Topology as Central Information in Building Models

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Keywords: Topology, Geometry, Building Product Models.

SUMMARY

This paper describes an approach where topological information is used as leading information in building product models. Geometry is regarded as a weight of topological information. This concept results in digital models where the number of geometric information is reduced dramatically compared to existing approaches. In addition, topological information is used as the basis for denoting the objects of a building. Thus, a digital model is derived that allows an efficient handling of geometric information as well as a coordinated denotation of the engineering objects.

ZUSAMMENFASSUNG

Der Beitrag beschreibt einen Ansatz für die Modellierung von Gebäuden, in dem die topologische Information die zentrale Rolle spielt. Die Geometrie wird als „Bewertung“ der Topologie betrachtet. Dieses Konzept führt zu digitalen Modellen, in denen die Anzahl erforderlicher Geometrieparameter gegenüber herkömmlichen Modellen dramatisch reduziert ist. Darüber hinaus bildet die Topologie die Grundlage für die Kennzeichnung der einzelnen Gebäudeteile. Das resultierende Gebäudemodell integriert die geometrische Beschreibung des Gebäudes und die Kennzeichnung von Objekten, welche für den Bauprozess von entscheidender Bedeutung ist.

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1 INTRODUCTION

It is state of the art to use modern CAE-systems (CAE: Computer Aided Engineering) in planning processes in civil and structural engineering. Technical solutions are documented by CAE-systems. In general, the systems provide a technology that has been adapted to the requirements in civil engineering. Typical requirements in civil engineering result from standards where, i.e. widths and styles of lines including their semantics are prescribed. CAE-systems operate on digital models. These models can be expanded. Proprietary and standardized models are used. For instance, Industry Foundation Classes (IFC) from the International Alliance for Interoperability (IAI) is such a standard. [1] Engineering objects like components and rooms are defined as data objects. Software systems supporting this standard are able to interpret the objects so that data can be exchanged between software systems from different vendors.

Geometrical information is leading in CAE models. For instance, a wall modeled in IFC (IfcWall) contains an object to store the shape of the wall (IfcShapeRepresentation). The shape itself can be modeled by several objects. Of course, there is also an object available to store topological information by vertices and edges (IfcTopologyRepresentation). However, the way of thinking in civil engineering is based on geometrical information. This is reflected by the models. For instance, points are specified by their coordinates in planning processes; points are connected so that the geometry of bodies like walls, columns, or slabs is specified by specifying geometric information.

The approach presented in this paper does not start with geometrical information. This approach can be regarded as a "topology-driven" approach. In a first step, only topological information is considered and specified. This information is used to denote the engineering objects of a building, components and rooms. A complete denotation of components and rooms is set up where no geometrical information needs to be specified. In a second step, geometrical information is considered. Geometrical information can be regarded as "weights" of topological information. Both, topological and geometrical information result in a complete description of a building.

In general, during a planning process more modifications in geometrical information take place than in topological information. For example, the existence of a wall including its connections to other components is modified less than the width of that wall. Therefore, the approach presented in this paper tries to consider these circumstances in such a way that the effort specifying digital models of buildings can be reduced.

In section 2, a topology is defined. The concept of topology is a basic concept in mathematics. It can be applied to different conceptual formulations. Section 3 describes how it can be used in the area of denoting objects of a building. However, specifying buildings require additional information in more detail. Section 4 describes how a model can be set up where topological information is strictly distinguished from geometrical information. The level of detail in section 4 is sufficient for describing buildings. Geometrical information is assigned to topological information. The model can handle over-determined geometrical information. Section 5 explains how over-determined geometrical information can be processed so that a consistent geometry is computed. The paper ends with conclusions and an outlook in section 6.

2 THEORETICAL BACKGROUND

A topology is defined in Mathematics as a set T where the elements of set T have specific properties. Equivalent definitions have been developed in Mathematics. A topology can be defined as follows:

The elements of a set T are subsets of a set M. The empty set and the set M are elements of T. All finite intersections and all unions of elements of T belong to T. [3]

The concept of topology can be used to analyze geometric models. It can be adapted to n-dimensional spaces. In a three-dimensional space, points are already specified as part of a topology. But these points do not have any coordinates. Points can be connected by edges. Several edges surround an area, and a body is surrounded by areas. A topology does not require geometrical information like the length of an edge, a distance between edges or areas. The objects of a building and their interconnections form a topology. Two sets can be identified, the set of components and the set of rooms. Relations between elements of these sets are needed to describe neighborhoods. However, the level of detail required for denoting components and rooms is not sufficient for planning buildings. But the principal concept can be transferred to a more detailed topology where the topology of the surfaces of rooms and components are modeled. As a consequence, topological information are available independently of geometrical information, and topological information is still used to denote components and rooms.

3 COMPONENTS AND ROOMS

A topology can be visualized by schematic presentations. But all these schematic presentations require geometrical information. This geometric information is only part of the presentation; it is part of the content to be presented. I.e. the objects of a building, components and rooms can be presented as a graph. The vertices of the graph are components and rooms. The edges represent neighborhoods of components and rooms. Experiences in the use of such presentation techniques show that such pictures cannot be interpreted very well. It is always helpful to have geometric information even if it is abstracted. Figure 3-1 shows such a model of a building where components and rooms of a building are visualized. The model describes a multi storage residential house. Rectangular solids are used to represent components and rooms. Components are visualized in red and rooms in green. Neighborhoods are presented by edges.

The core of the model shown in figure 3-1 consists of topological information. Relations between components, between rooms and between rooms and components are modeled.
The objects shown in figure 1 are denoted by different criteria. Locations and functions are used to denote rooms. Locations, functions and products are used to denote components. Figure 3-2 shows the terms and their structure that are used to denote each criterion. This denotation conforms to the standards that are used in civil engineering. [4] In figure 3-2, the more general term “zone” is used instead of the term “room”.

Each criterion can be used to decompose the sets into subsets. The criteria can be combined so that subsets can be determined based on the denotation. Figure 3-3 shows specific rooms on floor 3, and figure 3-4 walls and rooms on the same floor.

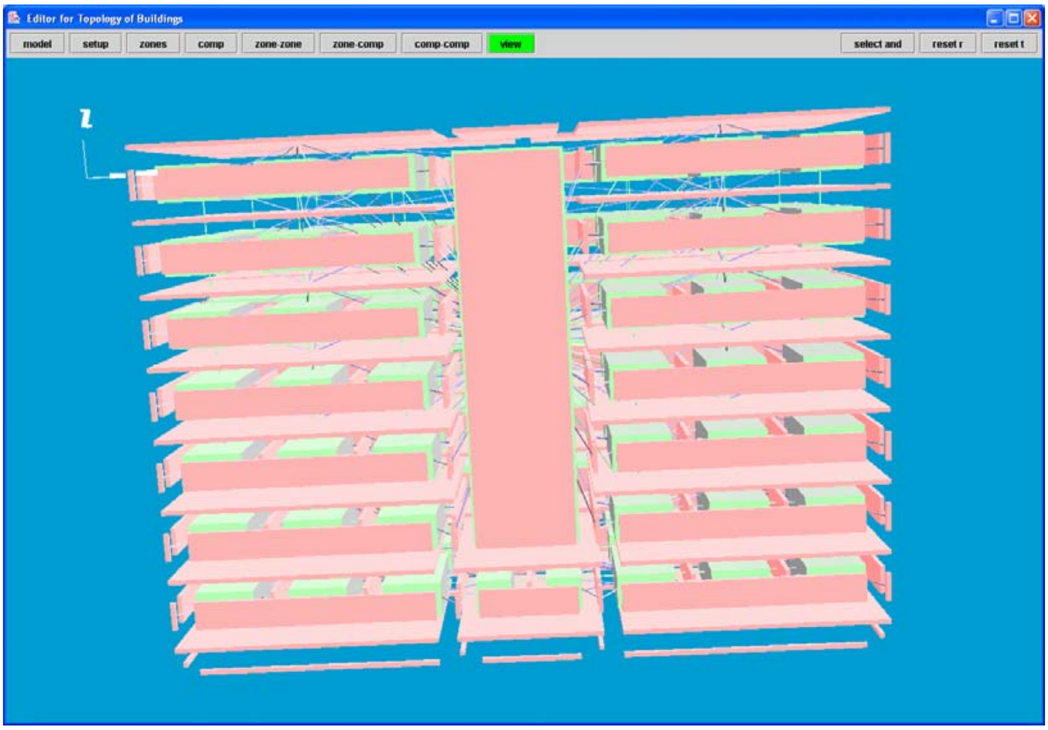

Figure 3-1: Components and Rooms of a Building

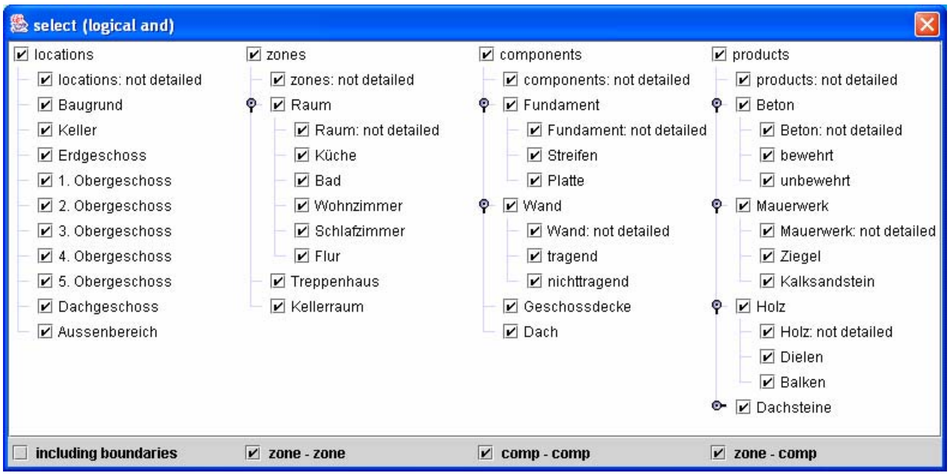

Figure 3-2: *Denotation of Components and Rooms*

The presentations shown in figures 3-1, 3-3 and 3-4 are not sufficient for planning processes. They illustrate that the denotations can be modelled independently of any geometrical information. However, geometrical information is necessary in real planning projects. For this purpose, surfaces of components and rooms need to be modelled in more detail. This requires a more detailed data model which is described in the next section.

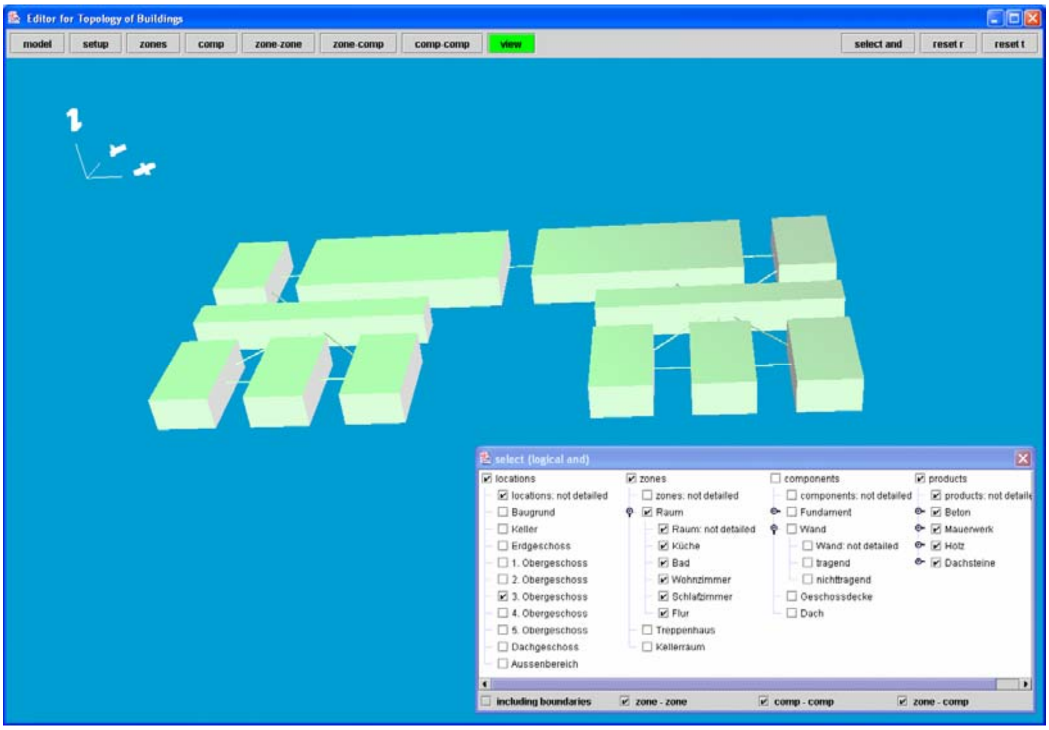

Figure 3-3: Selected Rooms

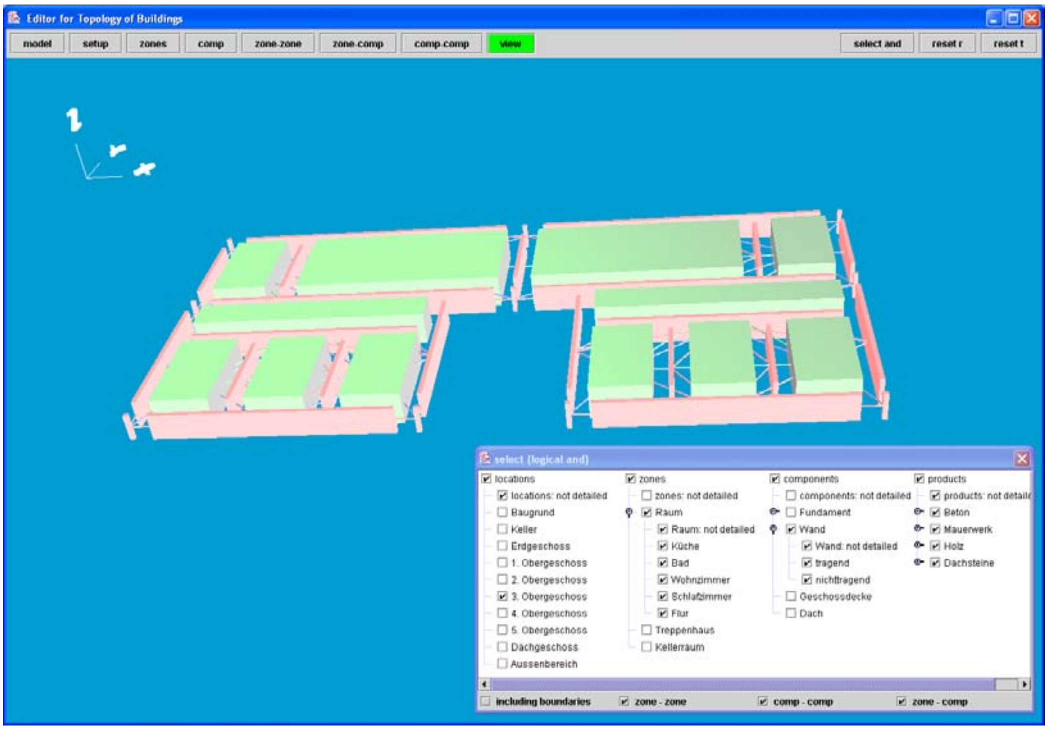

Figure 3-4: Selected Walls and Rooms

4 ASSOCIATION OF TOPOLOGY AND GEOMETRY

Within a research project on the department of geodesy and adjustment techniques of the technical university Berlin a data model for building geometry and topology was developed. The model minimizes the redundancy in the parameters and implies geometrical constraints. Basis of the data model is the strict separation of geometrical and topological information.

The mapping of topology is realized by cells of the dimensions 0 to 3. Topological entity types are vertex, edge, mesh and space.

Figure 4-1 shows the entity types of the data model an the belonging entity-relationship-model.

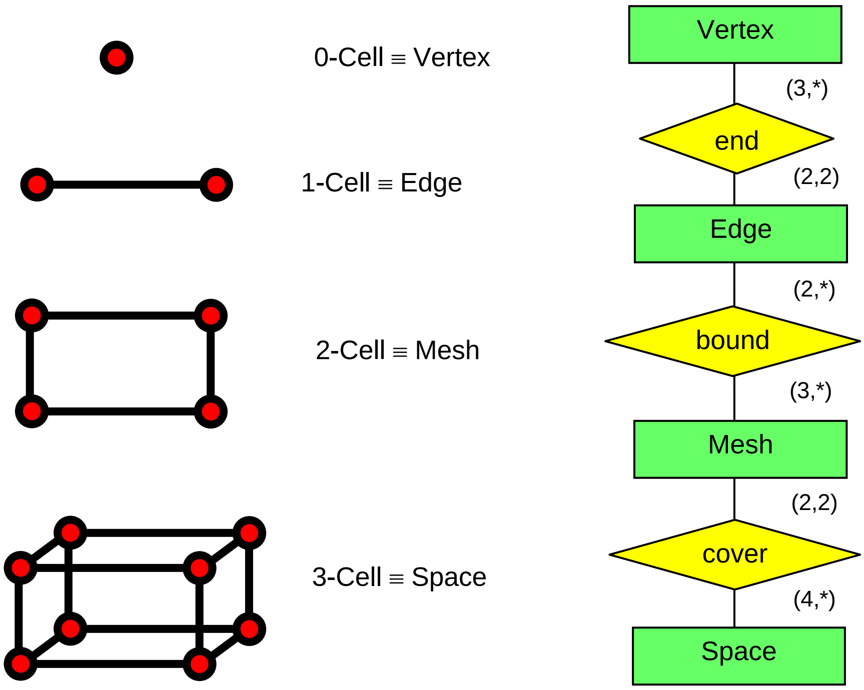

Figure 4-1: Topology in the Data Model

The description of geometry happens exclusively by planes. An extension of the geometry description by surfaces of second order (cylinder, sphere, cone) is intended for a further step. Each plane is parameterized by a normal vector $\vec{n}$ and its orthogonal distance to the coordinate origin *d*. The parameters fulfill the plane equation.

$$\vec{n} \cdot \vec{x} - d = 0 \ . \qquad (4.1)$$

This equation describes a two dimensional point set in a three dimensional space. A separate parameterization of the boundary is not necessary.

Figure 4-2 illustrates the geometrical meaning of the single variables.

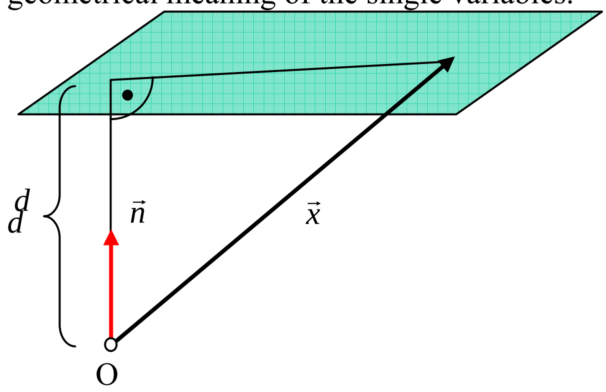

Figure 4-2: Geometrical Illustration of a Plane Equation

The only connection between topology and geometry is the n:1-relationship between the entity types mesh and plane.

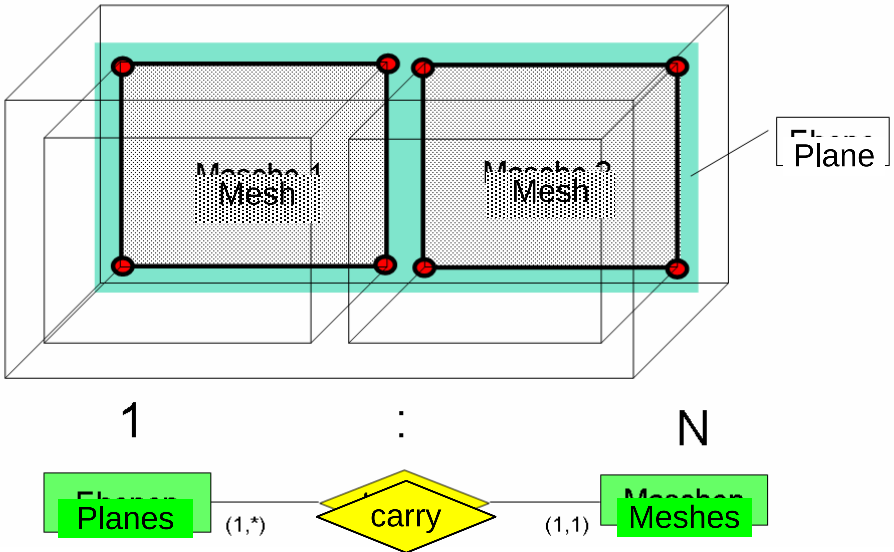

Figure 4-3: Planes Carry Meshes

Figure 4-3 shows two rooms of a building. The two wall meshes Mesh 1 and Mesh 2 refer to one and the same plane. The geometry of the mesh boundaries are not explicitly described but result from the intersection with other planes. The information which planes have to be intersected is completely contained in the description of the topology.
In that data model point coordinates exist just as a view on persistent plane parameters.

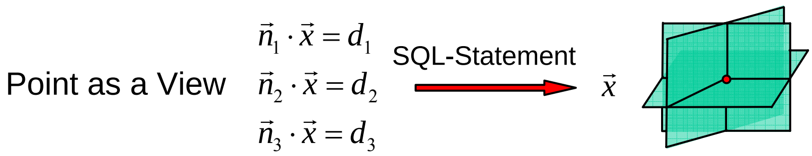

Figure 4-4: Point Coordinates as View on Plane Parameters

In a relational database a coordinate list can be created by a SQL statement.
The most buildings show a relatively regular structure. Walls, floors and ceilings are often parallel or orthogonal. The data model supports these geometrical constraints in a special way. The coplanarity constraint for instance is implicitly realized by the plane parameterization.

The parallelism of two planes is mapped by the association of these planes with the same normal vector. For that purpose an object class *normal vector* was introduced.
Orthogonality of vertical walls is described by the association of orthogonal normal vectors with the same parameters.

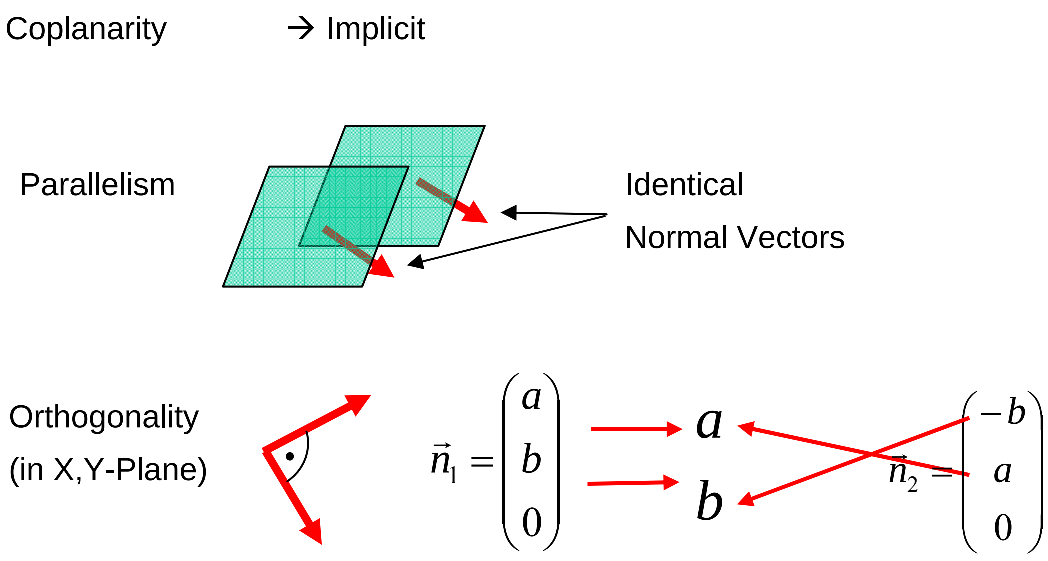

Figure 4-5: Mapping of Geometrical Constraints in the Data Model

The approach of "Parameter Sharing" reduces the number of necessary parameters compared to the use of coordinates dramatically. To illustrate that we consider a theoretical building with 10 floors, 4 walls lengthwise and 11 walls in transverse direction. In the case of a parameterization by point coordinates we get 10*10*3=300 rooms plus the external space with 8 corners each. This result in 2408 points with 7224 coordinate values.

The parameterization by planes results in 10*2+4*2+11*2=50 planes. Their orientation is given by 3 normal vectors with 9 parameters and their translation by 50 parameters, in summa 59 parameters. That means that the parameterization by planes needs just 0.8% of the number of parameters required for the parameterization by point coordinates.

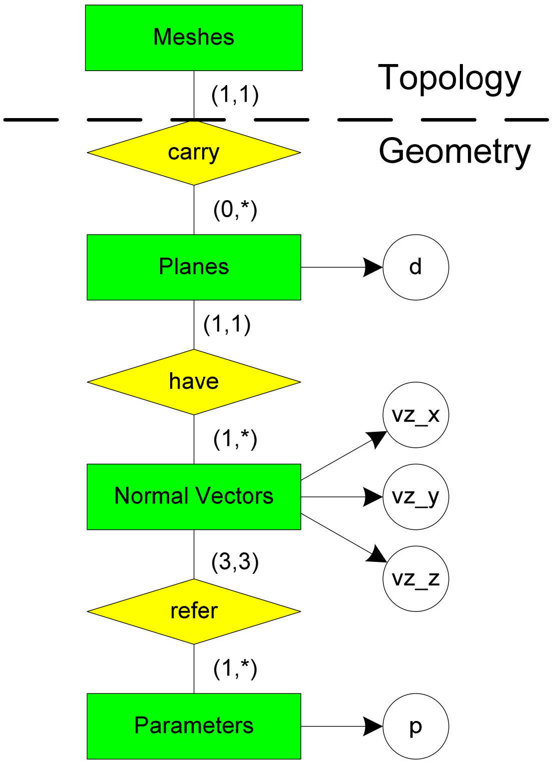

Figure 4-6: Association of Geometry and Topology

Figure 4-6 shows the mapping of geometry and the association to the topology in the data model. The unknowns in the sense of adjustment techniques are the translation parameters d_i and the rotation parameters p_i.

5 ADJUSTMENT TECHNIQUES

Aside from the saving of memory space and the avoidance of changing anomalies the extremely small redundancy in the geometrical parameters allows the application of geodetic adjustment techniques.

During the surveying of buildings the absolute geometry parameters (coordinates) necessary for the CAD can not be determined directly. Instead of that relative parameters like distances or directions are measured. In a calculation process absolute parameters are derived from relative parameters. For checking and accuracy improvement reasons more values then necessary for a unique geometry description are measured. Because of the fact that it is impossible to measure with arbitrary accuracy the measuring values have a determined uncertainty. Therefore, surveying the geometry of a building requires redundant random variables.

But there is a way to derive unique geometry parameters from redundant measuring values. The mathematical tool for that kind of transformation is the geodetic adjustment theory. It provides the option to map ambiguous measuring values onto unique geometry parameters. The uniqueness can be reached by formulating a boundary condition: Find exactly that solution for which the square sum of the weighted residuals is minimal.

$$\mathbf{v}^T\mathbf{P}\mathbf{v} \overset{!}{=} \min. \quad \text{with} \quad \mathbf{v}: \text{residual vector}, \quad \mathbf{P}: \text{weight matrix}$$

The results of an adjustment calculation are unique geometry parameters and their covariance matrix. In the most cases the ingoing observations are stochastically independent while the calculated geometry parameters are algebraic correlated.

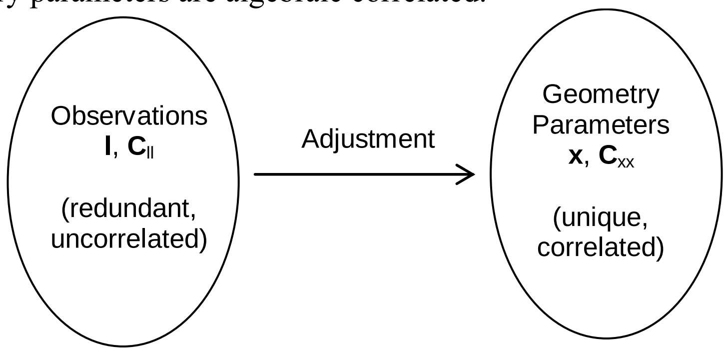

Figure 5-1: Mapping of Observations onto Unique Geometry Parameters

In general an adjustment calculation can be seen as a mapping of a point in the observation space onto a point in the solution space

$$p(l_1, l_2, \ldots, l_n) \in R^n \quad \rightarrow \quad p'(x_1, x_2, \ldots, x_m) \in R'^m \qquad (5.1)$$

whereby the dimension of the solution space *m* is smaller then the dimension of the observation space *n*. That mapping $\mathbf{l} \rightarrow \mathbf{x}$ is unique but not reversible.

Beside of the absolute geometry an adjustment calculation provides information about discrepancies in the relative measures and accuracy values for the absolute geometry parameters.

This approach of a unique mapping of redundant relative geometry onto a redundancy free absolute geometry can also be applied in the construction process. In that case it is not necessary anymore to know the absolute geometry a priori. Instead of that the first step of construction is the definition of the building topology. Topological elements like structural components, rooms and surfaces are the reference for information like material, usage, costs etc.

The geometrical parameterization of this topological model is realized first by relative measures. In a later step the absolute geometry is generated by an adjustment calculation. In the case of an accurate construction the relative measures are consistent and all absolute geometry parameters are calculable.

6 CONCLUSION AND PROSPECT

This concept of association of geometry and topology provides significant advantages compared to usual models. The number of necessary geometry parameters is extremely reduced (less then 1%). Geometrical constraints like coplanarity or orthogonallity are implied in the data model.
The mostly redundancy free parameterization of the geometry is a prerequisite for the application of geodetic adjustment techniques. The geodetic adjustment theory allows deriving unique geometrical parameters from redundant relative measures. [5]
The geometry can be seen as a valuation of the topology. During the construction of a building using the presented approach the user defines the geometry by defining relative measures.

REFERENCES

[1] http://www.bildingsmart.de, 10. January 2006.

[2] http://www.iai-international.org/Model/IFC(ifcXML)Sepcs.html, 10.January 2006.

[3] Duden Rechnen und Mathematik, Dudenverlag, Mannheim, 2000, S. 614.

[4] DIN 6779-12: Kennzeichnungssystematik für technische Produkte und technische Produktdokumentation, Teil 12: Bauwerke und technische Gebäudeausrüstung, Deutsches Institut für Normung, Beuth Verlag, Berlin, Juni 2003.

[5] Gielsdorf, F.: „Ausgleichungsrechnung und raumbezogene Informationssysteme" Habilitaiton an der TU Berlin, März 2005. http://edocs.tu-berlin.de/hab/2005/gielsdorf_frank.htm.

[6] Gielsdorf, F., Rietdorf A., Gründig L.: „Geometrical Modeling of Buildings – The Frame for the Integration of Data Acquisition Techniques", Vortrag auf der FIG Working Week, Athen 2004 http://www.fig.net/pub/athens/papers/ts23/TS23_2_Gielsdorf_et_al.pdf

BIOGRAPHICAL NOTES

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