Integrated Computer-Assisted Building Surveying for Architectural Planning
Recording and Adjusting Building Survey Data

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Abstract: The paper describes a concept for the step-by-step computer-aided capture and representation of geometric building data in the context of planning-oriented building surveying. Selected aspects of the concept have been implemented and tested as prototypes. The process of step-by-step capture and representation is determined by the order in which the user experiences the building. Only the information that the user knows (can see) or can reasonably deduce is represented. In addition approaches to the flexible combination of different measuring techniques and geometric abstractions are described which are based upon geodetic computational adjustment. The paper also examines the flexible combination of different surveying techniques and geometric abstractions achieved with the help of geodesic computational adjustment methods. Selected aspects have been implemented and investigated as prototypes. All prototypes will be shown and discussed.

1 THE AIM OF A PLANNING-ORIENTED BUILDING SURVEY

An essential prerequisite for planning within existing contexts is reliable and informative planning data. In most cases this is not available or has not been kept up to date with the current situation. As a result a building survey is necessary, either as an extension or validation of existing building documentation or to provide new documentation. A building survey which fulfils the needs of a planning task will be described as a planning-oriented building survey (Donath et al. 2003).

Despite the many different fields of application for building surveying and the resulting different demands, the representation of the building geometry is typically the most important aspect of a building survey. The gradual process of getting to know an existing building is mirrored in the capture and representation of geometric data. This paper concentrates on this process.
Without relationships to other kinds of information, geometric information on its own can only provide limited information for the planner. The research concept and approach is described in the paper “The building as a container of information” (Petzold 2001), which describes the context. This paper examines only one element of this concept: the building geometry.

2 A DIFFERENT APPROACH TO THE STEP-BY-STEP CAPTURE AND REPRESENTATION OF BUILDING GEOMETRY

In comparison to commercially available solutions we have chosen an approach that is oriented towards the way in which a user gradually gets to know and surveys a building.

The concept as developed is oriented towards existing and future requirements for the design and planning of building measures within existing buildings. It is not specifically tailored towards documenting historic buildings, monuments etc. although the concept could be equally well suited to this area due to the fine levels of detail possible.

The emphasis is on the planning strategy for building measures within existing buildings. The necessary information must be ascertained step by step and the architect or planner makes decisions based upon the available information. For example, initial planning strategies can be developed as soon as the basic room dimensions and interrelationships have been approximately ascertained.

Commercial solutions already exist to capture and store building data (geometry and attributes). Our concept has a number of qualitative and quantitative advantages over such systems:

- the ability to describe spaces (“rooms”) and define building elements;
- a step-by-step approach;
- freely definable approach and free combination of different capture devices.

This leads to the direct integration of such functionality into current CAAD systems which are based upon a building information model (see the discussion at the AEC report webpage (Khemlani 2004, Khemlani 2003)). The architect can plan within in a work environment (the CAAD system) in which viewing, planning and assessment can occur alongside one another.

At present the prototype is an independent development with data interchange interfaces for exchanging data with other systems. In the next three years we plan to have established a complete planning environment. The concept can accommodate buildings of differing characters and building types, whereby at present only buildings defined by vertical planar walls are supported. This nevertheless covers the large majority of typical planning tasks. At a horizontal level, the model can
accommodate any kind of shape of spaces, angular wall directions etc. The ability to define types and class definitions allows industrially prefabricated elements to be captured simply and repeated as often as they occur in reality. Likewise, individual deviations to the parameters of standard elements can also be captured should the actual situation dictate these. The next development stage envisages catering for freeform and curved walls. In the following aspects we will focus on the surveying of geometric information.

In the initial phase of a project survey, the surveyor gathers a ‘rough’ impression of the building as a whole. The surveyor can see the exterior elevations of the building and the surfaces of rooms indoors. As the surveyor goes from room to room he or she gradually takes in more and more information. Particular building elements within the rooms such as doors, windows, columns etc. can be identified immediately. Other elements such as the construction of walls, the elements of the structural system remain hidden from view. The surveyor then returns and begins to measure the dimensions of rooms from indoor surface to indoor surface, as well as the dimensions of building elements that are visible. The planner or surveyor can then deduce or infer how the building is constructed based upon the geometry of the building, his or her knowledge of (historic) building construction and possibly through localised examination of particular elements of the building.

The computer-aided support of this gradual process takes the approach “from sketch to detail”. In the first phase of the building survey, the surveyor makes a sketch-like overview of the arrangement of rooms, their surfaces and the external surfaces of the building (elevations etc.). The sketches are not to scale. The individual surfaces can be ordered in a form of semantic i.e. differentiated in walls, floors and ceilings. In addition further formal or informal information about the surfaces (material, appearance, damages etc.) are recorded. A touch-pad with pen is used together with the sketch tool from freak (Figure 1a). A commercial example of a design orientated and sketch-based approach is the tool “SketchUp” (@Last Software Inc. 2004).

During the second stage, the ‘model’ of the building that has resulted from the first stage is ‘enriched’ with geometric dimensions. A variety of different surveying techniques can be applied and combined according to the needs and tools at the surveyor’s disposal. The surveyor must also be free to choose where to begin and in which order the survey will be undertaken. The realisation of this gradual process of ‘enriching’ and correcting the geometric model employs techniques from geodetic computational adjustment.

After the model has been adjusted to represent the geometric dimensions of the original building, the building form is then ‘disassembled’ into its constituent building elements. The geometric parameters of these elements can then be derived automatically, i.e. height, breadth, depth.

The sketch-model can be dimensioned using a series of key distance measurements (Figure 1b). After computational adjustment this results in a correct geometric model that can be viewed in 2D-mode (Figure 1c) or as a 3D-model with standard room height. This paper concentrates on one aspect of this process, the adjustment of a sketch-model to a geometric model.
COMBINING DIFFERENT SURVEYING TECHNIQUES AND GEOMETRIC ABSTRACTION

As previously described, the surveyor should be able to use a variety of different surveying techniques. The most common techniques employed are manual measuring by hand, tacheometry and photogrammetry. All are able to determine the geometric location of a particular point (or series of points) in relation to another point with slightly different degrees of precision. In order to reconstruct the geometry of a building from these series of measured distances, certain geometric abstractions must be applied. For example, wall surfaces are generally regarded as being flat or planar. The use of such abstraction means that the geometric model will inherently contain an element of error in comparison with the original building. As a result the survey itself can be regarded as a process of modelling the building.

Geometric abstractions also help to speed up the surveying process and therefore to keep costs down. The down-side is a reduction in geometric precision. The surveying of window jambs serves as a good example. Depending upon the level of accuracy required and the form of the window, many window jambs can be regarded as being parallel. This level of abstraction means that only the dimension of the opening, the distance between the jambs, needs be measured. This is usually undertaken in the middle of the wall depth to keep model inaccuracies to a minimum.

The same principle of geometric abstraction of dependencies applies for other elements in a building. These include:

- Parallel and orthogonal orientation of surfaces;
- Horizontal and vertical surfaces;
• Symmetry;
• Geometric similarity (repetition) of particular elements, e.g. windows, columns etc.

To combine measurements from different surveying techniques and geometric abstractions a computational adjustment model from the field of geodetics is applied. This allows the conscious ‘enrichment’ or validation of the model with a view to improving the model’s accuracy. All measured dimensions and abstractions are recorded in a pre-positional form in a database and their representation in the form of a geometric model can be recalculated periodically as required.

The basic principle of adjustment of a geometric representation is relatively straightforward. The geometric representation is described using a surface model. Measurements and abstractions are “introduced” into the surface model (Figure 2).

Figure 2  Step-by-step surveying and model representation of a room in plan
These change the dimensions of the representation. Computational adjustment attempts to resolve conflicts between the representation in the model and the actual measured data in such a way as these are minimised and the model need be changed as little as possible. Using this approach it is possible to begin with a high level of geometric abstraction and only a few measurements and to gradually add further measurements and reduce the geometric abstraction to increase the accuracy of the model.

4 FORMALISING MEASUREMENTS AND GEOMETRIC ABSTRACTIONS

The adjustment model chosen is a mediating adjustment on the basis of observation, as this model produces small adjustment systems and because the calculated unknowns are required for the dimensional adjustment of the geometric module. All observations are presumed to be uncorrelated as the automatic determination of correlations is difficult and cannot be expected from a user without experience of geodetics. The following explanation provides an introduction to the computational adjustment model from the field of geodetics as well as experience from concrete applications.

The concept employs adjustment methods used conventionally in geodesy as a method of connecting measurements with user-configured geometric definitions and constraints. An initial approach links measurements to geometric form using point co-ordinates. Central to this approach is the determination of unknown values. As a result the adjustment computation method was chosen. Characteristic of the resulting equation systems are their small size, resulting from the direct determination of unknown values.

The determination of gradients is numerical. A modified Cholesky-approach with skyline-matrix is employed as fastsolver which has proven itself in the areas of geodesy and FEM. Initial tests use a continuous regularisation to improve the removal of singularities resulting from datum and configuration defects.

The introduction of observations is applied graphically. In practice, the surveyor models everything he or she has measured. The measurements are quite simply modelled. In a subsequent stage the geometry is modified via computational adjustment algorithms.

For the approach described here, the adjusted model and the geometric model are coupled with one another through the points of the geometric model. The coordinates of the points are unknown in the adjustment model.

Measurements and abstractions are modelled as observations according to the form:

\[ L + v = \varphi(\hat{X}) \]  

(1)
Here $L$ represents the value measured from the original and $v$ the deviation between $L$ and the adjusted model. A distance between two points would therefore be modelled as:

$$\|L + v\| = |p_2 - p_1|.$$  \hspace{1cm} (2)

By way of an example of geometric abstraction, a collection of points $p_1, \ldots, p_m$ are introduced which lie in the same plane. The abstraction is formalised using observations of the form:

$$0 + v = \frac{n \cdot (p_i - p_s)}{n}.$$  \hspace{1cm} (3)

Here $n$ represents the normal vector of the plane and $p_s$ the geometric centroid of the collection of points. The same pattern applies for the modelling of other measurements and abstractions.

The combination of different measurements and abstractions is achieved through the linearisation of the observations. The linearisation method is described in more detail in (Thurow 2004) and (Thurow and Donath 2004).

## 5 PROTOTYPICAL REALISATION

Most of the selected aspects of the concept as described have been realised in a prototypical system. The prototype with the name “experimental platform FREAK” consists of a series of extendable tools which access and work with the same database. The implementation of the system was realised as a series of prototypes which communicate with one another using a common data model (Figure 3).

This system provides a model for a better organisation of information for all areas concerned with the planning process in architectural practice. The tools allow the sketch-based, plan-oriented creation of simple building geometries and their adaptation to fit taken measurements. After the building geometry has been entered in sketch form the system looks for likely geometric abstractions. Using various different tools manual measurements or measurements obtained with tacheometry or photogrammetry can be introduced into the model. This combination of manual and semi-automatic surveying techniques such as tacheometry and photogrammetry is a central aspect of the concept (Figure 4).
Figure 3 3D and plan-oriented views of a geometry model using the tools “OpenGLviewer” and “PlanarViewer” showing an example of a manually measured survey of an office building.

Through the use of a motorised tacheometer with visible laser beam it is possible to compare model and reality in real-scale. The tacheometer rotates to show the location of points in the geometrical model as a laser-beam point in the real building (Figure 5). Another method is the visual comparison between a distortion-corrected photo and the geometry model (in development).

As previously noted, a geometric model of building surfaces is only one aspect of a building survey. The prototype allows the user to derive building elements from the geometric survey and to link these with attributes and with further kinds of relevant information in a variety of forms. Different kinds of information can be related to building objects and made available to all the project participants.
6 CONCLUSION

The software prototype is currently undergoing extensive testing. All survey test objects are defined by upright planar walls. Initial results provide indications of successful results and problem aspects but cannot yet be regarded as a conclusive appraisal.

The approach as described does contain a number of as yet unresolved but identified and described problems, particularly with regard to increased levels of detail and the creation of parameterized building elements by the user. Current progress does however provide good cause for optimism and the authors intend to pursue and improve the current approach as described.

Tests have shown that the duration of a building survey can be significantly reduced by improving the ergonomics of mobile computer systems and the linking of these to different measuring devices. This area is also currently being developed with the chair of “architectural computer science” (Petzold, Donath and Bürgy 2004) together with the underlying supporting software interaction.

The approach described strengthens the ever more relevant hope that digitally supported building models could become an integral part of architectural planning practice.

The planning of conversions and extensions of existing buildings based upon structured building information provides architects and planners with increased planning security and improves the cost-effectiveness, quality and longevity of building measures in existing buildings.
REFERENCES


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