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Computer assisted design of a building site

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ABSTRACT

This paper describes the package CCAO that enables the graphical modelling, the visualization, and the computer assisted design of a building site. The design problem is to decide the location of the different objects needed for the construction with respect to a set of constraints. A hierarchical object oriented data base system is used which is well suited to the modelization of the different parts of a building site. A toolbox (written in C++) facilitates the creation of the hierarchy of classes.The visualization is made with the use of PHIGS+, and the graphical interface is developed in OSF/MOTIF with the use of the XfaceMaker2 interface generator.

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INTRODUCTION

In the past few years , there were many works in Computer Assisted Design applied to architecture and construction.Some works are focused on the use of more realistic visualisation of buildings (image synthesis), to study for instance the future aspect of the building and its impact on the environment.Other works are concerned with the design phase of a building to extend the capability of traditional CAD system (Hall [11]). This is the case of researches on knowledge Based Computer assisted design in Architecture or the researches on the use of expert systems (Kimberley [12]).

Very few works have been made on CAD system for the building construction itself.This is the field of activity of the I3I society the objective of which is to offer to the building contractor a software tool to manage the whole process of the building construction. This paper presents the actual results of a two years joint research between this society, the ESSI school in Computer Science of Sophia Antipolis, and the I3S Research Laboratory in Computer Science. The whole system which is described here is named **CCAO** (in french Conception de Chantier Assistée par Ordinateur): Computer Assisted Design of a Building Site

I - MODELIZATION OF A BUILDING SITE

A building site is rather complex to model as it is composed of different parts:

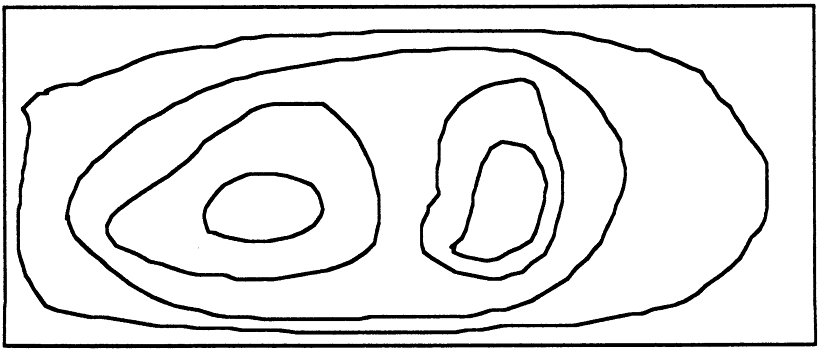
a) the building land and its surroundings,
b) the block of flats to be constructed,

c) the different objects needed for the construction such as cranes, cement mixers, workers housings...

Some objects (for instance cranes) are moving objects, so we have also to model their animation. The position of objects can be changed according to the evolution of the construction and we have also to represent the different steps of the building construction itself. We have developed a graphical package to enable such a graphical representation. In doing it, we have first taken the decision that the modelling of the building itself was certainly already made (in the design office) by the use of a CAD system. This is not the case for the landscape and its surroundings and for the different objects needed for the construction of the building. This is the first aim of our system.

I.1 Landscape modelling

The problem here is to model the landscape on which the building site must be set up. Our approach is to start from the digital data of the terrain given by the geometer.We represent the land by the contour lines:



This enables us to have the possibility to visualize it in 3D with PHIGS. Realism is possible (as in Thiemann and All [14]) but it is not our first objective in this particular application.

I.2 Object Modelling

Object modelling is a broad field the evolution of which is described for instance in Eastman [7]. Here, we use a B-Rep model of polyedrons objects (other objects are approximated by including polyedrons).

Each object is defined in its local coordinate system. Obviously there is not a unique definition of such a local coordinate system for a given object. The default definitions of our modeler is therefore described to the user by the graphical interface.

In this local coordinate system, many parameters can be associated with each kind of object:

* variables representing the dimensions of the solid: for instance variables Sx, Sy, Sz for the length of a rectangle parallelepiped. Notice that it is only in the local coordinate system of an object that these parameters can have semantic meaning as the width, the height or the depth. In the real world, it depends of the position of the eyes (of the human observer),

* the name of its vertices and faces and some associated parameters: the local coordinates of each vertices, the normal vector of each plane faces, a variable designing the color of a face...,

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For such polyedrons objects, that representation is completed with a derivative of the Brep model:

To each face of an object is linked:

* its normal vector (outward oriented),
* its algebraic equations (implicit and parametric),
* the list of parameters needed to define these equations,
* the list of the edges which defines its shape.

To each edge is associated:

* its direction,
* the two vertices which define that edge.

The geometry of each object is described with GPHIGS (a PHIGS+ implementation on the X Window system) the hierarchical data structure of which is well suited to the description of complex objects as cranes (with moving parts as the bottom on the rails, the tower, the jib, the wagon and the load itself).

Some of the surrounding objects are also important to be represented as they can represent obstacles for instance electric cables, trees, or existing buildings. As realism is not important here, it is adequate to model them as including polyedrons.

The different steps of the construction can be visualized in a wire frame representation or with a more realistic one with colours, textures and light sources with PHIGS +.

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I.3 Animation of objects

Moving objects like cranes are considered as open kinematic chains of N rigid bodies called *links*.

The *joints* are the points of articulation between links and are numbered so that joint *i* connects links *i*-1 and *i*.

The motion is described in a Cartesian coordinate frame.The relative position and orientation between objects is represented by homogeneous transformations between coordinate systems attached to links. The geometric transformation is described by homogeneous transformation or homogeneous matrix multiplication.The compactness of the homogeneous transformation matrices is advantageous for expressing consecutive transformations. This is well adapted with the viewing pipeline of PHIGS (Hopgood and Duce [1]) which is used for our implementation.

II. THE COMPUTER ASSISTED DESIGN PROBLEM

The design problem is to decide where to put the different cranes, cement mixers, workers housings, roads..., on the building land to facilitate the erection of the building with all constraints being satisfied (no collisions between moving cranes for example).

New tools exist now to solve the placement problem of fixed objects on the construction site (see for instance Gleicher [10], Kondo [2], Nguyen and Lafon [13], Sohrt and Brüderlin [4], Verroust, Shonek and Roller[5]).

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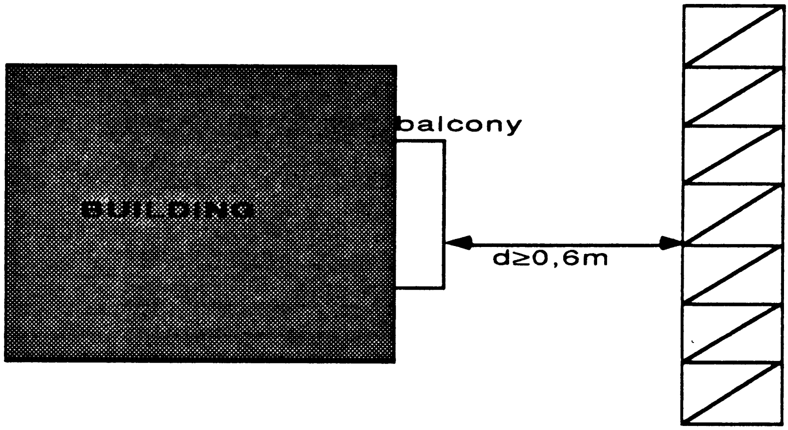
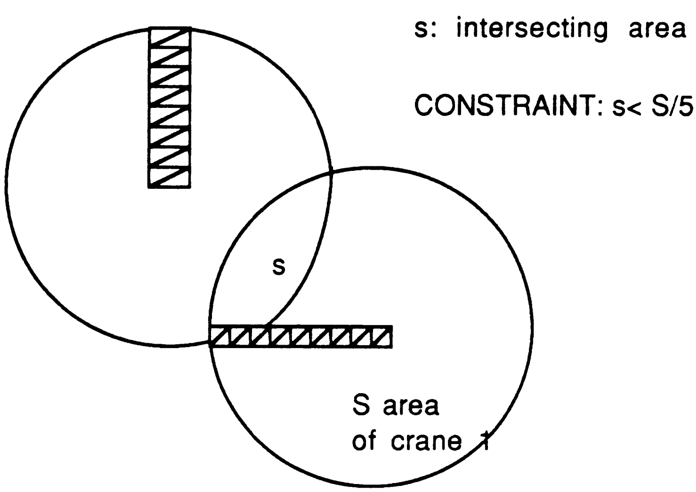
We have developed a graphical man-machine interface to enable the end user to specify the objects to be placed on the building land, to introduce the constraints to be satisfied and to interactively move these objects with the constraints being satisfied.

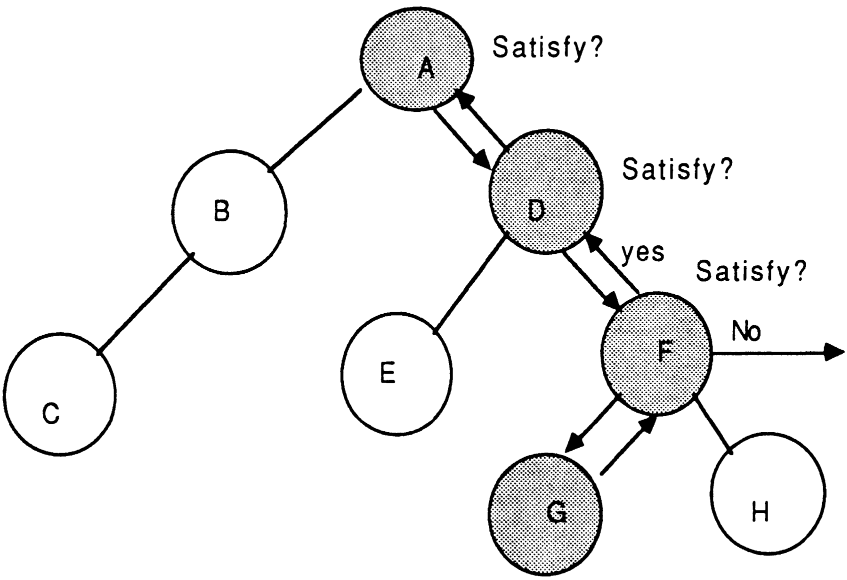


CONSTRAINT BETWEEN A CRANE AND A BUILDING



CONSTRAINT BETWEEN CRANES

The constraints involved will have to be resolved step by step during the placement of the objects, that is through the immediate resolving of the equation related to the creation of a constraint, and/or afterwards, while resolving simultaneously both the constraints and the equation system which they implied.



TEST OF A CONSTRAINT ON OBJECT G

The system will have also to transmit and maintain the constraints during the changes. That is solved in our system by the use of concepts existing in object-oriented languages: objects send messages to other objects when they are modified by the user.Each object then tests if the constraints are satisfied.

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The efficiency and the reliability of a program written in an object oriented language clearly depend heavily on the inheritance mechanisms of this language. So, the hierarchies of classes given below have taken into account the possibility of the language used for the implementation (C++).

The main point here is the way constraints between objects are implemented: we have chosen to consider the different functions needed for the propagation and the solution of constraints as methods associated with each class of objects. For instance, a constraint of the type "distant from" may exist as different methods in the different classes of objects.

The inheritance mechanism is therefore very useful here to limit the duplication of methods.

III. AN OBJECT ORIENTED DATA BASE

The heart of our system is an object oriented data base of all the objects of the construction site. A hierarchy of classes is defined with associated methods.
The different classes of objects are the following:

```
Yard---------------------------------- Site
                                       Cranes
                                       Mixers
                                       Stacks
                                       Cabs
                                       Buildings
                                       Relief
                ..........
```

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```
Obj_to_build
                Surrounding
                Site--------------- Relief
                                    Surrounding
                                    Ways
                                    Obstacles
                                        Way
                                        School
                                        Dwelling
                                        Tree
                                        Cable
                                        ----

                Storey--------------Walls
                                    Pillars
                                    Floor
                ------------
Construction_resources
        Officering
                Yard_Chief
        Manual
                Worker
                Construction_Tools
                        Mobile_Tool
                        ----------
                        Crane
                                    Rail
                                    Tower
                                    Top_of_Tower
                                    Worker_Cab
                                    Carriage
```

Our approach can be generalized to the creation of a Knowledge Data-Base (see for instance the work of Formoso and Brandon [8]).

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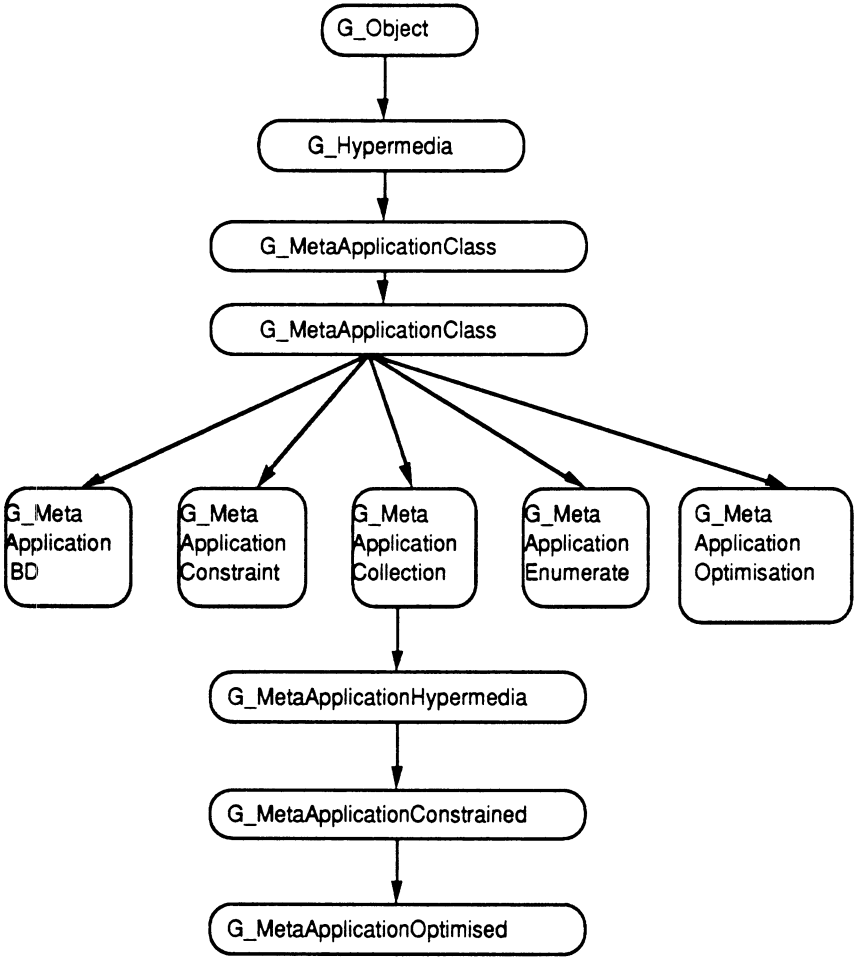
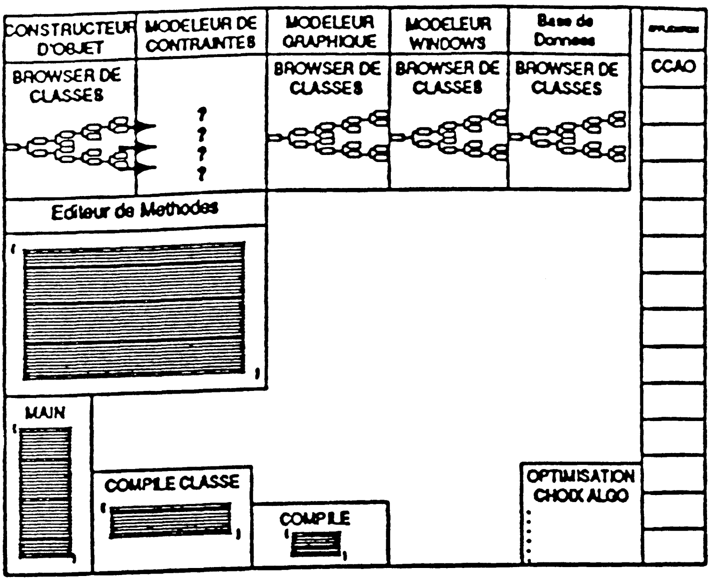
The following figure illustrates the hierarchy of classes created for this application:



Different methods are associated to each class (the inheritance mechanism is used here): New Object, Delete Object, Undelete Object, Goto Father, Goto Object Name, Goto Root, Set-Get List Son, set-Get Owner, Set-Get First-Last Child, Set-Get Current Child,Set-Get Constraint, Test Constraint, Print...

IV Graphical Interface

The Graphical Interface is developed in OSF/Motif with the XfaceMaker2 interface generator. The following figure illustrates the architecture of this interface:



The user can interactively defined classes by only simple definitions as names, parameters, methods owing to an editor we have constructed to do this. He can include directly the C++ code in files whose name is the same as the one of his class and of suffix .h or .cxx.So, we have all the advantages of the Object-Oriented language without the disadvantages.

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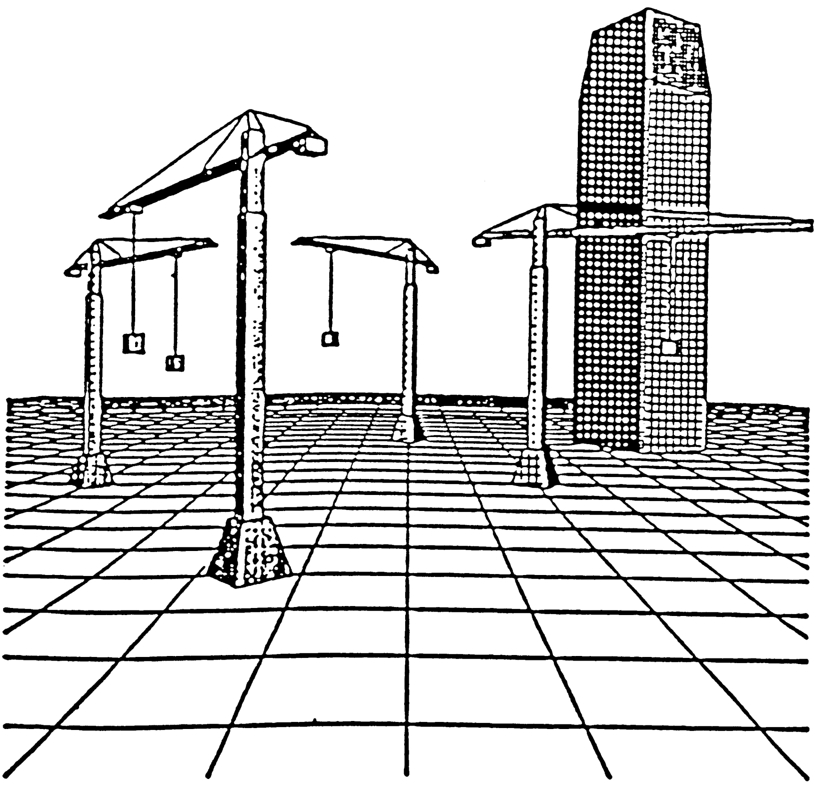
It is possible to pick one constraint with the hyper-media navigation mode and dynamically attached it to one specific object.

The following figure illustrates the graphical visualization of cranes with Phigs.



It is possible for the user to select different representation modes: wire frame, hidden Surface, colouring and shading.All these representations are implemented in Phigs +.

CONCLUSION

This Computer Assisted Design of a building Site is in fact a very big problem and many works remain to be made. In particular, we have not resolved in our project the planning problem of the construction itself. One classical approach to the problem of planning and scheduling of complex construction process is the use of simulation system (see Kano [9]) Some other interesting works exist on this subject (Kuczora [6], Raghunathan [3]). The knowledge-based approach, which is more general than our data-base approach is certainly also a promising area of research. We are convinced that their is also a great economic interest to develop an easy to use graphical interface to integrate and use different tools such as Graphical Modelling, Constraint solvers, Optimisation Methods, Branch and bound Methods...

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