3D Building Information Efficiently Acquired and Managed

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Summary

Reliable information about the buildings interior geometry is necessary for many purposes ranging from facility management applications to the prediction of earthquake induced hazards on man-made structures. But floor plans are often not available, not updated or not acquired in three dimensions. Therefore gathering three-dimensional geometric data of buildings is becoming increasingly important. Traditional surveying techniques are time consuming and expensive. From a practical point of view, indoor surveying is based on designing plots with a CAD tool, where the dimensions are taken from angular and distance measurements. Most often the measurements are taken on site and the drawing is done back at the office. But what should be done if some measurements are wrong or have been forgotten? What should be done if the outer walls of one floor plan do not align with the walls of another floor plan? The surveying staff will eventually have to return to the building for re-measuring.

This presentation shows how to model and parameterize a three-dimensional building geometry in a non-standard form that is suitable for a fast data acquisition based on least squares adjustment as tool of analysis. In contrast to existing CAD or GIS data models, the approach discussed does not use any coordinates, but is based on planes represented by their normal vectors.

As a consequence, the number of unknown parameters is significantly reduced, resulting in fewer measurements needed to be observed. The original measurements are part of the data model enabling software tools to be applied for statistical testing, robust estimation and stepwise refinement of the model precision.

The data model, presented here, addresses the three-dimensional geometric and topological structure of a building in a way that is suitable for all purposes of engineering surveying and least squares adjustment.

During the application it will be easy to determine the intersecting planes in each node, just by traversing the model instance, because the explicitly specified topology is an inherent part of the data model. One plane can carry multiple faces (*plane-sharing*), a normal vector can be referred by multiple planes (*normal-sharing*) and a parameter can be referred by multiple normal vectors (*signed parameter-sharing*).

Introduction

Gathering three-dimensional geometric data of buildings is becoming increasingly important. Virtual 3D city models and Building Information Models (BIM) require reliable information about the buildings interior. Floor plans are often not available, not updated or not acquired in three dimensions. Traditional surveying techniques are time consuming and expensive. From a practical point of view, indoor surveying is designing plots with a CAD tool, where the dimensions are taken from angular and distance measurements. Most often the measurements are taken on site and the drawing is done back at the office. But what if measurements are wrong or have been forgotten? What if the outer walls of one floor plan do not align with the walls of another floor plan? Probably the surveying staff will then have to return to the building for re-measuring.

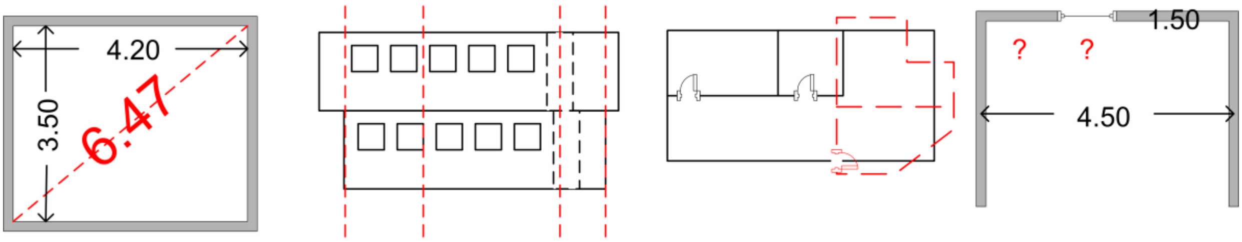

Fig. 1: Common errors during indoor data capture

This short paper shows how to parameterize a three-dimensional building geometry in a non-standard form that is suitable for fast data acquisition and least squares adjustment. In contrast to existing CAD or GIS data models, the discussed approach does not use any coordinates, but describes planes by their normal vectors (Fig. 2).

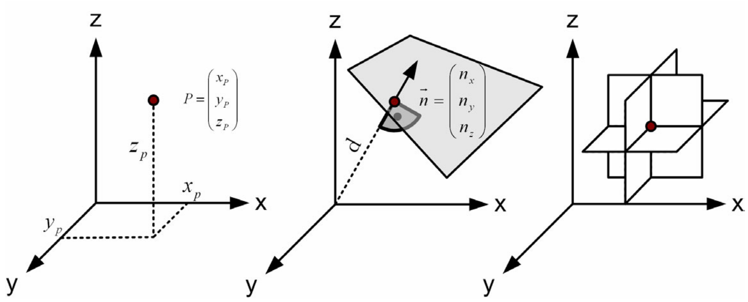

Fig. 2: a) point representation b) plane representation c) plane intersection

Using this approach, the number of unknowns is significantly reduced, resulting in fewer measurements to be observed. The original measurements are part of the data model enabling the software for statistical testing, robust estimation and stepwise refinement of the model precision.

Data model

The data model addresses the three-dimensional geometric and topological structure of a building in a way that is suitable for engineering surveying and least squares adjustment. For these purposes three main assumptions are made:

Firstly, the model must represent visible and observable parts of a building. Therefore Boundary-Representation with its explicitly specified topology was chosen. [Oosterom 2002] gives several reasons for this decision in context of surveying. Entity types of this domain are: Topological primitives *node*, *edge*, *face*, *solid* and the entity types for the topological orientation *half-edge* and *loop*.

Secondly, *stochastic observations* and *deterministic constraints* are integrated into the data model (Fig.3). This is because surveying engineers solve inverse problems.

An inverse problem is estimating the model parameters from a set of measured data. In the case of indoor surveying the model parameters to be estimated are those describing the building geometry. The data given are measurements gathered with surveying instruments. From the surveying engineer point of view, the parameters of the absolute geometry (secondary data) are derived from the original measurements (primary data). What is the benefit of this approach in everyday engineering life? A stochastically correct parameterisation allows for applying statistical tests during the process of geometric and topological generalisation. Storing the original measurements is robust, since gross errors and poor functional models (EDM offset, scale) remain identifiable.

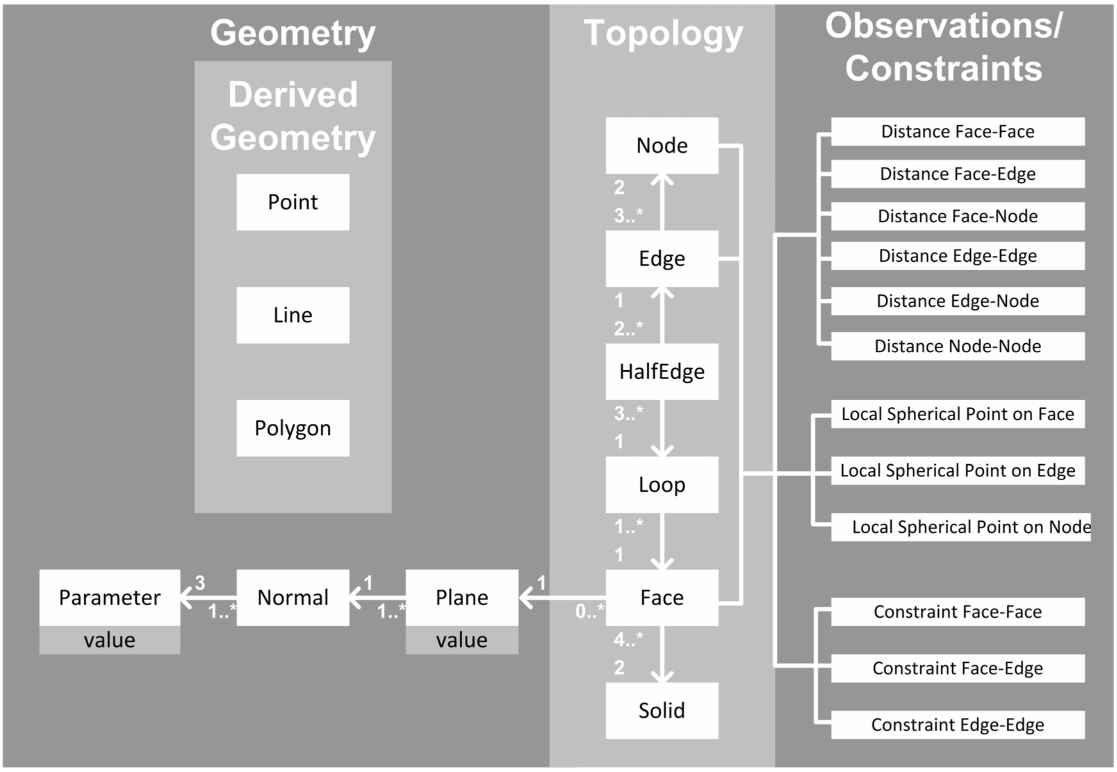

Fig. 3: A plane-based data model for 3D geometry, topology and indoor measurements

Thirdly, geometry is parameterised with planar surfaces [Gründig 2002]. The prevalent method for specifying location is making use of point representation, where every node is attached with three coordinate values *x,y,z* in order to specify its position. Additionally, implicit or explicit assumptions are made on planarity, parallelism and perpendicularity of faces [Kazar 2008]. The main idea of the discussed approach is to reduce geometric redundancy by replacing point representation by surface representation. A plane is represented by the *values* of its normal vector *nx,ny,nz* and the orthogonal distance *d* to the origin. This parameterisation is known as the *Hessian Normal Form*:

$$nx - d = n_x x + n_y y + n_z z - d = 0 \qquad (1)$$

By traversing the model instance, it is easy to determine the intersecting planes in each node, because the explicitly specified topology is an inherent part of the data model. The point coordinates can be calculated "on demand", solving:

$$\begin{bmatrix} n_{ix} & n_{iy} & n_{iz} \\ n_{jx} & n_{jy} & n_{jz} \\ n_{kx} & n_{ky} & n_{kz} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} d_i \\ d_j \\ d_k \end{bmatrix} \qquad (2)$$

Similar approaches use half-spaces in order to establish a closed polytope algebra that can be represented with finite digital representation of numbers [Thompson 2008]. Please note that in our model one plane can carry multiple faces (plane-sharing), a normal vector can be referred by multiple planes (normal-sharing) and a parameter can be referred by multiple normal vectors (parameter-sharing).

Least Squares Adjustment

Least Squares Adjustment allows for the integration of redundant measurements. The equations of the general method consist of observations, unknowns and constants. Using adjustment techniques in 3D GIS/CAD the model can be attach by mutually checking measurements/constraints, accuracy properties of measurements and unknown parameters. The resulting geometry is reliable and attached with reasonable accuracy information.

Stochastic Observation Equations

Stochastic observations or soft constraints do not have to be fulfilled strictly. For parametric adjustment the observations l and the residuals v (noise) are expressed as nonlinear functions of the unknowns x. This domain of information is considered as being stochastic, because the residuals are considered as random variables and are optimized with the Least Squares Adjustment.

One type of observations are distances (Fig. 4). Distances are measured with ruler, measuring tape, laser distance meter or simply by pacing. Although the following functions describe relations between topological primitives, the corresponding geometric representation can be determined easily by navigating through the topologic-geometric data structure.

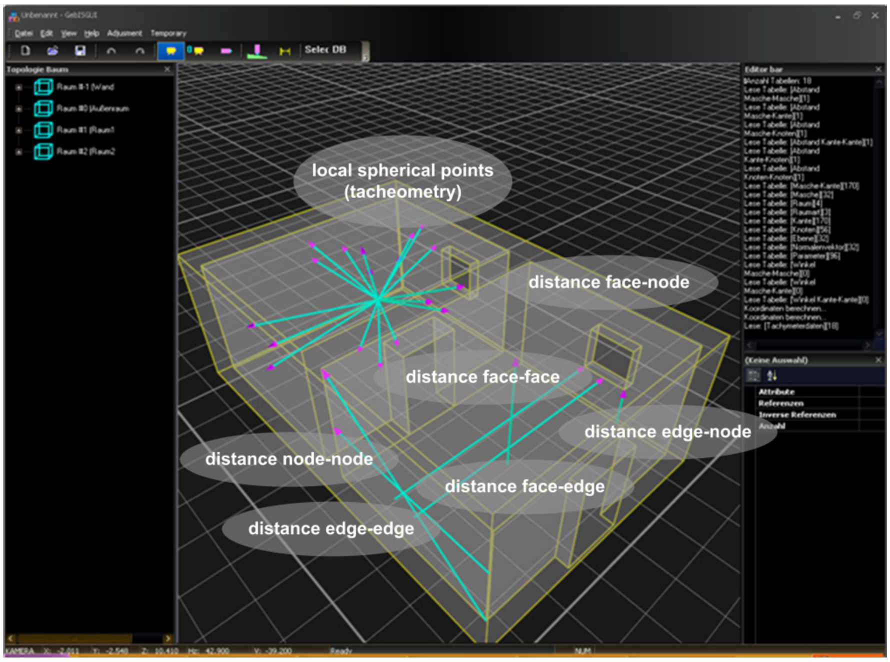

Fig. 4: Visualisation of stochastic observations (inverse picture)

Distance Face-Face. If a distance l between the parallel faces located on planes i and j is measured the observation equation is:

$$l + v = d_j - d_i \qquad (3)$$

Distance Face-Node. If a distance l between the faces i and node j∩k∩l, that is the intersection of the planes j, k and l, is measured the observation equation is:

$$l + v = \langle n_i, p_{jkl} \rangle + d_i \qquad (4)$$

$$p_{jkl} = \left[(n_j, n_k, n_l)^T \right]^{-1} (d_j, d_k, d_l)^T$$

Distance Node-Node If a distance l between node i∩j∩k and node l∩m∩n is measured the observation equation distance node-node is described as:

$$l + v = \| p_{ijk} - p_{lmn} \| \qquad (5)$$

$$p_{ijk} = \left[(n_i, n_j, n_k)^T \right]^{-1} (d_i, d_j, d_k)^T$$

$$p_{lmn} = \left[(n_l, n_m, n_n)^T \right]^{-1} (d_l, d_m, d_n)^T$$

Local spherical coordinates $(r, \theta, \phi)^T$ (Fig. 5) are taken with the total station at position $(x_T, y_T, z_T)^T$. Only one rotational degree of freedom ω remains for each instrumental set up, because the rotating axis of total station is adjusted to the vertical. The three components of $(r, \theta, \phi)^T$ are considered to stochastically independent. The observation equation of type spherical point i on face j is described as a conditional equation:

$$f(x,l+v)=\langle p_i,n_j\rangle-d_j \tag{6}$$
$$=\left\langle \begin{pmatrix} (r_i+v_r)\sin(\theta_i+v_\theta)\cos(\phi+v_\phi+\omega_T) \\ (r_i+v_r)\sin(\theta_i+v_\theta)\sin(\phi+v_\phi+\omega_T) \\ (r_i+v_r)\cos(\theta_i+v_\theta) \end{pmatrix} + \begin{pmatrix} x_T \\ y_T \\ z_T \end{pmatrix}, n_j \right\rangle - d_j$$

Deterministic Constraints

Deterministic constraints have to be fulfilled strictly; therefore no stochastic part (residual v) is contained in the mathematical function. Deterministic constraints have the advantage of reinforcing the estimated solution by increasing the (stochastic) redundancy. The disadvantage is that wrongly specified or linear dependent constraints could lead to singular equation system.

Normal vector. Since the Hessian Normal Form is valid only if the normal vector is of length 1, the algorithm must ensure the normalisation of the normal vector n.

$$\|n\|=\langle n,n\rangle=\sqrt{n_x^2+n_y^2+n_z^2}=1 \tag{7}$$

Angular Constraints are attached to the model for ensuring the observational integrity (like parallelism of faces that are connected by a distance measurement) and to find a mathematical description for “obvious” situations like “wall perpendicular to floor” or “floor parallel to ceiling”. Angular constraints are of type “Face-Face”, “Face-Edge” or “Edge-Edge”.

Angular Constraints Face-Face. If the planes i and j of two faces are perpendicular an additional constraint is attached to the system of equations. The constraint is given by the normal vectors dot product.

$$\left|\langle n_i,n_j\rangle\right|=0 ... perpendicluar \tag{8}$$

The constraints “face-edge” and “edge-edge” are modelled equivalently [Clemen 2008].

A good practice is to process the angular constraints as “soft constraints” in a first step by simply attaching a residual v to each right hand side of the equation. If the condition passes the statistical test, it can be considered as being deterministic in a second step.

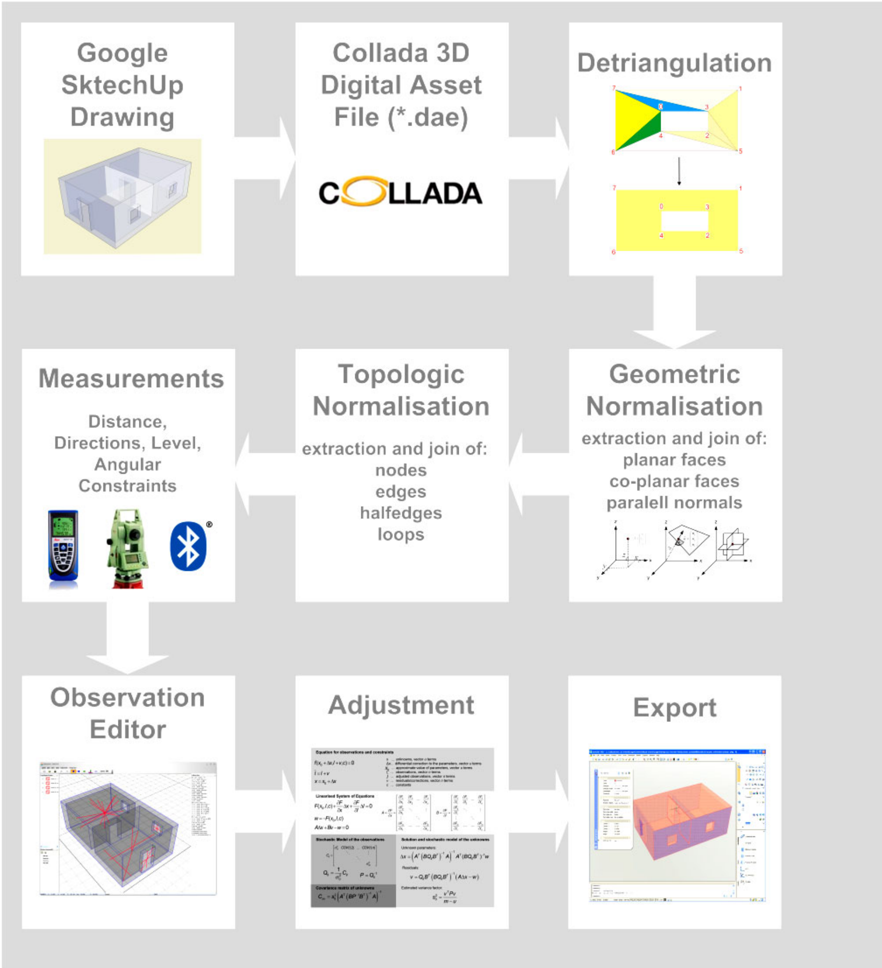

Fig. 5: Exemplary workflow to test the data model

Exemplary Workflow

In order to test the data model (Fig. 5), we use Google SketchUp as "Topology Editor". The 3D Model is draught on site. The exported Colada model is converted to an XML model instance that could be parsed and processed by our OpenGL based "Observation Editor". The measurements are collected using total station and laser distance meter. Back at the office they are adjusted with an "Adjustment Tool" and finally exported to dxf-format.

Future Work

Future work will be done in three domains: Use case evaluation, statistical testing and GUI integration. Evaluating use cases will include larger survey projects, deformation analysis, 3D data enhancement of existing model instances and the data model's application during the design phase of a building. The possibilities of statistical testing are not jet fully explored. Efforts will be made on applying well known test standards to the surface-based parameterisation. Currently we are working on the integration of our C++ algorithms to the Google SketchUp GUI in order to enable the user to work with only one software interface.

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