Spatial Information Theory and Construction Informatics – a Fruitful Symbiosis

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Abstract
Traditionally, Spatial Information Theory and Construction Engineering have been recognized as widely separated fields with only very little connections. However, in recent years the construction industry has undergone a substantial change: It is evolving from rather historic practices based on 2D drawings into modern digital processes based on information-rich 3D models that can be generated, analyzed and processed by means of computer technology. This progression, driven and fostered by the Construction Informatics Community, opens the possibility for innovative research in the fascinating area where Spatial Information Theory and Construction Engineering overlap. The paper gives an overview on ongoing activities in this area.

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1 Introduction
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The paper covers a number of research topics positioned at exactly this overlapping area.

2 Spatial analysis of 3D building and city models
The journey starts at presenting the 3D spatial analysis functionalities for building information models developed by the author [3, 4, 5]. Here, classical concepts of Spatial Information Theory originally developed for 2D Geographical Information Systems (GIS) have been transferred and applied to 3D building information models. As one example where spatial query functionalities are of great benefit, the automated generation of a precedence relationship graphs (PRG) from building information models is presented. The PRG forms an important component for automated construction progress monitoring, where point clouds are captured in regular time intervals and overlayed with 4D building models [23]. As however, many components remain invisible, the PRG helps to infer their existence in an indirect manner [7, 6]. Also in other scenarios spatial analysis provides powerful means for effective filtering [12, 9, 10]. This includes checking the spatio-semantic consistency of
building information models [8], but also the integrative analysis of both 3D city and building
models [11] across heterogenous data models, such as CityGML and IFC (Figure 1).

Figure 1 Querying building models by applying spatial operators, from [11].

Figure 2 Interactive parametric FreeCAD sketch that maintains visibility, movement, and
qualitative size constraints and the building model extruded from it. From [21].
3 Building design supported by spatial reasoning

The formal description of qualitative spatial relationships is helpful not only for analyzing completed designs and querying building information models, but also for supporting the architectural design process. A particularly powerful solution in this context is the integration of formal spatial reasoning with a feature-based parametric modeling engine [21]. We were able to demonstrate the proposed methodology by applying it to architectural floor plan layout design, where a number of spaces with well defined functionalities are automatically arranged such that particular functional design constraints are maintained (see Figure 2).

Recently, model synthesis, i.e. the automated creation of models on the basis of abstract engineering knowledge has received increasing attention [24, 22]. In this regard, the author’s group has been successfully applying formal graph transformation techniques to realize the knowledge-driven detailing of building components [25]. To this end, parametric modelling engines were coupled with graph transformation systems. The talk will give an overview on the progress achieved and discuss the remaining challenges.

![Figure 3](image) Application of formal graph transformation for automated detailing of tunnel models, from [25].

4 Semantic enrichment

An extremely important field of research is related to capturing the already built assets of the built environment. Here, the goal is to develop methods that allow to create a semantically rich digital representation from the raw data of point clouds and photographs in a largely automated manner. In this regard, the concept of semantic enrichment provides the possibility to assign volumetric 3D models with the respective semantics [20]. The applied rule-based approach for semantic enrichment heavily relies on spatial relationships between individual objects. In a related application field, rules with spatial semantics can be formulated to identify site equipment required for construction projects, for example [13].
5 Code compliance checking

Another field of application is code compliance checking. In the design and engineering of buildings, a large number of building codes and regulations have to be taken into account. Today, the compliance of building designs with such regulations is checked manually; both by the responsible architects as well as the building permission authorities. The available commercial solutions for code compliance checking mainly follow a black-box approach where the rules that make up a certain regulation are implemented in a hard-wired fashion rendering their implementation in-transparent and non-extendable.

A number of researchers have tackled this problem and have proposed various ways that allow the user to define rules, either in a standard programming language or in a dedicated language. However, AEC domain experts usually do not have the required programming skills to use these languages appropriately. To overcome this issue, we developed the Visual Code Checking Language (VCCL), which uses a graphical notation in order to represent the rules of a code in a machine- and human-readable form [18, 19]. As spatial relationships play an important role in code compliance checking, VCCL provides dedicated operators with spatial semantics among its basic building blocks (Figure 5).
6 Spatial cognition for pedestrian dynamics

Finally, we highlight the importance of spatial information for the simulation of pedestrians. In particular on the strategic and tactical levels of the simulation models, the proper modelling of wayfinding behavior is of utmost importance for achieving correct simulation results [2, 16, 17, 15, 14]. We demonstrate how elements of spatial cognition have been implemented in our pedestrian simulator MomenTUM (Figure 6) and illustrate their effect.

Figure 6 Architecture of the pedestrian dynamics simulator MomenTUM that relies on cognitive principles for modeling wayfinding behavior, from [14].

7 Conclusion

There are various fields of research where the combination of Spatial Information Theory and Construction Informatics results in strong synergies and enables new solutions for practical problems of the Architecture, Engineering, and Construction (AEC) industry. There is high potential for intensified research in this area.

References


