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Computational geometry in the context of building information modeling

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ABSTRACT

Building energy analysis has gained attention in recent years, as awareness for energy efficiency is rising in order to reduce greenhouse gas emissions. At the same time, the building information modeling paradigm is aiming to develop comprehensive digital representations of building characteristics based on semantic 3D models. Most of the data required for energy performance calculation can be found in such models; however, extracting the relevant data is not a trivial problem. This article presents an algorithm to prepare input data for energy analysis based on building information models. The crucial aspect is geometric simplification according to semantic constraints: the building element geometries are reduced to a set of surfaces representing the thermal shell as well as the internal boundaries. These boundary parts are then associated with material layers and thermally relevant data. The presented approach, previously discussed at the International Academic Conference on Places and Technologies (Ladenhauf et al., 2014), significantly reduces the needed time for energy analysis.

1. Motivation

The building sector, which accounts for over 40% of all energy use in the European Union, is the single biggest European energy-consuming sector. The reduction of needed energy as well as the increase of energy efficiency has become a societal responsibility. Buildings constructed and designed with a high degree of energy efficiency will reduce energy consumption. As a direct impact this will decrease the wastage of conventional fossil fuels resulting in a reduction of emissions of certain atmospheric pollutants and the damage caused by the greenhouse phenomenon. Economically optimized buildings are cheaper in terms of running costs than conventional ones with regard to the evolution of prices of raw materials and energy.

The assessment of the energy performance of a building takes place in the middle of the planning process, during the preparation of the mandatory energy performance certificate. Major decisions for energy efficiency, such as geometry, orientation, opening planning or construction, however, are done much earlier – during project development, pre-design and design. At this early stage, however, most of the details about quality of components, heating, ventilation and air conditioning (HVAC) systems, etc., are still missing, which makes the full energy efficiency rating impossible. However, the costs of the preliminary estimate of energy efficiency stay the same since the main factor is the detection of areas of the thermal shell of the building.

Assuming that the design is most likely to change in the further planning process, this estimation is to be executed repeatedly. By computer-assisted creation of the building model (based on the budget versions of the ongoing planning process), this effort could be significantly reduced through automation, making the integral energy efficiency planning much more realistic.

Based on previous work [1], we present a solution to improve and simplify the thermal analysis for complex buildings: for the use of simple forecasting calculations complex planning processes have to be reduced to simple structures (e.g. geometry and system configurations). The majority of needed data is already included in an Industry Foundation Classes (IFC) model. The semi-automatic creation of such simple models would allow planners a much easier

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detection and control of the energetic impact of their plans and measures.

2. Related work

The approach and its algorithms presented in this article include techniques from various fields of application: data management in the context of Building Information Modeling (BIM), energy performance analysis in the context of Building Energy Modeling (BEM), and computational geometry with a focus on semantic modeling.

Mitchell [2] points out that thermal performance of buildings has a long history of application and has become a central focus today as a means to improving building environments yet using less resources. This has put a new demand for multiple performance optimizations that embraces the basics of structural stability, health, egress, fire protection, etc., with environmental qualities of noise control, daylighting, and indoor comfort.

The enhanced product assembly and quality as well as the application of advanced manufacturing techniques have added further dimensions to the modeling and analysis task. Franconi [3] introduces the concept of a framework for building energy modeling methods and processes. The effort involves examining modeling tasks across modeling applications, creating a structure for organizing them, and specifying the detailed development of shared components.

The digital representation of the design process is reflected by the Industry Foundation Classes, an open data model for building and construction industry data developed by buildingSMART, formerly International Alliance for Interoperability [4]. Intended to facilitate interoperability in the building industry, it has become an ISO standard [5] and a commonly used format for building information models.

The question how to close the gap between BIM and energy performance simulation has been a subject of research in recent years. Hitchcock and Wong [6] analyze different efforts in this field, concluding that automatic data exchange between BIMs and energy simulation is still an “elusive goal”.

The Lawrence Berkeley National Laboratory (Berkeley Lab) realizes the approach most similar to the presented one: they are developing a methodology to semi-automatically perform energy simulations based on original data from an IFC-based BIM. The methodology involves model checking (to ensure that the BIM meets certain requirements), and, as its key step, automated data transformation from the BIM to a format suitable for energy simulation [7]. For the latter step, they developed an algorithm that splits up space boundaries (the surfaces where spaces meet building elements) based on what is on the “other side” of the building element, so that each resulting space boundary has constant one-dimensional heat flow across its area. These split space boundaries and building elements as vertices, as well as the physical connections between them as edges, constitute paths of heat transmission in a building graph [8].

The main difference to our approach has its roots in the Austrian calculation methodology for energy performance certificates. It is defined in the *OIB-Richtlinie Energieeinsparung und Wärmeschutz* and the ÖNORM B 8110. The goal is to keep the effort for certificate issuance to a justifiable amount, yet provide “good enough” results, e.g. to enable meaningful comparisons of different buildings on the market [9]. The input data necessary for such a calculation include:

- building geometry data, namely the building elements’ area quantities, gross area, and gross volume;
- the building elements’ thermal transmittance (*U*-values), or definition of their material layers (material, thickness);
- heating-degree-days (in German: Heizgradtage) per year (determine the period in which the space heating is used);
- monthly climate data (average temperature, solar radiation for horizontal areas and all cardinal directions).

Another approach to facilitate exchange of IFC data between different tools is the implementation of Model View Definitions (MVDs). This approach responds to the problem that one usually does not know what to expect from an IFC model: IFC, by its very nature, is rich, but flexible and redundant, because it has to address various needs from architects, suppliers, engineers, and others. MVDs define subsets of the IFC schema for certain exchange tasks, outlining what data are expected in a specific use case [10]. Official MVDs are being developed by buildingSMART, with the Coordination View being the first and most widely implemented view [11]. For the Coordination View, there even exists a “Space Boundary Add-On View” to support the usecase of energy analysis [12]. The specification of MVDs is done manually, and Venugopal et al. propose a more formalized approach [13]. In any case, specifications are of course only the first step, and it depends on BIM software vendors to implement them.

Meanwhile, the transformation from BIM to a format suitable for energy analysis is based on computational geometry algorithms to simplify geometry with respect to semantic constraints. These constraints are a set of rules formulated by civil engineering experts with respect to thermal performance guidelines and laws. Needed building information is extracted from the IFC data as much as possible.

Applying computational geometry algorithms to BIM requires the incorporation of numerical robustness aspects. For an introduction to the robustness problems that arise with geometric computation we refer to the work of Hoffmann [14]. A more recent discussion of the topic is the work of Kettner et al. [15]. They discuss the problems of using floating point arithmetic for algorithms that assume real arithmetic and show that simple algorithms may fail under such conditions.

In the context of architecture and building information management, plane based representations are of special interest. More specifically, Bernstein et al. [16] and Krispel et al. [17] applied a plane based representation together with exact floating point predicates [18] to calculate Boolean operations on solids organized in binary space partitioning trees. Furthermore, the method has been applied for efficient robust polygonal boundary evaluation of swept Minkowski sums [19].

Our algorithms use floating-point arithmetic as well. In contrast to the methods mentioned above, we employ additional information stored in IFC data to cope with numerical issues: in most cases the result of a geometric operation (intersection, union, etc.) is (directly or indirectly) available. Therefore, it is possible to use a snapping-based technique.

3. Algorithm

The goal of the algorithm is to create simple building models for energy analysis based on complex building information models. Currently, this task is done manually, i.e., by re-creating models from scratch. The ideal algorithm would do the same as a human expert who is modeling the data for energy analysis by looking at and using the data from the IFC model. Faced with a complex, yet incomplete representation of a real-world building, he or she decides, which data are relevant and which are not based on semantic understanding.