Design modelling.

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ABSTRACT.
In Computer Aided Drafting three groups of three-dimensional geometric modelling can be recognized: wire frame, surface and solid modelling. One of the methods to describe a solid is by using a boundary based representation. The topology of the surface of a solid is the adjacency information between vertices, edges and faces. To develop a design model, however, topological information on all relevant elements (vertices, edges, faces and solids) is required.

The design model presented consists of two representations: the Edge Based representation (E.B.- rep) to describe the boundary of a solid and the Face Based representation (F.B.- rep) to describe the boundary relations between solids. The topology of both representations can be represented by the quad edge data structure, that is, embedding of graphs in surfaces.

One of the applications of the bipartite design model is parametric design. The E.B.- rep can be used for representing parametric objects. With the F.B.- rep we can also define parametric relations between (parametric) objects to realise Computer Aided Design. To support the design process of a structural engineer, for instance to design prefabricated concrete constructions, we introduce three phases: the grid, the structure and the construction.
Other applications for the developed design model will be a connection with production assembly and information- exchange.

For more detailed information about the subject of this paper see lit. [1].

INTRODUCTION.

In drawing systems (*Computer Aided Drafting*) three levels of representing an object can be distinguised:

- Physical objects. The real objects in the three dimensional world.
- Mathematical objects.The physical objects can be idealized and placed in a modelling space.
- Representations. A representation must be assigned to the mathematical object which is suitable for computer manipulation.

Geometric models represent the geometric shape of the mathematical objects. There are three groups of geometric modelling:

- Wire frame modelling. The object is represented by the edges and endpoints of the faces.
- Surface modelling. Not only the vertices and edges but also the shape of the faces is represented mathematically.
- Solid modelling. The shape of a physical object can be represented completely.

To develope a design system (*Computer Aided Design*) the representation of the shape of the objects is not enough. Information about objects in respect of each other is also needed to represent the shape of a design, composed of objects: design modelling.

In this manuscript a design model (and its representation) is introduced based on a solid model.

SOLID MODELLING.

Basicly, the drawing systems used for structural and architectural applications were two dimensional and based on a wire frame model. These systems are evolved to a three dimensional modelling space but still based on a wire frame or surface model. Gradually these models are going to be replaced by solid models. One of the possible representations based on a solid model is the Boundary representation (B- rep) with which the shell of objects can be represented.

In the drawing systems for mechanical applications a solid model is used based on the Constructive Solid Geometry (CSG- rep). This representation contains primitives (like a cylinder or cube) to model massive objects with (by additing or subtracting primitives). This way of modelling corresponds with the designing and production in the mechanical oriented environment: by working on a massive object (e.g. drilling or milling) the product results.

The design- and production- proces in buildings however is not to work on but to work up of materials: the various parts are joined together. This assembling approach fits with the B- rep (see figure 1).

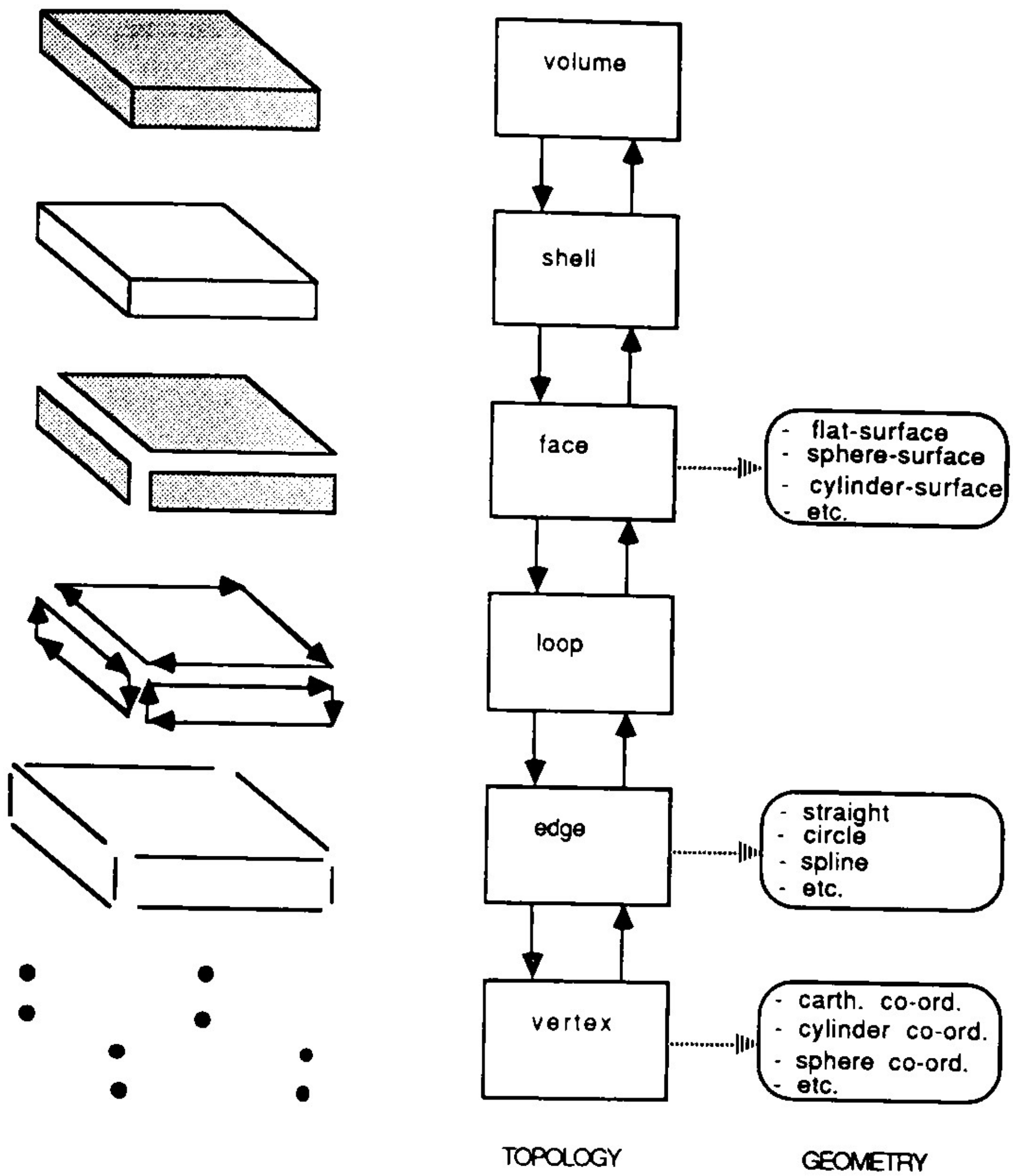

Figure 1 Topology and geometry boundary- representation.

In the B- rep a distinction is made between the geometry and topology of the object. The geometry contains both face and curve descriptions and point locations. The adjacency information between vertices, edges and faces is referred to as the topology. The topology serves as the glue holding all the element information together. Given the three topological elements nine element adjacency relationships are possible (see figure 2).

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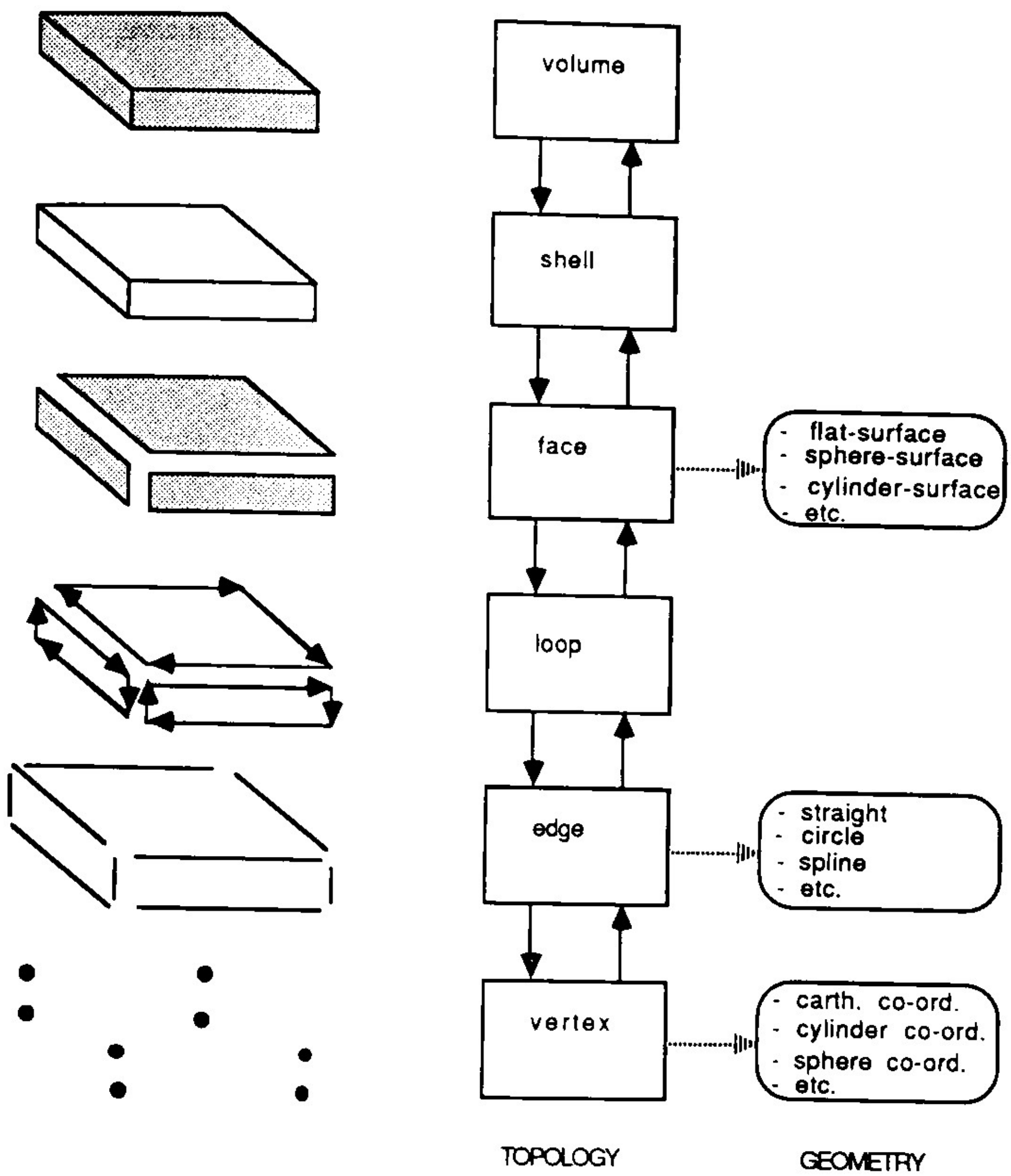

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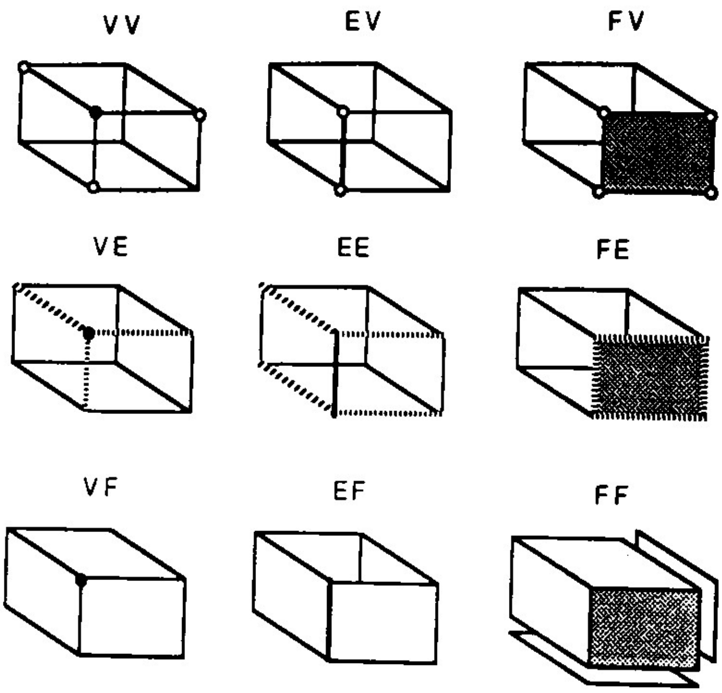


Figure 2 Adjacency relationships (solid modelling).

The topology is independent of the geometry and can be described formal by using embedded graphs (see lit. [2]). De edges and vertices of the object can be regard as the lines and points of the graph. The graph can be embedded in a closed, oriented surface. The regions of the surface are the faces, the surface itself is the shell of the object. Figure 3a shows an example of a graph embedded in a sphere-surface, which represents the shell of a cube.

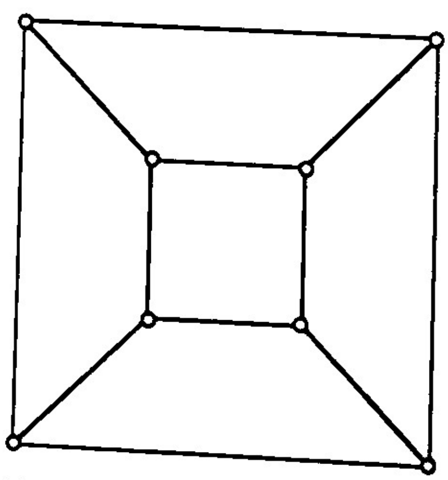


Figure 3a Embedded graph of a cube.

An embedded graph, that means the topological information, can be represented by several datastructures, dependent on its goal (see figure 3b). Examples of developed datastructures are the modified winged edge datastructure and the quad edge datastructure (see lit. [3], [4] and [5]). All these datastructures need to be sufficient. Sufficiency is the ability to recreate all of the relationships of figure 2 without error or ambiguity. It's not nessesary to store information of all relationships to achieve suffiency.

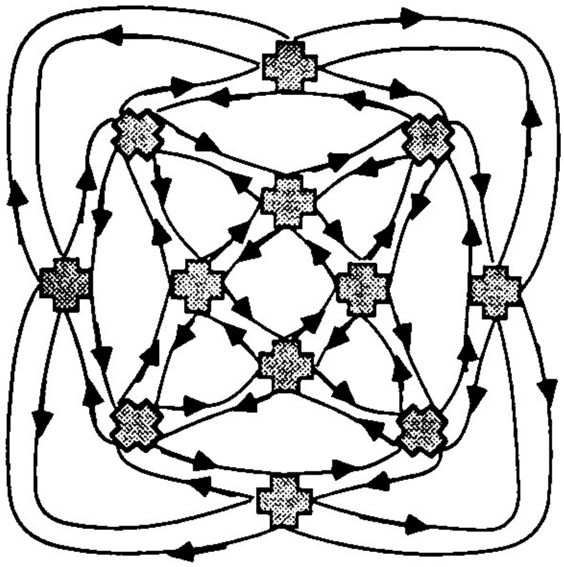


Figure 3b Datastructure embedded graph

A restriction of the B- rep is that only the shéll of an object or design (which is composed of objects) can be described. An example is shown in figure 4. Two cubes are placed with one face to each other. The same result can be obtained by placing a face in a cube. With the B-rep the shell of the joined cubes can be described but not the inner face (an edge belongs to at most two faces). This example shows that the B- rep can be used to lay down the topology (and geometry) of the shell of objects but the topology between objects to describe a design is missing.

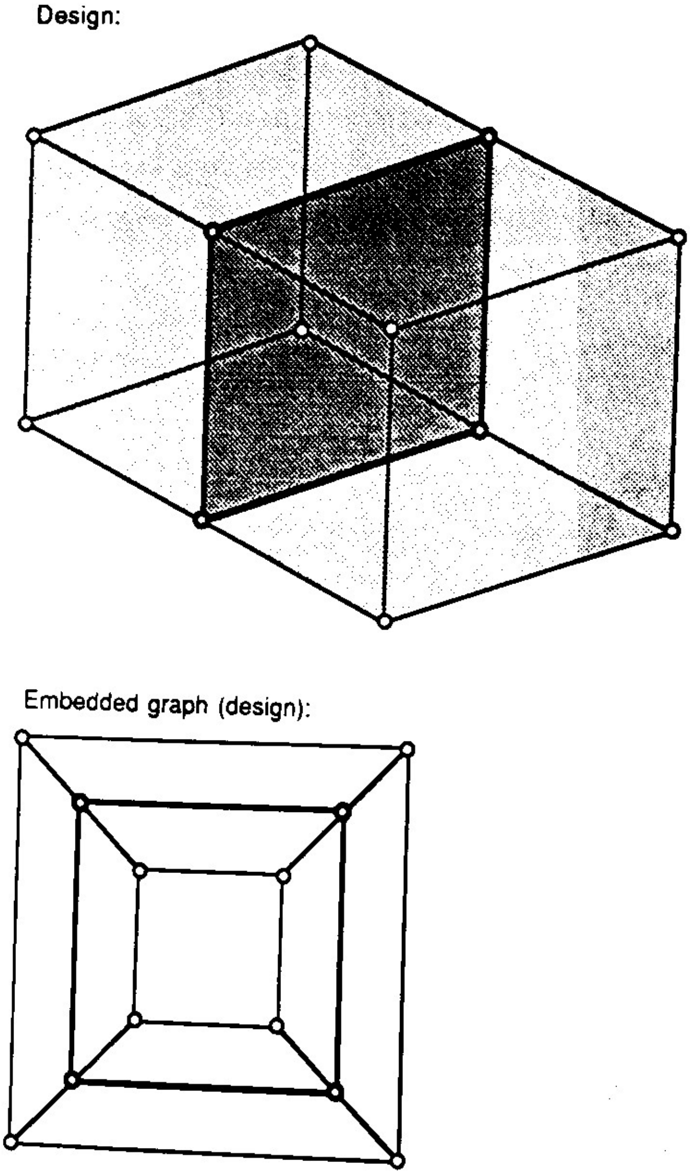


Figure 4 Example Boundary-representation.

DESIGN MODELLING.

To describe the shape of a design, composed of objects, the topology between objects is needed. Therefor the 3- element- topology of figure 2 must be replaced by the adjacency relationships between vertices, edges, faces ánd solids (see figure 5). Analogous to the datastructures of the B-rep the datastructures of the 4- element- topology must be sufficient to represent a design.

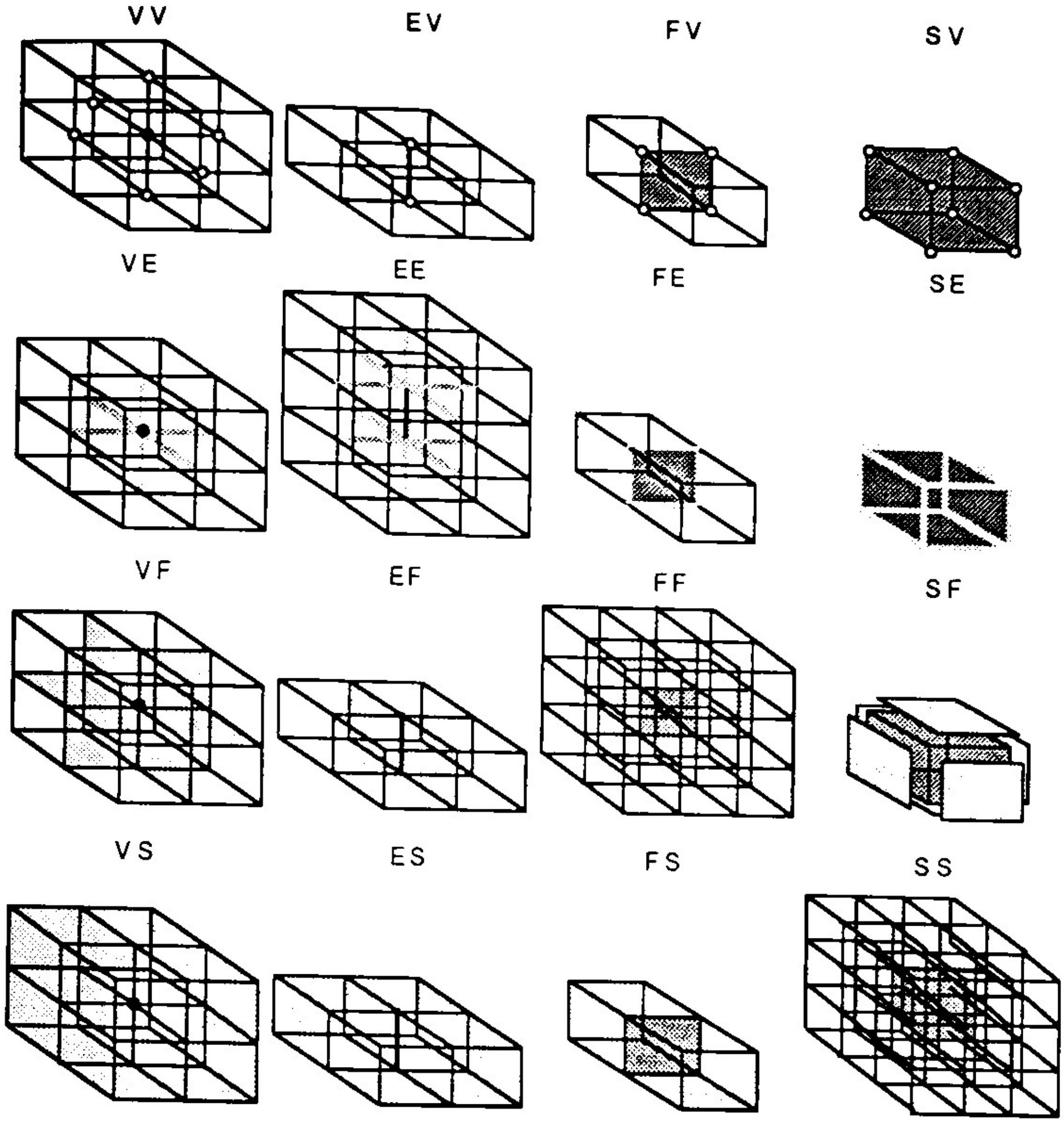
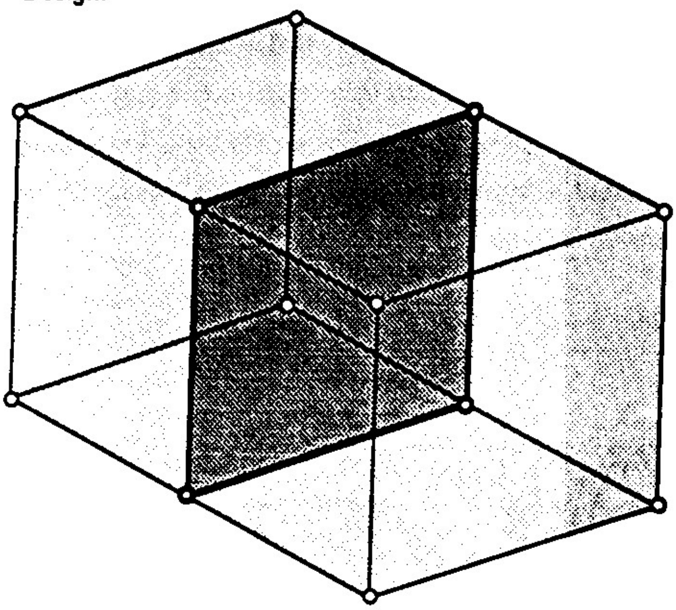


Figure 5 Adjacency relationships (design modelling).

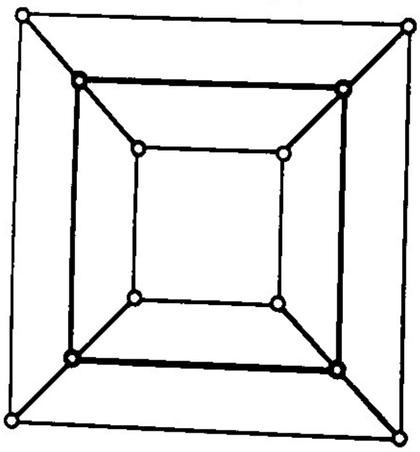
The developed design representation consists of two parts. To represent the topology (and geometry) of the seperated objects the B- rep can be used. This representation is based on the edge description and is called the Edge Based representation (E.B.- rep). The meaning of the embedded graph is as follows:

embedded graph	meaning
point	vertex
line	edge
region	face
surface	solid

Design:



Embedded graph (design):



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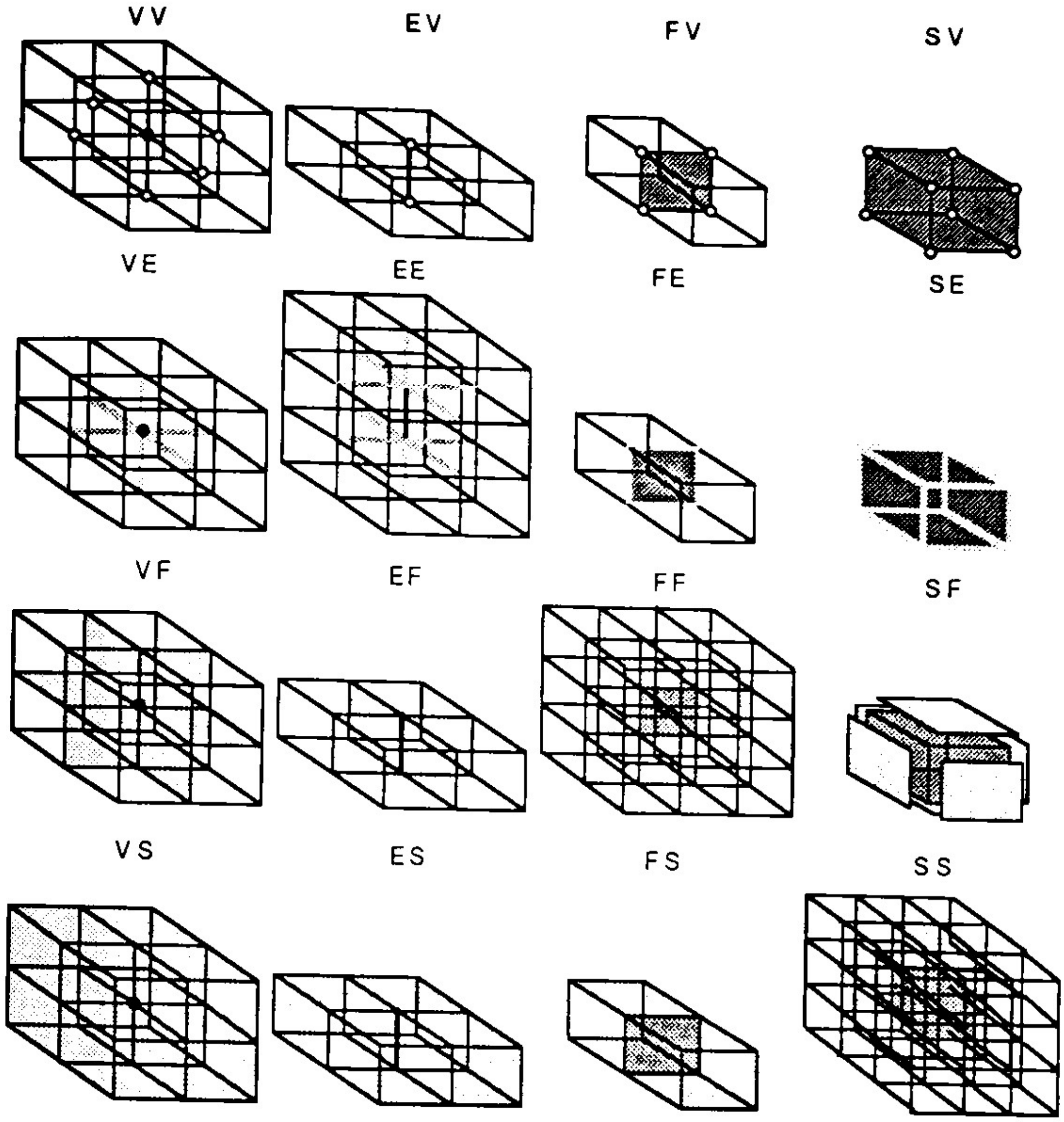

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To descibe the topology between objects a second representation is introduced: the Face Based representation (F.B.- rep). This representation is also based on the B- rep but the meaning of the embedded graph is 'one dimension higher' as listed below.

embedded graph	meaning
point	edge
line	face
region	solid
surface	design

Both representations together are called the design-representation (D- rep) in which between every topological element (vertex, face, edge and solid) a logical order (loop) is defined.

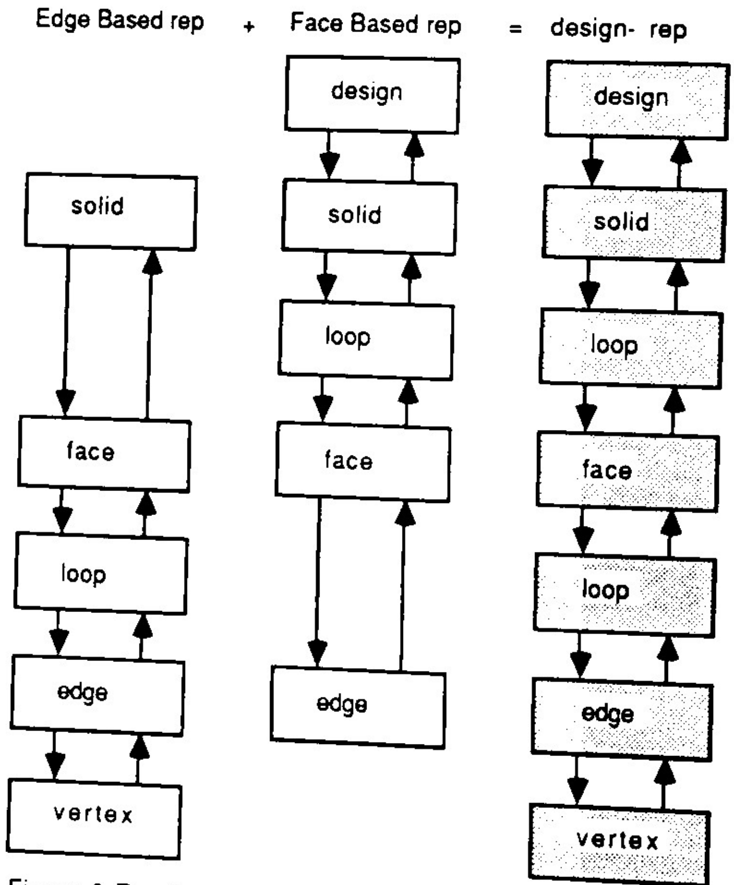


Figure 6 Topology bipartite design representation.

In figure 7 again the example of two joined cubes is shown to illustrate the D- rep. The E.B.- rep lays down the topology and geometry of the separated cubes and the F.B.- rep describes all faces of the design.

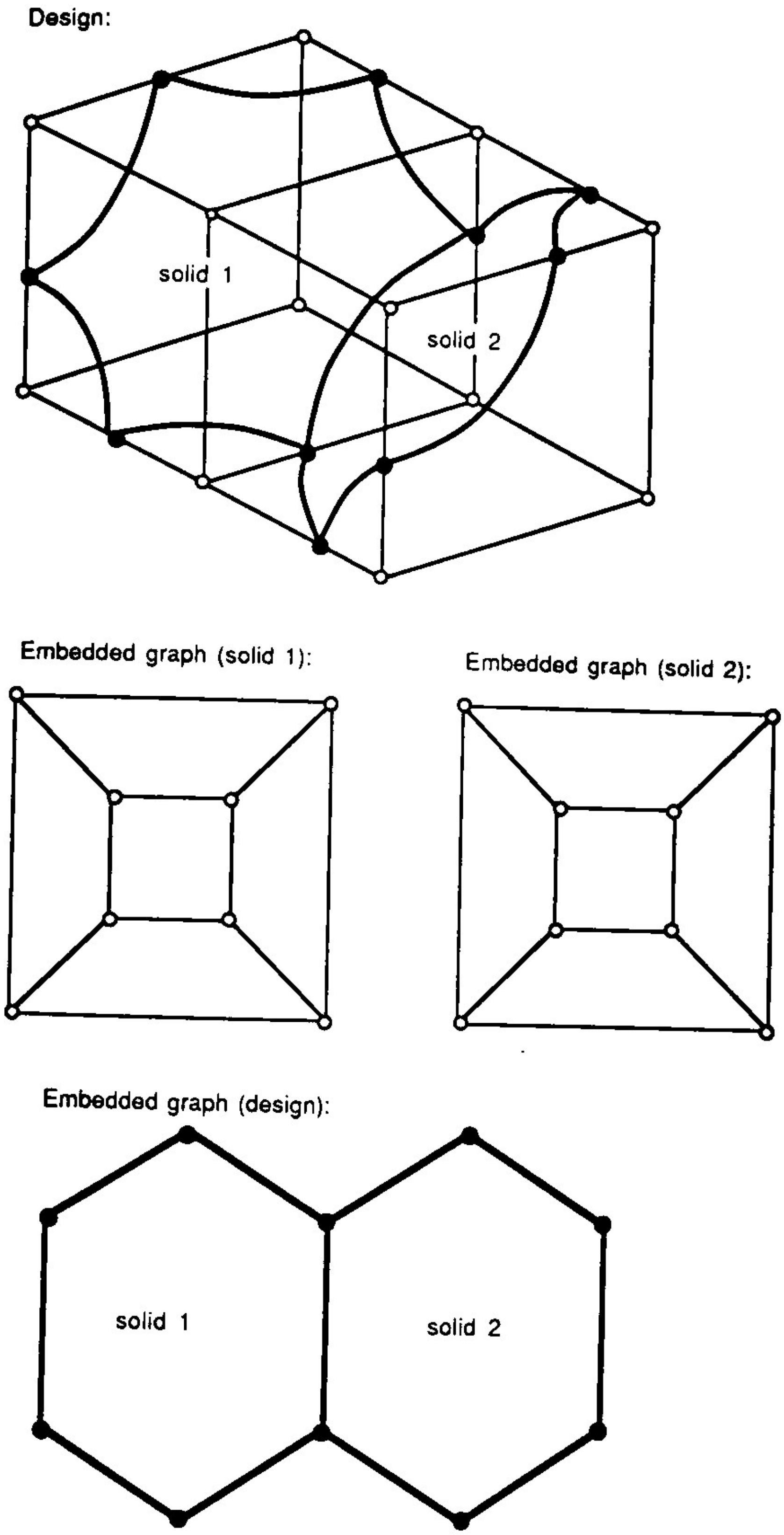
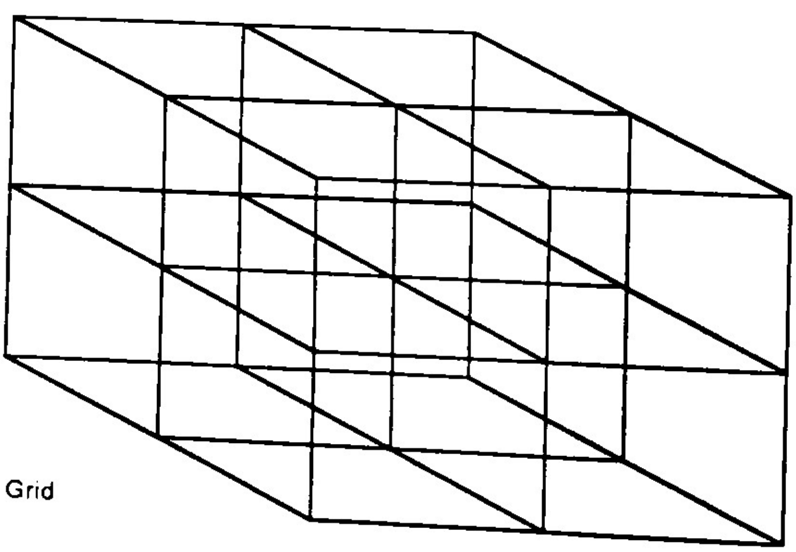


Figure 7 Example Design- representation.

The seperated description of the geometry (objects) and topology (relations) in the D- rep makes it possible to describe arbitrary designs. That means, it is not nessesary to define beforehand a fixed tree-structure which contains all possible designs. The logical order in the topology makes it easy to build up or modify a design. The representation can be described formal by a graph-grammer. With this, various design-depressed areas can be laid down mathematically in a similar way. By splitting the D- rep and basing it on the B- rep existing drawing systems can be transformed to design systems. The drawing system provides the visualization of solids (objects) whereas in a database the topology between solids (coherence) can be described. The drawing system takes also care of the interaction between the user and the design model (user-interface).

DESIGN SYSTEM.

One of the possible design depressed areas in which the bipartite design-representation can be put into practice is the designing of constructions. The user of suchs a system is called a *CADesigner* to accentuate the difference between a traditional designer and the future designer who creates a design with the help of a design system, in this case prefabricated concrete constructions. The designing proces is subdivided into three phases, denoted by the result that is brought about in that phase: the grid, the structure and the construction (see figure 8). Every phase contains a design model in which the shape of the objects and the coherence is described.



Grid

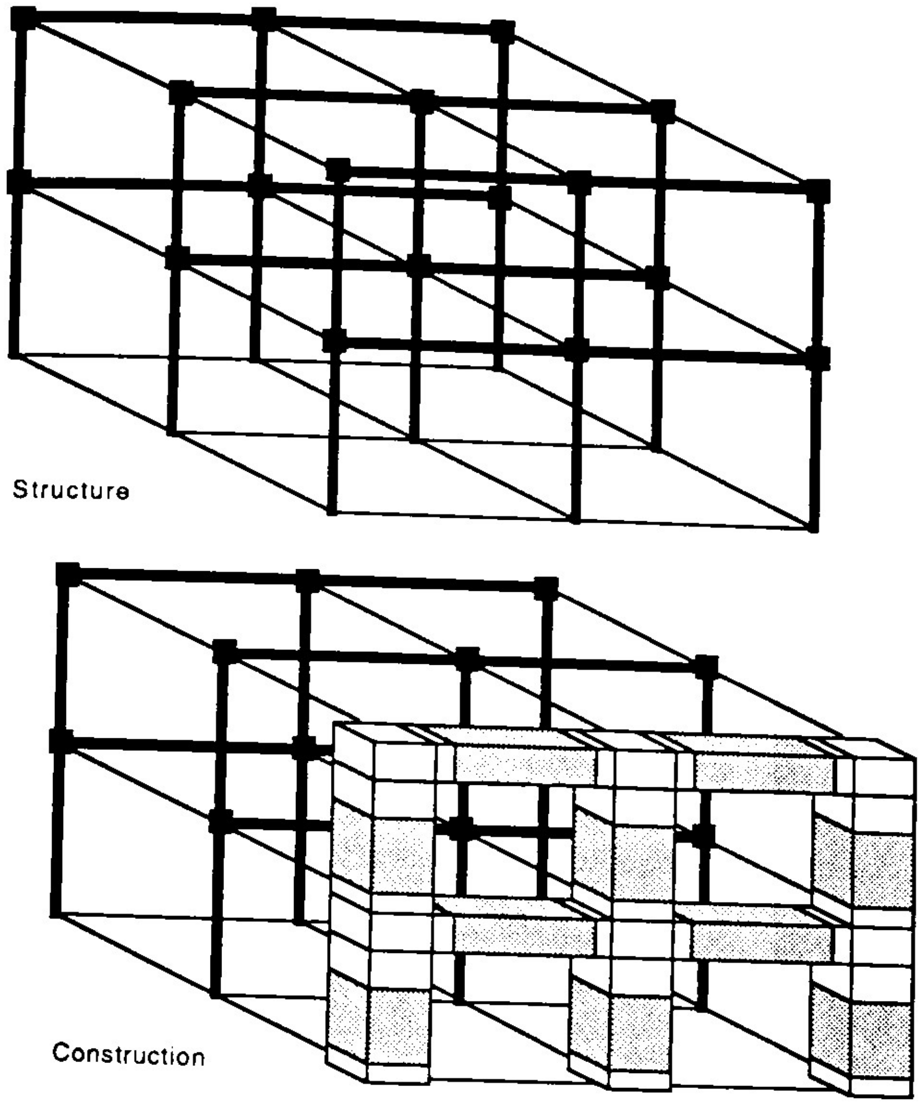


Figure 8 Design phases prefabricated concrete constructions.

Grid.

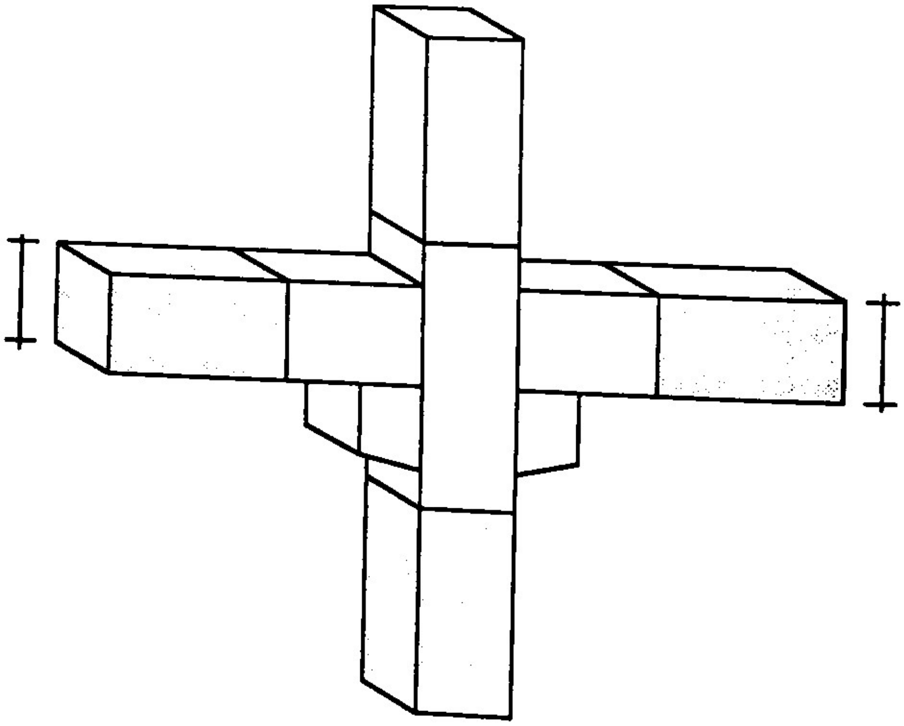
With a sketch-design as a starting point the cadesigner constructs a grid for the future building by placing gridlines. Although the visualization of the grid shows a three-dimensional wire frame all seperated gridlines and its intersections are known by the cadesigner just as the faces and volumes mounted by the grid lines. With a minimum input (the gridlines) all these components of the grid must also be generated by the design system.

Structure.

To every part of the grid a bearing meaning can be attached. A gridline can mean a column- or beamtype, a face a wall- or floortype and a volume a kerneltype. Where these element-types meet arise connectiontypes which must also be specified. Due to the fact that the coherence of the grid is described the cadesigner can also design the other way around. On ground of the specifications of already placed types other types can be placed automaticly. All types do not have a dimension (they do not represent material) but together with their coherence they lay down the structure of the construction.

Construction.

When the structure is build up the cadesigner can give the types their dimensions by attaching elements and connections. Therefor the components of the construction are divided into parts. This subdivision follows from the vision of both partners in the designing-proces of a construction. For the manufacturer the construction consists of the elements he delivers and the connections he puts up. The cadesigner makes a drawing-technical subdivision: a connection is a detail including the element-ends, the elements itself are bodies without ends. The construction-phase must support both visions to make it possible to design with elements or connections (important for a connection with production and for extracting quantities). The parts of the elements and connections are described in the design system as parametric objects. By this the shape of all diferent objects are stored once. Relations between parametric parts can be defined on which parameters can be added. This makes it possible to place objects in drawings automaticly or make changes while the consistency of the design is garanteed. In figure 9a an example is shown of a connection of two precasted concrete beams and a through-column with consoles.



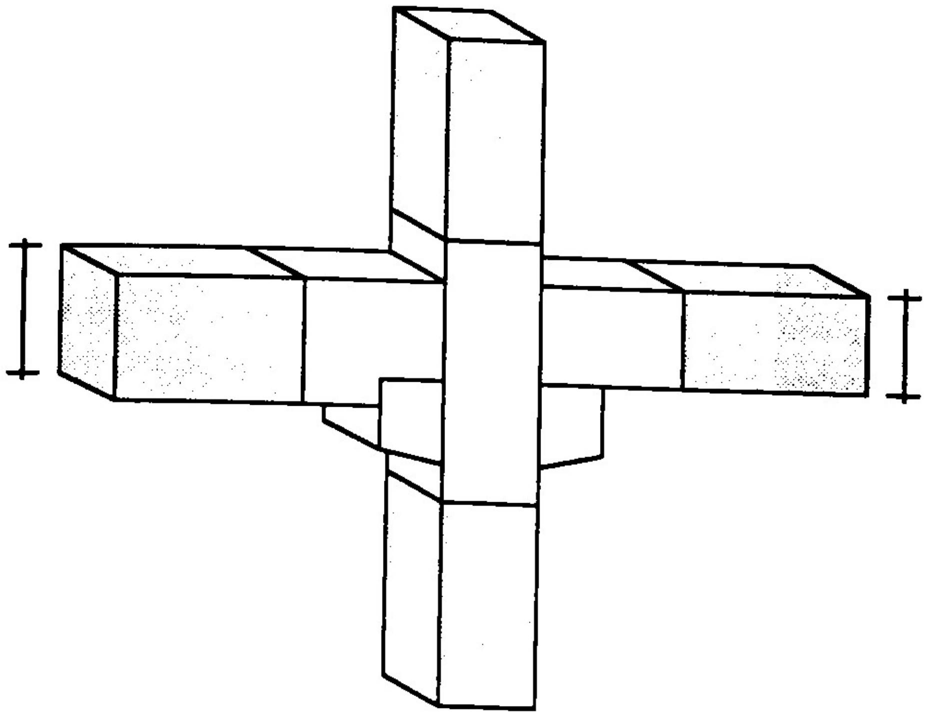


Figure 9 Example parametric relations between (parametric) objects.

Suppose the relation exists that the upper side of the two beams must be at the same height to cause no shift in the floorfields. When the dimensions of one beam must be enlarged this has consequences for the connection. In figure 9b the beam-end is replaced by a tooth-connection (automaticly or after a selection of the cadesigner).

The design model can also be used as input for external programs like calculation-software which verifies the strength, the deformation and the stability of the construction. An other application is a connection with production assembly and the exchange of drawings without supplementary information is needed. This information is already stored during the design-proces itself.

CONCLUSION.

In the eighties the drawing systems has become common in structural and architectural environments. The trend for the nineties is the developement of design systems. An example of a design system to construct prefabricated concrete constructions is shortly described. Three phases in the design-proces are recognized: the grid, the structure and the construction. Every phase helds a design model consisting of objects and relations.

A bipartite design-representation is introduced, based on existing drawing systems, to represent and manipulate the design model in a computer. The distinction between the geometry and topology makes it possible to realize designs without a closed solution-space. The design-representation can also be used for other applications. In the begining these areas must be small and clearly defined to avoid extensive databases. With the increasing complexity a balans is needed between the storage of information, the response, the clarity and the working (e.g. a chain reaction as a result of a modification). Perhaps after the nineties the knowledge- or expert-systems will be introduced to protect the user against too much (unnecessary) information.
The evolution from drawing- via design- to knowlegde-systems has its reflection upon the workingfield of the designer. He must think about his role in the design-proces and must come to an methodical structural approach which can be partial taken over by a computer. Suchs a designer can rightly be called a *CADesigner*.

LITERATURE.

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