL ENVIRONMENT FOR BUILDING CONSTRUCTION

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Abstract: The construction industry has acknowledged that its current working practices are in need of substantial improvements in quality and efficiency and has identified that computer modeling techniques and the use of prefabricated components can help reduce times, costs, and minimise defects and problems of on-site construction. This paper describes a virtual environment to support the construction process of buildings from prefabricated components designed within the FutureHome project. The environment can import a library of 3D models of prefabricated modules that can be used to construct a building. These models will then be used to represent the dynamics of the FutureHome construction site enhancing current construction practices that uses flat 2D plans and Gantt charts. This work is the first stage in generating an environment to support the construction process of a building from its initial modular design to its on-site construction, and maintenance during its lifetime, as part of the FutureHome project.

Keywords: modular construction, prefabricated components, virtual construction environment.

1 INTRODUCTION

The construction industry has acknowledged that its current working practices are in need of substantial improvements in quality and efficiency, with the Egan report[6] setting targets for the construction industry to reduce costs and times by 10%, and defects and problems with on-site construction by 20% per year. Information Technology and more specifically visualisation has been highlighted as one of the most important tools for construction management towards achieving this goal[5]. Such visualisation tools could assist the site manager in obtaining a better perception of the project and could be achieved by integrating the schedule management of the project with an animated virtual environment display. A 4D simulation of the construction process could help with decision making within the project and also act as a tool for improved communication between the project partners. This could lead to an increase in the quality of the project management and a reduction in defects and construction times and costs.

This paper will present work conducted within the FutureHome project. This is a 3-year, 5-million Euro, EU funded project that brings together 15 partners in six European countries and forms part of a global project under the Intelligent Manufacturing Systems (IMS) programme. Its aim is to research housing for Europe in the new millenium, to enable the production of affordable, high quality homes for all. FutureHome will develop adaptable and sustainable building system concepts that can take advantage of advanced manufacturing systems and methods. It will promote the use of prefabricated parts and assemblies, and develop the tools for design, configuration, production and assembly. Off and on site production and assembly processes will be developed, that will be heavily dependent on the use of intelligent automation and an IT infrastructure involving agent technology. Overall, the FutureHome project intends to produce leaner design and construction processes, that will focus on value for money, improved productivity, maintainability and sustainability. The projections of benefits from the project are estimated at 30% in the cost of construction, 35% in construction time and a reduction of 60% in the number of defects.

As part of this research a prototype virtual environment has been implemented that allows a model of a house to be constructed from a library of prefabricated components defined within the FutureHome project. The construction of the model requires minimal user interaction as the environment supports automatic constraint recognition between the components, so that as the user is constructing their model the system automatically detects whether the components the user is manipulating can be linked. A database has been designed that holds the types of modules that are used in the building. As the user constructs the building, the construction information is also stored in the database along with the order of construction and any dependencies between tasks. Aswell as being able to review the building that they have constructed from within the virtual environment, the construction order of 3D model can be replayed to provide an animated 4D model of the construction process. The database also holds information relating to the construction site, such as stock, resources and delivery information and has been designed to be compatible with IFC specifications.

This paper will focus on how a virtual environment can support the construction process of buildings using prefabricated parts and assemblies. The paper is organised as follows: Section 2 discusses related work in the areas of 4D construction systems and virtual environments. Section 3 describes the implemented system in use using a conceptual prototype defined within the FutureHome project as a developmental case study. Section 4 describes the system architecture that is required for the development of a virtual environment to support the construction of buildings. This is followed by Section 5 listing the conclusions and future work to be undertaken within the FutureHome project to further enhance the virtual environment.

2 RELATED RESEARCH WORK

Virtual Environments can offer the area of computer aided design many valuable extensions as it can provide a more intuitive means of communication with the computer. Much of the work involving virtual environments and construction has been related to architectural walkthroughs. These can allow for such factors as aesthetics, e.g. lighting, acoustics and internal layout, and also the spatial location of the building and its impact on the surrounding environment to be evaluated, e.g. see [10]. Such visualisations tend not to be dynamic: the user can navigate through the environments but has limited or no interaction with the artifacts within the environment. Furthermore, the models of the buildings themselves will only be realistic in their appearance, they will not be realistic as far as the actual composition of components is concerned. These examples only deal with the final stage of the process, visualising the completed building, whereas the construction planning and scheduling tasks deal with the entire construction process from its conception until the completion of the construction.

Research has been conducted in the utilisation of computer graphics in planning and scheduling. OSCON[2] allows users to construct buildings from parts such as doors, windows, slabs, etc. OSCON incorporates a time and cost model within its architecture and the models that are constructed can be viewed in VRML and queries regarding such variables as cost, visualising the information on the 3D model, or time, showing the state of the construction at any specified time can be performed. OSCON provides further project management capabilities over its 3D visualisations and query facilities, for full details see[2]. Adjei-Kumi[1] is similar to OSCON in that it can provide a visualisation of the construction process at the building site. This work aims to supply the site managers with visualisation tools so that they are better equipped to plan the construction process as there current activities rely on intuition, imagination and judgement. Such tools allow for 3D visualisations of the construction process and can help site planners organise their activities. Other systems that generate and simulate the process of construction use CAD environments rather than VR technology, these include[3, 11].

3 FUTUREHOME CASE STUDY

In this section the current system in use will be described using some of the demonstrator modules and houses that have been developed within the FutureHome project. These have been designed to give an early overview of the concepts that the FutureHome project is investigating and these modules will be further developed and built by the FutureHome partners. Figure 1 gives a view of an example building constructed within the virtual environment using these modules, and its associated construction schedule.

Within the building design environment the user can navigate freely through the 3D environment to view the components and the building; select components within the environment and apply rotations and translations to these; and construct a building by bringing components together. The system automatically detects how components can be linked together and so eases the task of construction within the environment.

Currently the user can either begin constructing a building from the empty environment or can load a partially constructed building into the environment and continue construction on that model. Interaction within the environment is achieved with a LogiCAD3D SpaceMouse. Using the mouse the user has six degrees of freedom (6DOF) of movement and control available to them. This allows them to move about the environment freely and use the buttons on the SpaceMouse the call up a menu and make selections. From the menu the user can select a component to add to the building. Figure 2(a) shows the top level of the rotating menu that depicts the initial breakdown of the module types. The user can rotate the menu with the SpaceMouse and also select the module type which is shown foremost on the screen. This will bring them down the tree menu to the next level which will display further module types and/or specific modules for selection. When a module is selected the user can then move that module to where they wish to add it to their current building. Figure 2(b) shows a service module that has been selected and is about to be added to the current building.

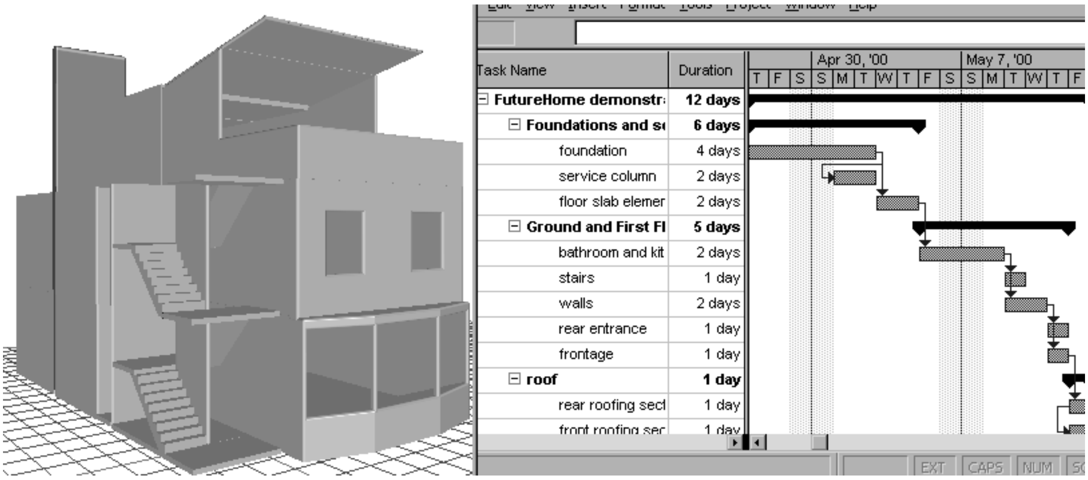
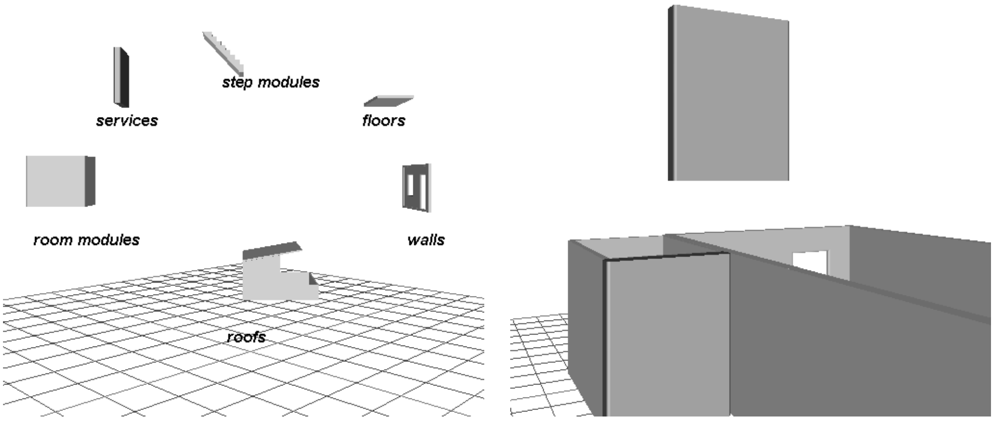


Figure 1: A building constructed in the virtual environment and its construction schedule



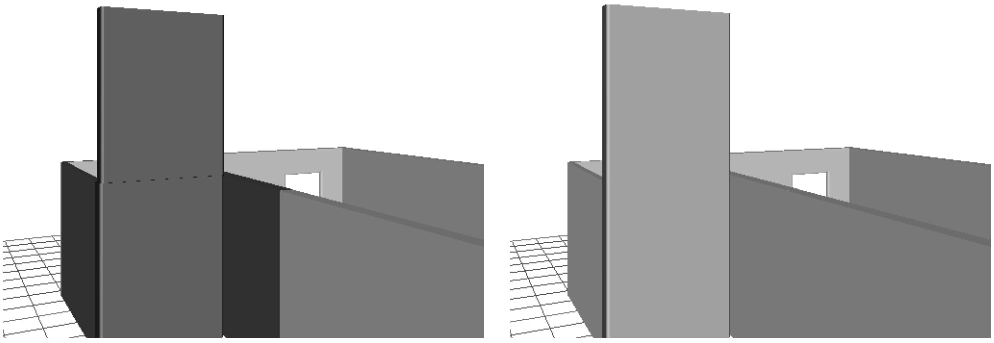
(a) Selection of the components is via a rotating tree menu

(b) Component selected to be added to the environment

Figure 2: Selecting a component

As the user drags the service module towards the building, the system's collision detection component within the environment detects surfaces that are colliding and highlights them (in this case by altering their colour), see Figure 3(a). The user can continue to drag the component until they are happy with the alignment. The user does not have to align the parts exactly—the system automatically detects which surfaces can be mated together and aligns each of the components exactly for the user. The user releases the part when they are happy with their alignment (shown in Figure 3(a)). When the component is released, the system aligns the parts exactly as shown in Figure 3(b). This is performed using the constraint manager within the virtual environment that aids the user in aligning parts exactly within the environment and maintains the relationships between each of the modules and their construction order (the constraint manager is defined in Section 4.2). As each component is added to the building, information on the component, its placement, etc are stored within the database.

Using this approach and with the import of additional 3D models of the modules the building can be constructed. Figure 1 shows the external view of a building modeled using the virtual design environment from the modules. With the complete building, the virtual environment can replay the construction process of the building using the knowledge of the components and their order of construction to provide a 4D animated model of the construction of the building. The



(a) Collision between the selected component and other components within the environment are highlighted

(b) The component is released and constrained appropriately

Figure 3: Example of constraning/constructing a component

construction schedule of the building can be altered as the schedule can be exported to a schedule management software (in this case Microsoft Project). The construction schedule of the building can be seen in Figure 1. The user can alter the schedule using this software and the new schedule can be imported into the virtual environment. When the building is reconstructed within the environment, the order of construction will be according to the newly imported schedule.

In this section it has been shown how the current system can import any previously defined 3D CAD models as a library of components to the virtual design environment, and allow the user to construct a building within the environment from these prefabricated components. The system architecture that is required of the virtual environment will now be defined.

4 SYSTEM ARCHITECTURE

The system architecture builds upon the authors' previous research on constraint-based modeling, virtual environment interface design, product and object databases, and other relevant state-of-the-art technologies, see Figure 4. The four main components to the system architecture are: the virtual environment—for importing the CAD models of the modules and display and navigation about the environment; the constraint manager—for defining how each of the modules are connected in relation to one another and maintaining allowable movements and relations between each of the components; the construction database—for storage of the construction components, schedules and resource information; and the task manager—for handling interactions and tasks between the user and the interface. The following sections will discuss each of the main components of the system's software architecture defined above.

4.1 Virtual Environment

The virtual environment is developed around the OpenGL Optimizer libraries from SGI. The Optimizer libraries were chosen as the graphics engine for the virtual environment due to their powerful CAD capabilities and the optimisations available to reduce rendering time of the data. A CAD interface was developed as a part of the IPSEAM project[9] for importing CAD data into the environment. Once the assembly parts are loaded into the environment via the CAD interface, the VE interface allows the user to select and manipulate objects in the 3D space, navigate through the environment and specify constraints between components within the environment to construct a building.

4.2 Constraint-based Modeling

The constraint manager supports constraint-based interaction between the components of the building to model their assembly and disassembly. The assembly process consists of a succession of tasks, each of which consists of joining components to form the final assembly. Parts are considered joined when the necessary contacts and alignments between parts have been established. These contacts and alignments are referred to as assembly relationships, which are described in terms of geometric constraints and are solved using the Geometric Constructive approach[8]. For further information on constraint-based modeling see[9].

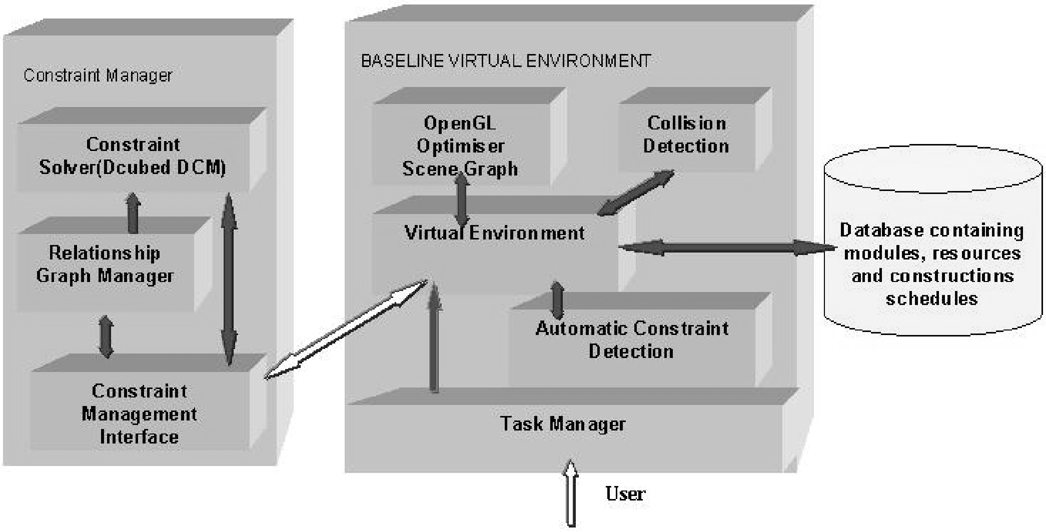


Figure 4: Software architecture of the virtual construction environment

Automatic constraint recognition removes the costly requirement of having the user specify each constraint individually and relies on the system to detect the constraints as the user manipulates the components. Bier[4] proposed a 3D snapping technique for building 3D models. These concepts were further extended by Fernando[8] to support interactive assembly modeling. In this construction environment, constraints are recognised between geometric elements when the assembly parts come together and full 3D automatic constraint detection is supported.

4.3 *Construction Database*

The construction database manages all the information relating to a construction project and has been designed to be compatible with IFC specifications. The database stores information on each of the building elements that are available to the user for construction. As the user selects these elements and constructs their building, the components used and the order and form of the construction is also stored within the database. The database also stores information on construction sites, their stock and resources, and deliveries to the sites.

Using this information the building can be reconstructed from its constituent modules according to the construction order and its dependencies and also according to deliveries and stocks at the construction site.

4.4 *Task Manager*

The task manager manages the interface between the user and the system. Current interactive software systems can be hard to learn and baffling to the users even with their visual interfaces. One of the major problems is because the underlying software system has no concept of what the user is trying to achieve at the system, i.e. it has no internal task knowledge. The user of the system is trying to complete a task, e.g. to construct a building. This in turn may be decomposed into subtasks such as joining components together. These are the tasks that the user is trying to complete but the system has no internal concept of these tasks. If these tasks could be built into the system then this could provide many benefits to both the end user and the programmer of the software system.

For the end user, a system with built in knowledge of the tasks they are trying to achieve can provide certain advantages such as context sensitive help while the user is performing their task. This makes the interface easier to learn as the user can query the system as to its current state, the tasks that are currently viable and how the user should proceed during a task, and proves to be less distracting than having to refer to either printed or online manuals. For the programmer of the software system the task manager offers the benefits of rapid task prototyping as the specification of task order is easily altered. Also, unlike event based systems where the programmer has to examine the code to identify the order of tasks within the system, the task networks can easily be visualised as they are explicitly defined within the program. For more information on the task manager see[12].

5 CONCLUSIONS AND FUTURE WORK

This report discussed the development of a virtual construction environment to allow prefabricated building components to be used to model the construction processes. The main outcomes of the work presented are the development of a geometrically constrained building environment to allow for the assembly of a library of prefabricated components, the object database for storage of the construction concepts, and the development of a task manager. The building environment allows for the import of construction components and allows the user to create a geometrically constrained design from these components. The order of construction can be exported and edited using schedule management software (currently Microsoft Project). This allows the order of construction to be altered and, with the import of the this information into the virtual construction environment, is reflected in corresponding changes to the 4D construction simulation. The models can then be used throughout the construction and maintenance of the building as a reference tool to aid the construction site planners. The task manager supports the user of the system and also benefits the programmer designing the virtual environment software.

Further development of the interface will allow it to be used in a CAVE and Reality Centre type environments that are housed within the Centre for Virtual Environments. A cost-oriented model of the assembly processes is also being integrated into the system. This work is a continuation of the research developed during the OSCON project[2].

This 4D model will provide more effective communication of the FutureHome construction process, making clear the sequence of construction and the utilisation of intelligent automation and site sensors at the construction site to establish the constructability of proposed systems. The virtual environment will be further enhanced with prefabricated component information to provide a mechanism for exploring cost, quality, and time trade-offs. A by-product of the use of virtual reality is that the completed model can be examined in the future when the building owners need to perform some maintenance or replacement. Instead of handing over as-built drawings, FutureHome will provide an adaptable 3D model of the building. The research presented in this paper aims to increase the construction company's competitiveness through the integration of technology, a priority highlighted in a recent EU paper[7].

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