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Reconstruction of edges in digital building models

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ABSTRACT

Traditionally, the geometry of building components or rooms is either described by their boundary or it is defined by constructive solid models. Modeling tools are available which are based on the principle of constructing building components and of composing a building by adding building components step by step. However, topological relations are relevant besides the shape of components and rooms. These topological relationships are not necessarily explicit information in boundary representation or constructive solid models. As a consequence, they must be computed. At present time, there exists to the best knowledge of the author only a single approach in this subject area that is able to reconstruct topological relations including their geometry. The objects which need to be considered are building components, built-in components and rooms. The challenge is to calculate the three relevant aspects of geometry in digital building models completely and in an efficient way. These three relevant aspects are clashes, voids and contact faces. The existing approach to calculate these aspects is based on space partitioning concepts. Space partitioning concepts store neighboring relations explicitly. The approach presented in this paper is also based on space partitioning. One basic and novel consideration of the approach presented in this paper is to execute the reconstruction procedure in a mesh. The mesh itself is not refined anymore at a certain point during the calculations to avoid uncontrollable refinements. The second basic and novel consideration is the way of avoiding topological inconsistencies. Integer values are chosen for coordinates, and a specific algorithm is presented that guarantees that topological inconsistencies cannot occur. The research presented in this paper addresses the first step on the way to compute clashes, voids and contact faces. This is the reconstruction of edges. This paper presents the theory and a pilot implementation for the reconstruction of straight edges. Examples show the benefits of the approach presented. Open questions are discussed.

1. Introduction

There is at present time to the best knowledge of the author no approach available that is able to check all three relevant aspects of geometry in digital building models in an efficient way. The three relevant aspects of geometry in digital building models are clashes, voids and contact faces. Clashes are locations which are assigned to more than one object. Voids are locations in the interior of a building with no building component, built-in component or room. Clash detection is state of the art, e.g. [33] or [28]. The detection of voids is partly addressed during clash detection procedures but not solved in a general way which can handle any geometry. A computation of the exact geometry of contact faces is not addressed.

The research presented in this paper contributes to this extensive task. It presents the theory for and results of a first step in this field: the reconstruction of edges. The approach is validated and verified. A comparison of results to the only existing other approach in this field shows the power of the presented approach.

The overall task is as follows. The geometry of all building components, built-in components and rooms of a digital model of a building is assumed to be given. In the context of this paper, this geometry is given as a mesh of planar triangles for each building component, each built-in component and each room. A calculation procedure answers the following questions and computes the geometry:

1. Are there overlaps of any given objects?
2. Are there voids in the interior of the building?
3. Where are contacts between objects?

The first question is typically named clash detection. The second question does not only include the calculation of spaces where persons forgot to model objects. It also includes the recognition of gaps between objects.

One basic idea of the research presented in this paper is to answer these questions based on the concept of space partitioning. Typically, building models are specified by constructing components or defining and placing built-in components. In a second step, rooms are specified once the surrounding components and built-in components were modeled. Such models are constructed by adding objects.

The basic consideration of space partitioning is a stepwise modification of a valid space partitioning. Data structures are setup in such a way that topological neighboring relationships are stored explicitly, see, for instance [8] or [9]. A calculation of topological relationships is obsolete once a valid space partitioning is guaranteed.

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To the best knowledge of the author of this paper, only a single approach is presented in the literature that allows to answer all three above mentioned questions in a single step [19]. In this approach, the theory is described, a pilot implementation is presented and the application is shown. The approach is also based on space partitioning. The approach contributes to research because it is the first approach that solves this problem. However, the approach has the disadvantage that uncontrollable refinements can occur. This results from well described problems in the field of mesh generation, for instance in [25].

The approach presented in this paper avoids uncontrollable refinements basically. This is achieved by two considerations:

1. The coordinates of vertices of given triangles are stored as integer values.
2. A valid space partitioning is the basis. This space partitioning uses all vertices of all given triangles, but this partitioning is not refined during the reconstruction processes.

The fundamental problem in this field results not from the theory. Mathematical formulations are not the challenges. The fundamental problem results from the fact that memory in the computer is finite. Real numbers are stored in an array of a specific number of bits so that decimal values are cut off and round-off errors can occur. Consequences are that tests, for instance concerning the location of a point on a plane can give ambiguous results. Topological inconsistencies might occur even if integer values are used as coordinates for vertices. This is well described in the literature, for instance in [29].

The challenge is to find a way to reconstruct given objects in such way that both, topological inconsistencies and uncontrollable refinements are avoided.

A topological inconsistency is shown in Fig. 1 in the two-dimensional space. A given edge is shown as a dashed edge with its start and its end. Start and end are on the grid. In addition, a part of a triangle is shown. The shown vertex of that triangle is also on the grid of integer values. All points on the grid are surrounded by a single bold line.

The intersection points between the edges of the partitioning and the given edge are not guaranteed to lie on the grid. Numerically round-off errors can result in situations where the correct location is not exactly on the edge of the partitioning. This is indicated by the grey areas around the edges of the partitioning. It can happen, as shown in Fig. 1, that, coming from start, concerning the calculated coordinates the first intersection point is behind the second intersection point. The space is folded in this case. The topology is incorrect and inconsistent. In the literature, also the term "bad angle" is used to describe shapes with very small and sharp angles where the round-off error can result in numerical problems so that topological inconsistencies can occur. A classification of such shapes is given by [6]. It is shown in Fig. 2.

The algorithm presented in this paper can handle these situations. Using integer values as coordinates allows a robust and fast computation of the location of points concerning edges, straight lines, triangles or planes in the case that these objects are specified by vertices with integer values as coordinates. As a consequence, the effort of computation decreases compared to the adaptive precision floating point arithmetic.

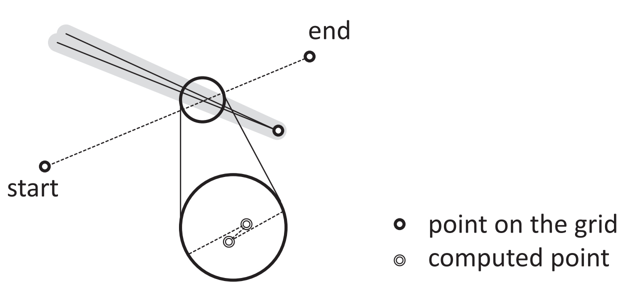

Fig. 1. Illustration of a topological inconsistency.

Using integer values as coordinates allows a correct identification of the geometry where an intersection point is located. Coordinates of intersection points are never used to check the location of geometrical objects to one another. This allows the avoidance of topological inconsistencies.

The second basic idea is the avoidance of uncontrollable refinements. The phenomenon is described by Ruppert [25] in the two dimensional space. Fig. 3 "shows why small input angles can be a problem for the basic algorithm: *p* encroaches upon *qr*, which is split at *s*, which encroaches upon *qp*, which is split…".

In this research, reconstruction takes place in a space partitioning which is not refined any more. As a consequence, a phenomenon as shown in Fig. 3 cannot occur by the nature of the algorithms.

The research addressed in this paper has the long term goal to establish space partitioning as a concept of modeling the geometry of digital building models. The paper differs a little bit from other papers published in this journal which focuse on geometry. For instance, Amadori et al. [1] accepted existing CAD concepts. Based on these existing concepts, they started their research in the field of design automation. Another example is the work of [32]. Semantics is in the focus of this research to improve CAD data exchange with the goal to transfer design intent. The research addressed in this paper scrutinizes the way of using geometry. Therefore, geometry itself is the main focus. Research which is more focused on the beneficial use of space partitioning concepts in digital building models is conducted once theoretical research as presented in this paper has been worked out.

The paper is structured as follows. Section 2 presents related research. Section 3 describes the theory and aspects of a pilot implementation. In Section 4, examples illustrate that the approach presented is able to fulfill the described requirements and that the approach can be used for digital building models. Section 5 presents a summary and a discussion of the achieved results, and further steps on the way to solve the overall scientific issue are described.

2. Related research

The research presented in this paper is essentially based on three extensive subject areas. These subject areas are testing the location of geometrical objects to each another, mesh generation and partitioning of space. The following subsections give a short overview of aspects of these fields. However, there are also other approaches which address parts or aspects of the overall scientific issue. The first subsection gives an overview on these approaches. They focus on topological relations in digital building models and methods to calculate them.

2.1. Topological relations in digital building models

Topological relations between objects are relevant in architecture and civil engineering. For instance [18] present "a geometric reasoning system called Construction Spatial Information Reasoner (CSIR) that derives construction-specific spatial interpretation of a building model to support automated construction planning." They need topological relationships between building components and present as part of their research an algorithm which is specifically focused on specific building components. However, they do not offer a general solution for the determination of topological relationships.

Lin et al. [21] present a path planning algorithm for 3D indoor spaces. They use an IFC file (IFC: Industry Foundation Classes) as input. Beside geometrical information, semantical information of space and components is used. They map this input onto a discretized grid. Results are presented for a single storey. Limitations exist, for instance in handling multi-storey buildings. Teo et al. [31] present a method to generate "a multi-purpose geometric network model (MGNM) based on BIM and explore the strategy of indoor and outdoor network connections." The authors uses an IFC file as input. "To achieve the goals, the IFC-to-MGNM conversion includes the following: (1) extraction of