INTEGRATION OF PARAMETRIC GEOMETRIC MODELING AND CONSTRUCTION SIMULATION

Parametric geometric modeling and construction simulation

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Abstract

In early ages 'Designing' of a building could not be differentiated from 'building' it, since the Master Builder was also the designer. With the increased complexity of design, this arrangement changed. Currently designing a building and constructing it are two different tasks. The description of design is done using drawings, whether in 2 or 3 dimensions, while construction operations is usually described by means of construction schedules. Three-dimensional details of building assemblies are often used for describing the design details. If we can describe the building details parametrically with construction operations only, then we can save time in developing assembly details and improve constructability. This paper describes a new approach to store design description of assembly details as intelligent objects. Each of these objects represents a building assembly. These assemblies are linked to a database of networks, that generically describe how the assemblies are built/drawn (i.e. the components used and the geometric/construction operations). A prototype system EASYBUILD is introduced.

Keywords: Architecture, engineering, construction, simulation, geometric, modeling parametric.

1 Introduction

Computer aided design and drafting (CADD) has been a viable tool for the Architecture Engineering and Construction (AEC) industry. A major drawback of today's automations in building design is that design tools are defined in alienation from the construction stage (De Vries 1995). CADD systems are developed without taking available construction operations into account. Increased computer capabilities lead to increased design possibilities that are difficult to construct.

In the building delivery cycle of today there are several gaps between design and construction. Part of the reason for this is due to the separation of the design description methods and the construction description methods. Construction is usually described by the construction schedule. Methods like CPM, PERT or activity cycle diagrams for cycle/repetitive processes can be used to describe construction processes. The design of the building is usually described by a drawing, made up of geometric primitives that represent physical construction objects or abstractions of these objects. There are several stages in the building design process in order to reach from a basic drawing description of the building to the construction schedule stage, as shown in Figure 1. The design synthesis stage is where the design concept is formulated. After the design concept is formulated, an automation stage can develop the design concept and provide details for that design. This is the focus of this paper. Checking from the designer can refine the detailed design or iterate through the design cycle again.

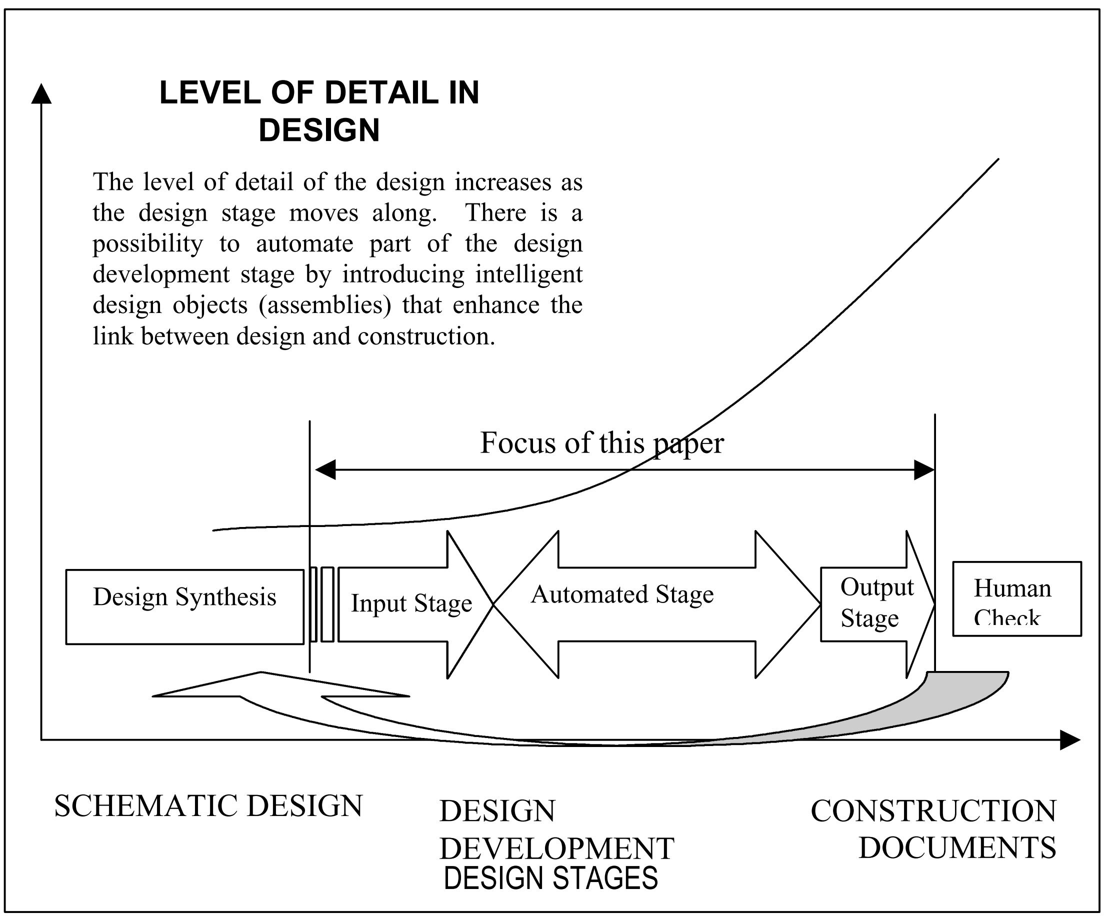

Fig. 1: The design/construction process and the possible integration stage

We can integrate the design geometric modeling operations and the construction operations for building assemblies. Each of the geometric representations of the assemblies can become a dynamic object that is linked to a description/schedule of how it is built. Each time the assembly representation is used in a design it builds itself virtually on a computer by drawing its components. The sequence in which the components are drawn is described by a set of parametric operations. Components used can be three dimensional geometric objects. The construction sequence can then generate a realistic 3D model of the building for different assembly shapes and component sizes. This requires us to describe the sequence of construction and the geometric modeling operations that are required to generate the model in an integrated way. To accomplish this we firstly need a building product model that breaks down the building into various objects and relationships. This has been discussed in earlier in the literature (Nassar 1998; Eastman and Siabiris 1995). Secondly, in order to be able to reuse the objects the geometric modeling and construction operation must be described in a parametric way that gets evaluated for each specific design situation.

The developed prototype system, EASYBUILD allows the designer to parametrically describe how certain assemblies are built using a simulation network structure. This network is evaluated for each specific design to produce the final detail of the building.

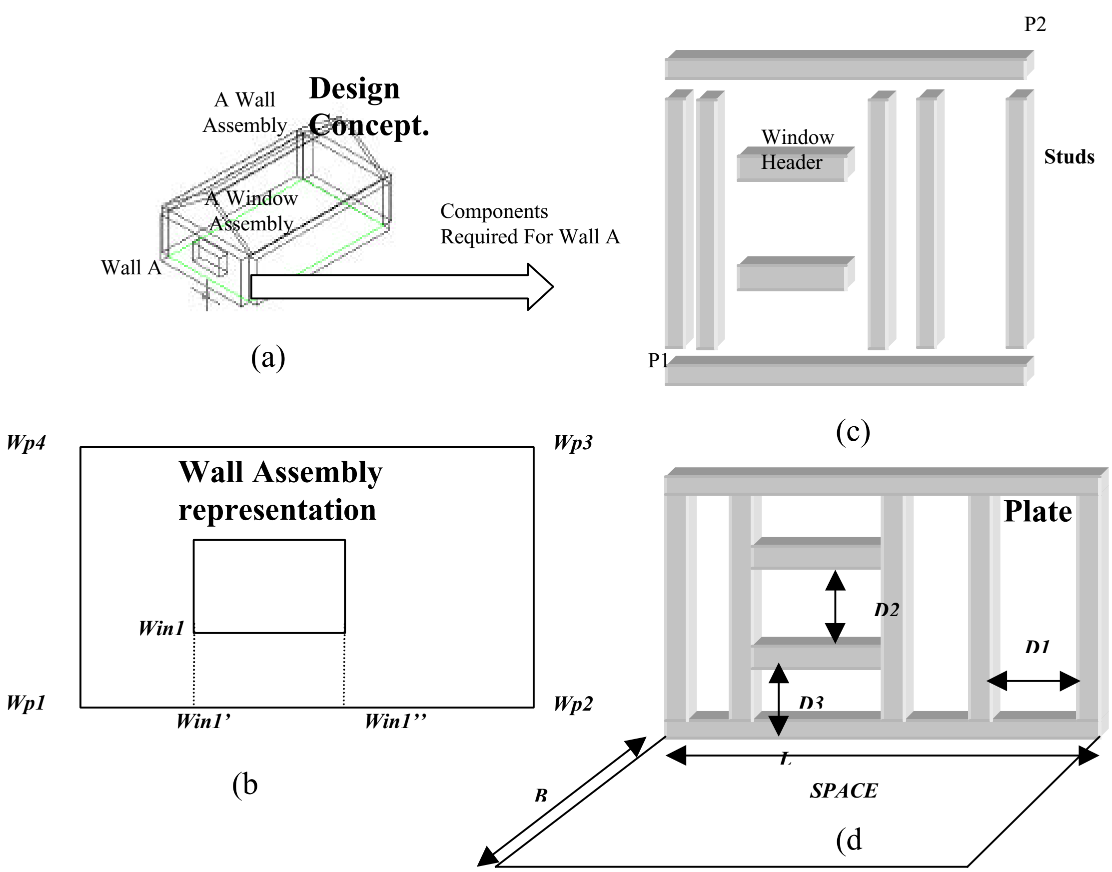

Fig. 2: The example stud wall and the parametric variables

Parametric modeling techniques are described in section 2. Section 3 introduces simulation networks as a construction process modeling technique. Finally in section 4, we describe how we can integrate the two techniques and a computer prototype system EASYBUILD is described.

2 Parametric modeling

There are two main issues in geometric modeling, first the geometric representations of the components, and second the relationships between these components. In addressing the problems of design, the relationship between the components is more problematic (Hall. 1991).

To specify the geometric relationships between the components in a simple wall assembly so that these relationships get evaluated for each particular design, several parametric modeling techniques can be used. The goal is to describe and store the assembly parametrically so that each time the assembly is used in a design it is drawn automatically. In Figure two a simple design concept (a), a geometric representation for two of the assemblies (window and wall) used in that concept, (b) and the components required to build the assemblies (c) are shown. A description of the geometry of the detailed assembly (d), in a parametric form is required, so that the parametric description can be reused for other assemblies. In this case the detail is for a wooden stud wall. Below we will describe two of the parametric modeling techniques, simultaneous equations and constructive specification. A complete description of parametric modeling techniques can be found in (Roller 1991; Cugini at al. 1998; Lee and Andrews 1985)

2.1 Simultaneous equations

The simultaneous equations method is based on translating all dimensional constraints into equations, where the unknowns are the coordinates of the characterized points of the geometric model. In the example the characterized points are shown. Subsequently a system of equations is defined which can be solved by an iterative numerical method. For example the linear distance D between the 2 points $Wp1(x1, y1, z1)$ of the wall assembly and $P1(x2, y2, z2)$ of the plate component, can be translated into the constraint equation,

$$F = (x1-x2)^2+(y1-y2)^2+(z1-z2)^2-D^2 = 0 \quad \textbf{(1)}$$

This approach can continue until we have fully constrained our model. Constraint equations are in general non-linear and are usually resolved using the Newton-Raphson iterative Method (Lee and Andrews 1985). This approach usually requires skilled user intervention to condition and solve equation systems.

2.2 Constructive specification

This approach utilized the construction sequence of the design. Different parametric design methods based on this approach have been devised. One of the approaches (Roller 1991) introduces three classes of geometry, FIX, VARIABLE and

FLEXIBLE. Geometric elements that are to have fixed dimensions are constructed in FIX mode. For elements that require variable dimension parameters (length, radius, angle) VARIABLE is used. Sometimes the length of an element is not explicitly known but has to be fit between existing points (e.g. the length of the window header in Figure 2). FLEXIBLE mode is used for this type of geometry.

In order to relieve the user from explicitly specifying all of the implicit constraints a set of constructive operations can be devised, e.g. in 2 dimensional geometry, POINT_to_POINT fixes one shape to a certain point on another, LINE_HORIZONTAL forces an edge of a shape to be horizontal. EASYBUILD is a prototype system that allows constructive specification operations for building assembly. In EASYBUILD these operations act on 3D components in the assembly. A set of constructive operations is defined in EASYBUILD. A PLACE operation for example positions a component relative to 2 characterized points and a rotation, (relative to the assembly geometric representation coordinate system).

In Figure 2 for example, in order to specify that we need to place a plate at the lower left corner of a wall,

PLACE (wall, plate, *wp1, p1*, 0)

Since all of the wall assembly geometric representations have a characterized point *wp1*, the actual coordinates can be evaluated for all of the walls with wooden stud construction. Currently EASYBUILD utilizes a set of constructive operations; CUT, PLACEARRAY, REMOVE, SHAPE, ASSEMBLE. Future development will introduce other operations. We now need to introduce construction simulation as a process modeling technique, which can help us to model these constructive operations.

3 Construction simulation

Several simulation techniques focus on the construction industry and attempt to describe a construction sequence. A detailed description of simulations in construction can be found in Martinez (Martinez 1996). Simulation models allow a concise representation of repetitive activities and explicit formulation of resource flows (Senior and Halpin 1998).

CYCLONE (Senior and Halpin 1998) is probably the most common known of construction simulation techniques. Stroboscope (Martinez 1996) is another simulation tool based on CYCLONE that provides many additional utilities. In stroboscope active states are referred to as COMBIs and NORMALs and units are held in QUEUES. A description of simulation models can be found in (Martinez et al. 1994). Next we will describe how the parametric constructive operations can be integrated with simulation networks.

4 Integrated approach

The proposed approach allows designers to specify the construction sequence of the assemblies generically using simulation networks. These events (COMBIs and

NORMALs) in these simulation networks are made up of constructive geometric operations.

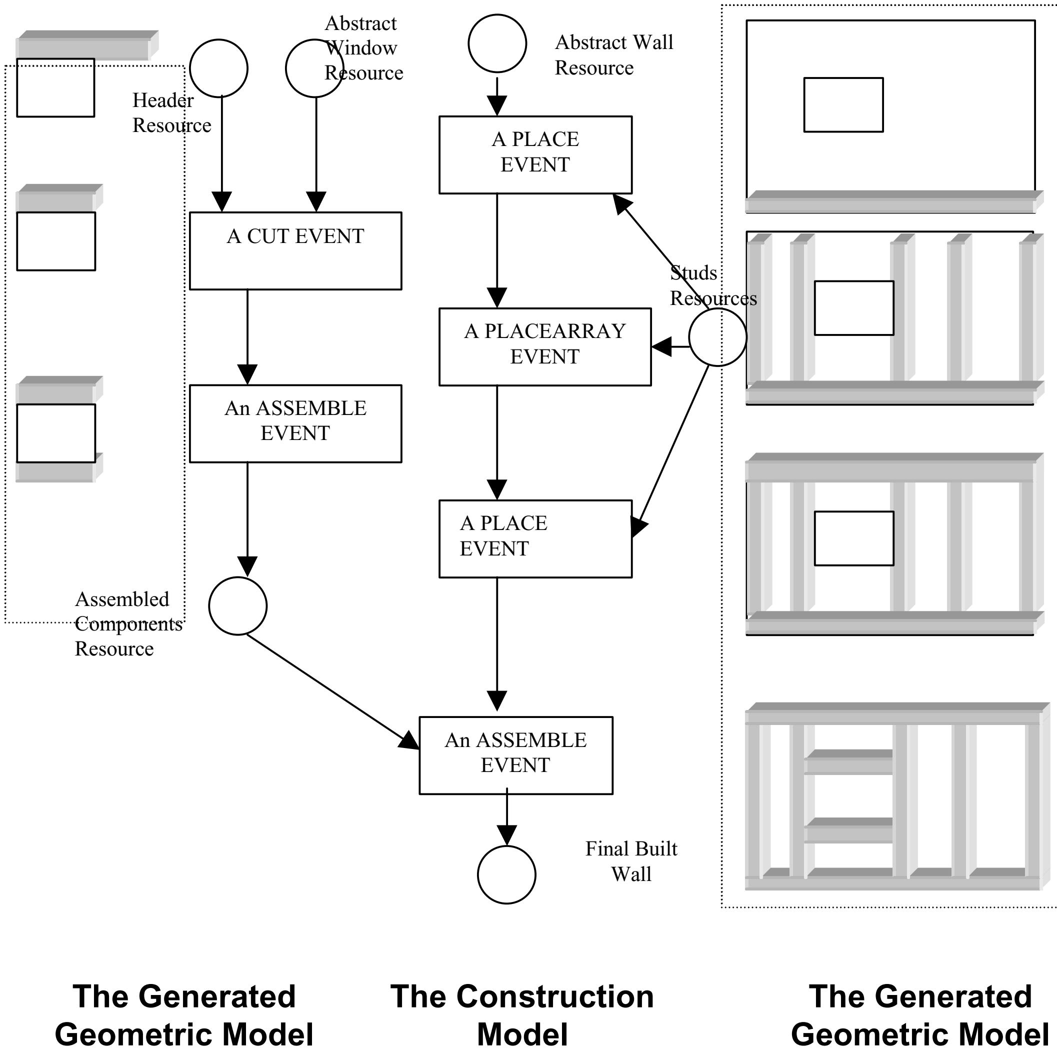

Fig. 3: A simulation network showing a cycle for one wall assembly

The components that make up the assembly (e.g. the studs, headers and plates) are considered resources. Resources are objects that the various events in the network use to perform their tasks. Also, the assembly itself is modeled as a characterized resource type. Characterized resource types are a special kind of resource that can have particular attributes and specific values for each individual resource entity. In stroboscope a queue of a certain type can carry resources of its subtype. Each instance of the assembly resource is modeled as a subtype. So for instance the wall assemblies are considered a resource type and are assigned to a separate queue. The queue is filled with a set of subtypes resembling the different walls in the design concept. Each of those subtypes carries with it the geometric information (the parameters to the operations).

In the example shown in Figure 3, the wall and window are modeled as characterized resources. These resources are called abstract characterized resources because they do not actually get used but only their attributes are used to perform the geometric operations. The constructive operations are defined as the events that act on the resources. The wall resource has as its attributes the characterized points. The operations in the events are defined parametrically, i.e. they specify the characterized points of the assemblies as variables. These points are specific for each wall. As the wall resource moves through the network the operations act on it to construct the 3 dimensional model.

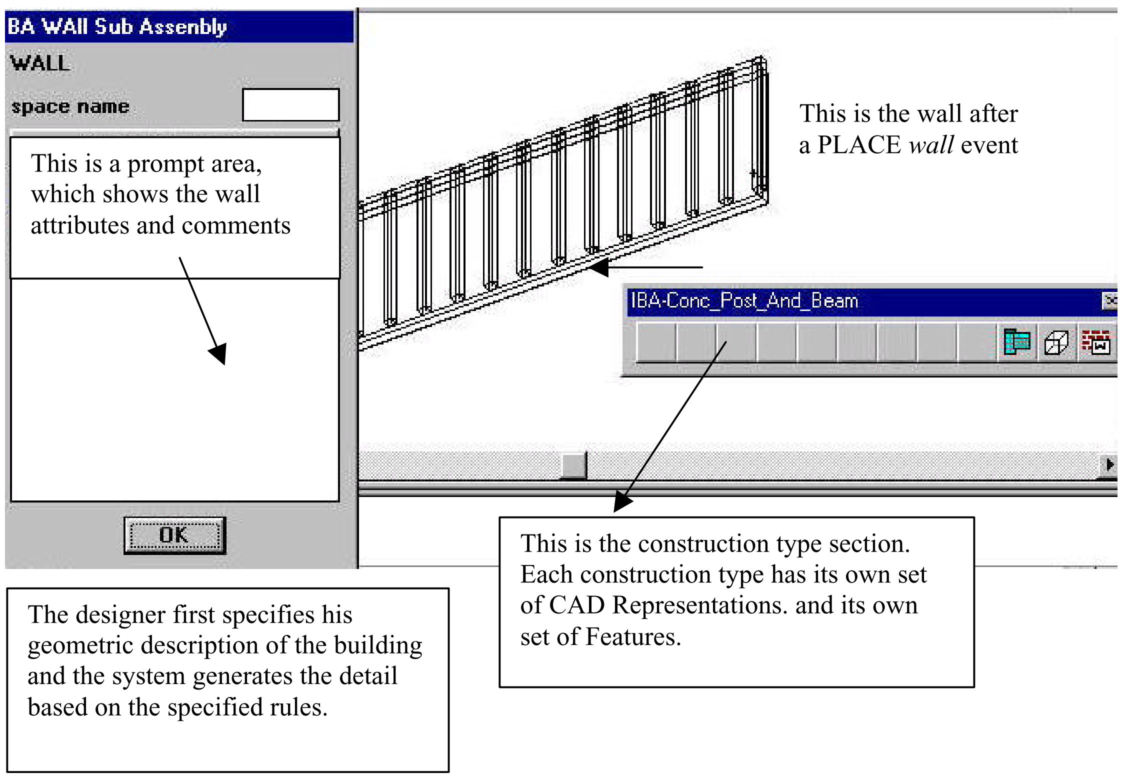

Fig. 4: The prototype system, EASYBUILD

5 Conclusions

In this paper a new approach for integrating construction and geometric modeling processes of buildings was described. This approach allows the designer to generically describe how certain assemblies using a simulation network structure. This network is evaluated for each specific design to produce the final detail of the building. A prototype system EASYBUILD (Figure 4) is underway. The EASYBUILD system allows the user to define a construction sequence. The user also can then specify the design of the building in terms of the various building assemblies. By reasoning with the specific design geometry the predefined simulation networks are set up with the proper variables and resources. Running through these networks produces a 3D model of the building assembly details in a commercial CADD package (AutoCad).

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