Geometrical Modeling of Buildings – The Frame for the Integration of Data Acquisition Techniques

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Key words: Data Modeling, Adjustment, Facility Management, Architectural Surveying

SUMMARY

As buildings are mostly parameterised by 3D point coordinates in CAD systems, the acquisition of geometrical data for buildings can be a very expensive task. Even for not very complex buildings this approach results in large data sets of redundant data. As a consequence, geometry is often disregarded for facility management systems or will be added just as descriptive information.

The authors show that by the parameterization of surfaces instead of 3D point coordinates, the number of parameters and therefore the data set will be reduced considerably. The presented approach is based on parameters of surfaces and a strict modelling of the 3D topology. In addition to an appropriate building data model the improvement of the data processing procedure rather than the data acquisition methods applied on site have to be focussed and solved. Based on this approach, proposals for an economic solution of the task of geometrical data acquisition of buildings can be derived.

For ordinary buildings, robust and simple to handle measurement tools can be applied, like measurement tapes or hand hold laser distance measurement instruments.

In addition, the data model provides the frame for an integration of different types of measurements and even for updates. Measurements with tacheometers or laser scanners can be used efficiently to determine local surface parameters which will be transformed according to the rules of the building data model.

ZUSAMMENFASSUNG

Da die Parametrisierung von Gebäuden in CAD-Systemen im Allgemeinen durch 3D-Punktkoordinaten erfolgt, ist die Erfassung von Geometriedaten für Gebäude oft sehr kostenintensiv. Selbst bei relativ einfachen Gebäuden führt dieser Ansatz zu großen Mengen redundanter Daten. Infolgedessen bleibt die Geometrie in Facility-Management-Systemen oft unbeachtet oder dient lediglich als beschreibende Information.

Die Autoren zeigen, dass sich bei einer Parametrisierung von Flächen anstatt von Punkten die Datenmenge wesentlich reduzieren lässt. Der neue Ansatz basiert auf der Verwendung von Flächenparametern und einer strengen Modellierung der 3D Topologie. Neben der Entwicklung eines geeigneten Datenmodells wird das Augenmerk vor allem auf die Verbesserung der Auswertemethoden gerichtet.

Auf Grundlage des vorgestellten Ansatzes können effiziente Lösungen für das Problem der Geometriedatenerfassung für Gebäude abgeleitet werden. Für das Aufmass von nicht allzu komplexen Gebäuden genügt der Einsatz einfacher Messmittel wie Handheld Laser oder Messband.

Beobachtungen verschiedenen Typs sind integraler Bestandteil des Datenmodells, was die Aktualisierung von Geometriedaten entscheidend vereinfacht. Beobachtungen von Tachymetern oder Laserscannern, die zu lokale Ebenenparametern vorverarbeitet wurden, können durch verkettete Transformation in das Gebäudemodell integriert werden.

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1. INTRODUCTION

The result of an on site architectural surveying is always a large number of redundant relative measured values acquired by different sensors as there are simple tools like measuring tapes or handheld lasers but also by tachometers, laser scanners or cameras. It is the task of the different post processing steps to generate a unique absolute geometry including the elimination of blunders and the estimation of the accuracy of the geometrical parameters. The typical tools of the surveying engineer to realize that transformation are adjustment techniques. Prerequisite for the application of adjustment techniques is a parameterization of the geometrical model without or at least with low redundancy, because each redundant parameter leads to an additional constraint equation.

The parameterization of 3D geometry in common CAD system is almost exclusively realized with point coordinates. Such an approach leads to a very high redundancy in the geometrical data and is therefore not appropriate for the use of adjustment techniques. For the integration of different data acquisition techniques, what always leads to an adjustment problem, it is necessary to develop a new approach of parameterization which minimizes the number of parameters.

In many cases the geometrical data acquisition takes place to different times with different sensors of different accuracy. For example, the first step could be a digitization of existing construction plans and a later step a partially tacheometrical measurement. New absolute geometry parameters have to be calculated after each step. Therefore it is necessary to map not only the parameters of the absolute geometry in the data model but also the original observables.

During the survey of a building in general two types of data will acquire. One type contains the building geometry and the other type contains descriptive information like building material or building defects. The question is who should do the surveying, the surveying engineer or the civil engineer respectively the architect? The result of an architectural surveying done by an architect is often an unsatisfying quality of the geometrical data; on the other hand a surveying engineer is not able to give a professional opinion to an architectural problem in any case. A solution of this problem could be an appropriate division of labor between the two specialists. Supposition is that it succeeds to displace the intelligence of the geometrical data acquisition from the measurement on site to the post processing. In that case the architect or civil engineer could do the measurement on site parallel to the acquisition of descriptive data whereas the surveying engineer processes the redundant relative measurement values to a unique absolute geometry. As it can be seen, even this problem can only be solved with an appropriate data model which supports adjustment techniques.

2. DATA MODEL

2.1 Topology

A typical feature of the suggested data model and at the same time a condition for the minimization of the number of parameters is the strict differentiation between topological and geometrical information. Topology is expressed by the type's node, edge, mesh and space. Figure ***1*** shows the basic types of topology implemented in the data model.

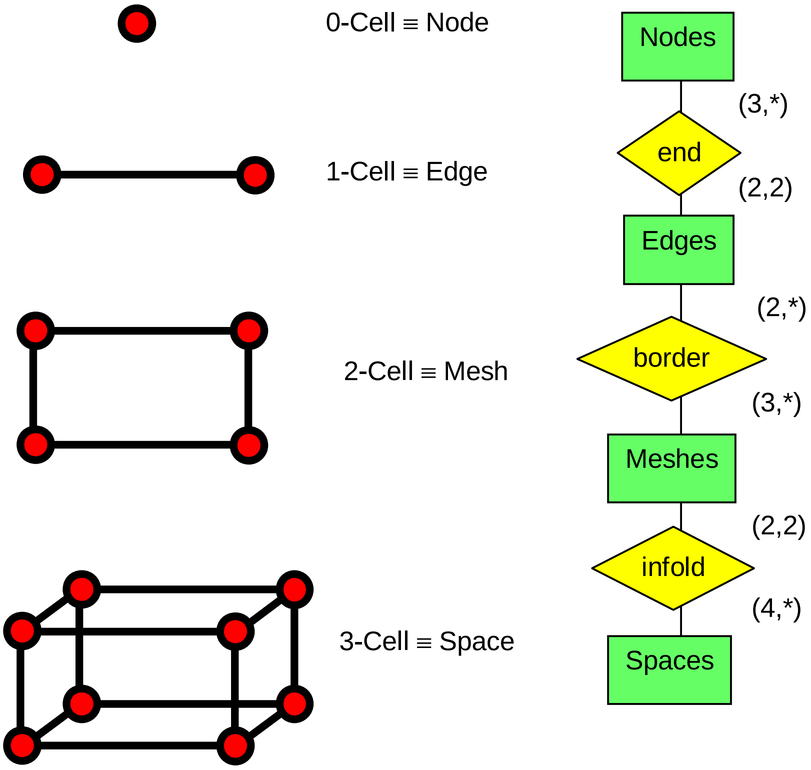

Figure 1: Topological Types in the Data Model

2.2 Geometry

Considering the geometry one has to differentiate between absolute and relative geometry. The absolute geometry results of the post processing; it is unique and therefore consistent. Because the parameters of the absolute geometry are functions of original measurement values, they are correlated stochastic variables.

2.2.1 Absolute Geometry

The absolute geometry in the presented model is exclusively expressed by planes. It is intended to extend the data model by surfaces of second order like cylinders, cones, spheres etc. Planes are parameterized by their normal vector and their orthogonal distance to the point of origin.

$$\mathbf{n}^{\mathrm{T}}\mathbf{x} + d = 0 \qquad (0.1)$$

It should be pointed out that equation (0.1) describes an open point set in a 3D space, what means that the plane has no boundary. Boundaries are defined as intersections of planes using topological information.

In the majority of buildings the most walls, ceilings and floors are parallel respectively orthogonal. This leads to an essential reduction of the number of parameters.
Figure ***2*** shows the relationships between planes, normal vectors and parameters.

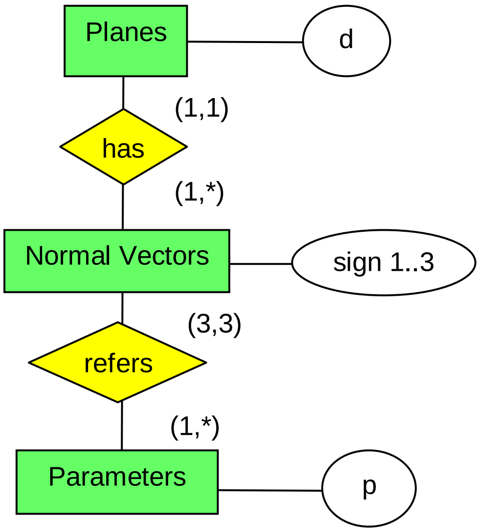

Figure 2: Relationships between Planes, Normal Vectors and Parameters

The model permits to use one normal vector to define the orientation of many different planes. For example, all horizontal planes belonging to ceilings, floors, top or bottom meshes of windows or doors refer to one single normal vector $n = (0,0,1)^{\mathrm{T}}$. For their individual positioning just one translation parameter d_i is necessary anymore. The same is valid for parallel vertical walls.

2.2.2 Relative Geometry

In difference to the absolute geometry, which expresses the position of an object related to a higher-level reference frame, relative geometry expresses the position of objects related to another object respectively to a local reference frame like an instrumental coordinate system. Components of relative geometry are mainly original or derivational measured values. Measured values are in general redundant, original measured values are furthermore uncorrelated.

2.3 Relation between Topology and Geometry

The only connection of topology and geometry is the 1:n-relationship between meshes and planes, so that one plane is able to carry many planes.

To illustrate the dramatic difference between coordinate and plane parameterization consider a theoretical building. The building has 10 floors, 4 walls lengthwise and 11 walls in transverse direction, doors and windows remains neglected. In the case of coordinate parameterization one has 10*10*3=300 rooms plus the external space, with 8 corners each. This gives 2408 points with 7224 coordinate values.

In the case of plane parameterization one gets 10*2+4*2+11*2=50 planes. The orientation is determined by 3 normal vectors with in all 9 parameters and the translation with 50 parameters *d*. In summa one need 59 parameters for the plane parameterization this means 0.8% of the coordinate parameterization.

The example illustrates the enormous redundancy which accrues by applying coordinate parameterization. Only the drastically reduction of the number of parameters gives the option to use adjustment techniques for the generation of absolute 3D geometry.

Coordinate lists can be generated as a view on geometry and topology. The topology contains the information about which planes intersect in a specific node. The Coordinate calculation can be integrated in an ordinary SQL statement.

3. ADJUSTMENT AND INTEGRATION

The presented adjustment approach is based on the data model explained in the previous section. Prerequisite for the practical application of adjustment techniques is the, as far as possible, elimination of redundancy in the parameterization.

Buildings can be surveyed in different ways. Possible data sources are manual measurement, tachometry, laser scanning, photogrammetry and digitization of available construction plans. In the general case several of these methods will applied parallel and provide a set of relative geometric data which is redundant and inhomogeneous with respect to accuracy. To process these data to a unique absolute geometry is a typical adjustment task.

In the current stage of development the used system is able to process manual and tachometric measurements as well as laser scans. Global coordinates of discrete points descending from other analyses can be introduced as well. It is intended to develop the system further for the processing of the other mentioned observation types.

3.1 Observables

3.1.1 Manual Measurement

The Observations accruing by a manual measurement are mainly distances measured with a hand held laser or a measuring tape. Following observations are possible:

- Orthogonal distance of parallel meshes
- Orthogonal distance of a mesh and a parallel edge
- Orthogonal distance of mesh and node
- Orthogonal distance of parallel edges

- Orthogonal distance of edge and node
- Distance of two nodes
-

In a mostly regular building the main part of observations is constituted of distances between parallel meshes. All observables resulting of a manual measurement are regarded as uncorrelated.

3.1.2 Tacheometry and Laser Scanning

Tacheometers as well as laser scanners are polar measuring instruments. The accuracy of distance determination is comparable for both. They differ in measuring velocity as well as in accuracy and controllability of the direction determination. A tacheometer provides the option to point to arbitrary directions with accuracy in a range of 0.3…1 mgon and a comparatively low measuring velocity of up to 1 point per second. A laser scanner measures points with a fix direction increment and a very high sampling rate of up to 50.000 points per second. The accuracy of direction determination is in a range of about 10 mgon.

In order to reduce the number of observables it is sensible in both cases to pre process the original data. In the presented approach the result of this pre processing are adjusted local plane parameters which refer to the local instrumental coordinate system. The four parameters of a plane (three components of the normal vector and one translation) are highly correlated among each other. Therefore it is necessary to store their covariance matrix for further calculation steps. Locale plane parameters of different planes are not correlated (in contrast to adjusted global plane parameters).

3.1.3 Observed Global Coordinates

Often exist global coordinates of discrete points of a building which descend from previous measurements. These global coordinates can be introduced by the following observation types:

- Orthogonal distance of point and mesh
- Orthogonal distance of point and edge
- Distance of point and node

In the majority of cases the distance of a point and a topological object has the value zero (for example if a node were determined by photogrammetry or the out site edge of a building were measured with a tacheometer).

3.2 Unknowns

Unknowns can be classified in two groups. The first group contains the global parameters $\mathbf{x}_i$ and d_i of planes referring the higher-level reference frame; the second group contains transformation parameters of the particular local coordinate systems of instrument set up's. The transformation of a local polar instrumental coordinate system into the higher-level reference frame is determined by three translations and tree rotations. In the presented

approach the parameterization happens by a translation vector $\mathbf{t}_i$ and a rotation quaternion $\dot{q}_i$ for each instrument set up.
The datum determination is given by the fixation of three non-parallel planes, for instance two outsides and the first floor of a building.

3.3 Adjustment Approach

For the adjustment the Gauss-Helmert-Model – condition adjustment with unknowns and restrictions between the unknowns – will applied. The restrictions are responsible for the normalization of the quaternions and the normal vectors.

$$\begin{aligned} \mathrm{f}(\bar{\mathbf{l}}, \bar{\mathbf{x}}) &= s_1 \\ \mathrm{h}(\bar{\mathbf{x}}) &= s_2 \end{aligned} \tag{0.1}$$

Basis of the model is an interconnected 3D transformation. In contrast to a common 3D transformation which transforms point clouds using identical points the presented model transforms groups of unbounded planes using identical planes. This plane adjustment happens simultaneously with the adjustment of the manual measures and the observed global point coordinates.

3.4 Parameter Reduction and Generalization

Aim of the parameter reduction is to find co-linear normal vectors respectively co-planar planes. Results of the adjustment are adjusted global plane parameters. The global normal vectors can be tested in pairs for co-linearity. Test value is the quotient of the cross product of the normal vectors to be tested and its empirical standard deviation. Using this test, normal vectors can be unified pair wise in an iterative process. The adjustment has to be repeated after each unification. Results of this process are groups of parallel planes whose elements refer one and the same normal vector.

In a further step parallel planes will be tested for identity. Test value is the quotient of their orthogonal distance d_i-d_j and its empirical standard deviation. In order to minimize the effort, the plans will be sorted by their global d_i and just neighboring planes will be tested. The plane unification process takes place analogue to the normal vector unification.

The bound value for a given significance level could be calculated by variance propagation to the test values. In this case the result of the parameter reduction would be determined by the accuracy of measurements. But in many cases additionally a generalization of geometry is desired. Walls and pillars in different floors should stand upon each other and have the same gauge; edges of windows in a facade should be co-linear; doors in one floor should have the same height etc. This generalization process can be controlled easily with just one parameter – the bound value of the unification tests; as higher the bound value as more generalized the geometry.

4. CONLUSIONS

Building geometry is needed for many different purposes and the requirements of accuracy and degree of generalization depends of even this purpose. Frequently it is the most efficient way to combine different measuring methods. Results of a measure are in any case redundant relative geometry parameters. The processing of these redundant measure values to a unique absolute geometry with simultaneous elimination of blunders is a classical task of adjustment. Prerequisite for the application of adjustment techniques is a low-redundancy parameterization of the absolute geometry. Is this requirement fulfilled adjustment techniques provide the option to integrate measures of different sensors. Adjustment techniques in combination with statistical analysis can furthermore be used as a tool for the generalization of the building geometry.

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