Spatial Information Theory and Construction Informatics – a Fruitful Symbiosis

André Borrmann

Chair of Computational Modeling and Simulation, Technical University of Munich, Germany
https://www.cms.bgu.tum.de
andre.borrmann@tum.de

─── **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.

1 Introduction

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 has open the possibility for innovative research in the fascinating area where Spatial Information Theory and Construction Engineering overlap [1].

The paper covers a number of 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).
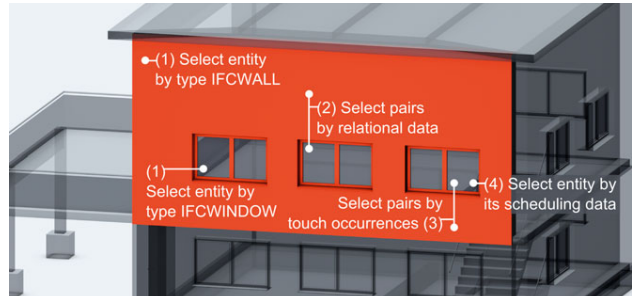
Figure 1 Querying building models by applying spatial operators, from [11].
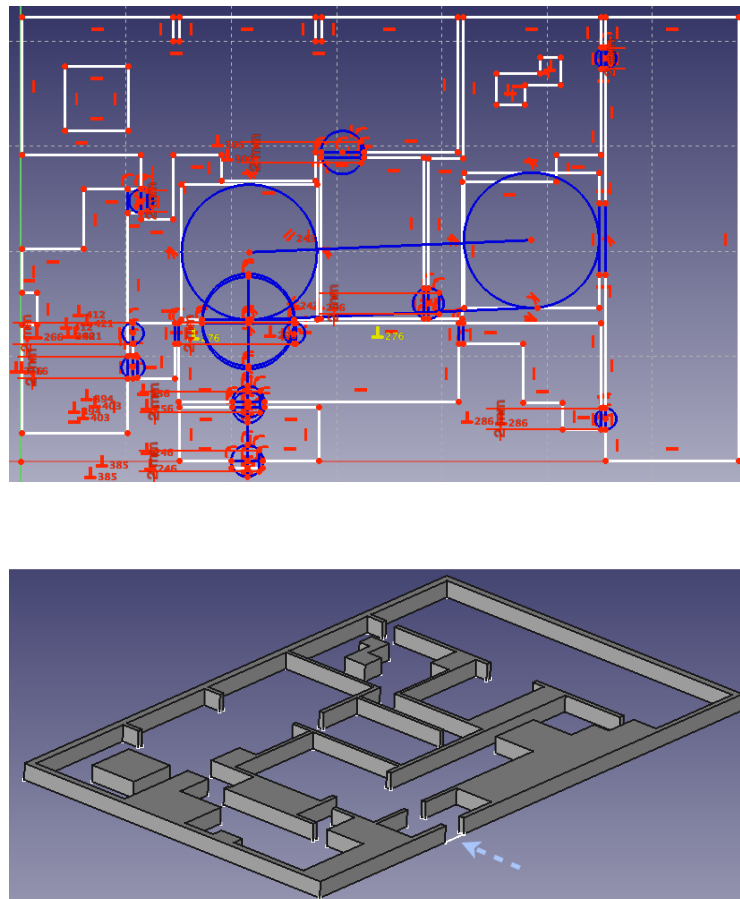
Figure 2 Interactive parametric FreeCAD sketch that maintains visibility, movement, and qualitative size constraints and the building model extruded from it. From [21].

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 detaili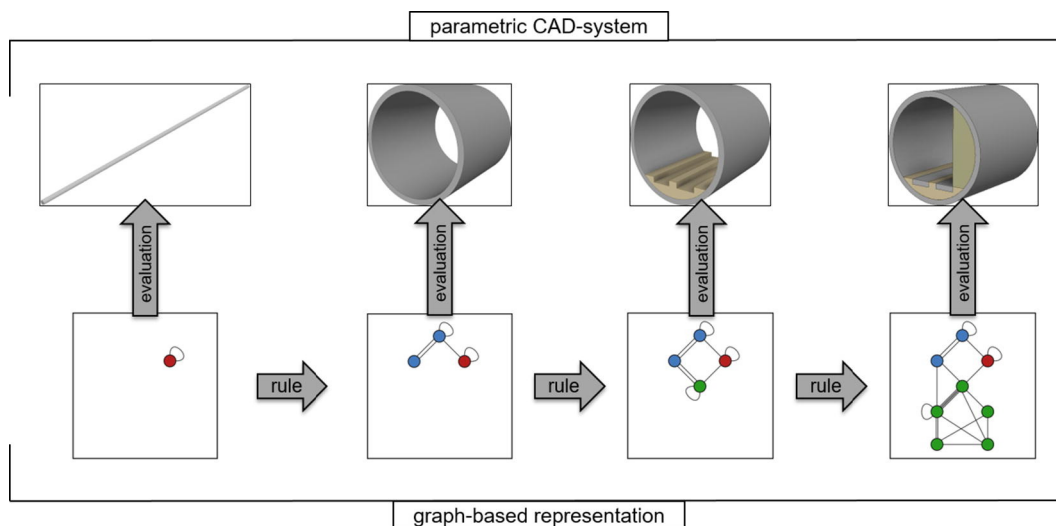ng of building components [25]. To this end, parametric modelling engines were coupled with graph transformation systems. The talk will give an overview on the progress achieved and discuss the remaining challenges.

Figure 3 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].

Element Group	Element description	#	Bridge	Primary Girder	Capping beam	Transverse beam	Deck slab panel
				111		201	301
Bridge	Bridge		00000000000000yy00	xnxnnyxxnnnynxnynn	xxnnnnxxnnnnyxnyxn	nnnnnnxxnxnnxxnynn	xxxnnnxxnnnnynynnn
Deck Superstructure	Primary Girder	111	xnxnnyxxyy0000ynyy	nnnnnnyxxxnynxnnxx	nnnnnnnxxnnynxnnyx	yynnnnnxnnnnxxnnxx	yxxnynyynnnynynnnn
Deck Superstructure	Capping beam		xxnnnnxxyy0000ynyy	nnnnnnyxxnynxnnnx	nnnnnyyxxnnynxnnx	nnnnnxyynnnnxxnnnx	nnnnnnnynnnynynnn
Deck Superstructure	Transverse beam	201	nnnnnnxxyy0000ynyy	yynnnnnxxyynynxnnxx	nnnnnxynyynnnyxnnyx	nnnnnyyxxnnxxnnxx	nnxnxnnynxnynnnxn
Deck Superstructure	Deck slab panel	301	xxxnnnxxny0000ynyy	yxxynnynnynynxnnny	nnnnnnnnynnynnnyx	nxnxnnnnnxnnxxnnxy	xxxnnnyxnxnynnnxx
Substructure	Bearing		nnnnnnxxny0100ynyy	ynnnnnxynynynxnnyy	xnnxnnxnnynynxnnyy	nnnnnnxcnynnxxnnxy	nnnnnnxynynynynnyx
Substructure	Plinth (capping beam)		xnnnnnnxxny0000ynyy	nnnnnyxnynynxnnny	ynnynnxnnynnyxnnyy	nnnnnnxnxnnxxnnxy	nnnnnnxynxnynnnxx
Substructure	Plinth (abutment)		xnnnnnnxxny0000ynyy	nnnnnnxynynynxnnny	nnnnnnxynnynynxnny	nnnnnnxnnxnnxxnnxy	nnnnnnynxnynnnxx
Substructure	Shear Key (capping beam)		xxnnnnxxny0000ynyy	nnnnnnxxnynxnnnxx	ynnxnnnxnynnynnyn	nnnnnnxxnxnnxxnnxy	nxnnnnxynnnxnnnyy
Substructure	Shear Key (abutment)	401	xxnnnnxxny0000ynyy	nnnnnnxxnynxnnnx	nnnnnxxnynnynxnnyx	nnnnnnxxnxnnxxnnxx	nnnnnnynxnynnnyn
Substructure	Abutment	403	xxxnnnxxyy0000ynxy	nnnnnnnxxxnynnnnx	nnnnnxyxxnynxnnxx	nnnnnnyxnxnnxxnnxx	nnnnnnnynnnnxxnnx
Substructure	Column	405	xxynnnxxyy0000ynxy	nnnnnnxxnynynxnnnx	ynnnxnnyxnnynxnnnn	nnnnnnnynnnxxnnxx	nnnnnnnynnnxnnnxn
Non-structural	Lamp post		xxxnynxxxy0000ynyy	nnnnnnxnynxnnxn	nnnnnyxnynynynn	nnnnnnxxnnxxnnnx	nnnnnnnnxnynnnyy
Non-structural	Safety barrier	507	xxxnyxxxyy0000ynyy	nnnnnnyxnynxnnxx	nnnnnxnxnynnyxnnyx	nnnnnnxxnxnnxxnnxx	nnnnnnynnxnynnynn

Figure 4 Condition matrix for identifying the semantics of geometric objects of scanned bridges, from [20].

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).

Figure 5 VCCL program for checking a building model for compliance with accessibility regulations, from [19].

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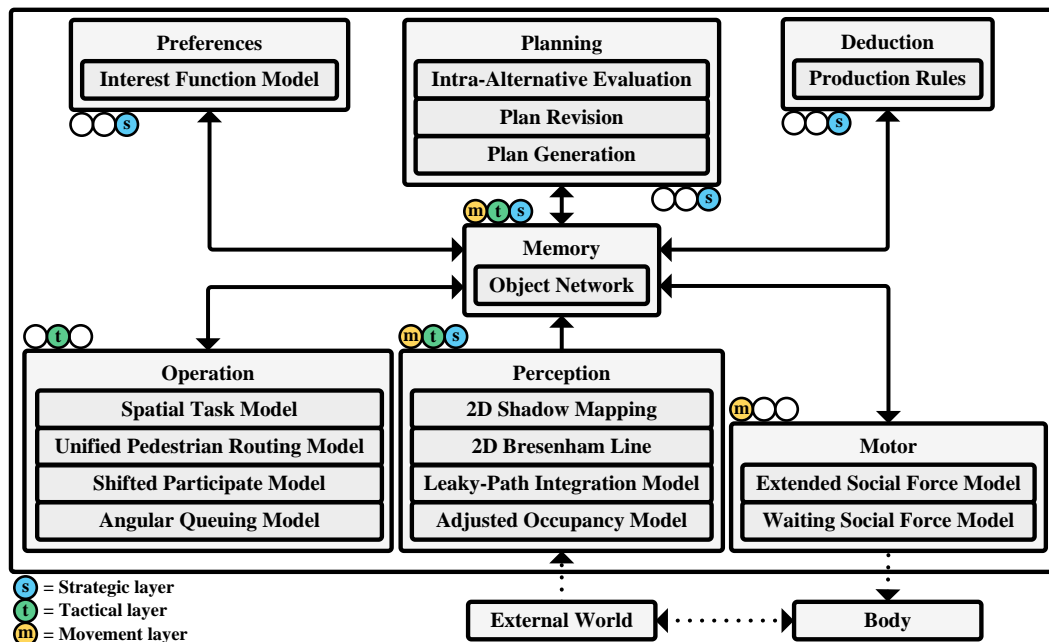
Figure 6 Architecture of the pedestrian dynamics simulator MomenTUM that relies on cognitive principles for modeling wayfinding behavior, from [14].

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

1 M. Bhatt, A. Borrmann, R. Amor, and J. Beetz. Architecture, Computing, and Design Assistance. *Automation in Construction*, 32:161–164, 2013. `doi:10.1016/j.autcon.2013.01.001`.

2 D. H. Biedermann, P. M. Kielar, A. M. Riedl, and A. Borrmann. Oppilatio+ - A data and cognitive science based approach to analyze pedestrian flows in networks. *Collective Dynamics*, 1:1–30, 2016. `doi:10.17815/CD.2016.9`.

3 A. Borrmann and E. Rank. Specification and implementation of directional operators in a 3D spatial query language for building information models. *Advanced Engineering Informatics*, 23(1):32–44, 2009. `doi:10.1016/j.aei.2008.06.005`.

4   A. Borrmann and E. Rank. Topological analysis of 3D building models using a spatial query language. *Advanced Engineering Informatics*, 23(4):370–385, 2009. `doi:10.1016/j.aei.2009.06.001`.

5   A. Borrmann, S. Schraufstetter, and E. Rank. Implementing Metric Operators of a Spatial Query Language for 3D Building Models: Octree and B-Rep Approaches. *Journal of Computing in Civil Engineering*, 23(1):34–46, 2009. `doi:10.1061/(ASCE)0887-3801(2009)23:1(34)`.

6   A. Braun, S. Tuttas, A. Borrmann, and U. Stilla. A concept for automated construction progress monitoring using BIM-based geometric constraints and photogrammetric point clouds. *ITcon*, 20(8):68–79, 2015.

7   A. Braun, S. Tuttas, A. Borrmann, and U. Stilla. Automated progress monitoring based on photogrammetric point clouds and precedence relationship graphs. In *The 32nd International Symposium on Automation and Robotics in Construction and Mining (ISARC 2015)*, Oulu, Finnland, 2015.

8   S. Daum and A. Borrmann. Checking Spatio-Semantic Consistency of Building Information Models by Means of a Query Language. In *Proc. of the International Conference on Construction Applications of Virtual Reality*, 2013.

9   S. Daum and A. Borrmann. Simplifying the Analysis of Building Information Models Using tQL4BIM and vQL4BIM. In *Proc. of the EG-ICE 2015*, Eindhoven, The Netherlands, 2015.

10   S. Daum and A. Borrmann. Enhanced Differencing and Merging of IFC Data by Processing Spatial, Semantic and Relational Model Aspects. In *Proc. of the 23rd International Workshop of the European Group for Intelligent Computing in Engineering*, Kraków, Poland, 2016.

11   S. Daum, A. Borrmann, and T. H. Kolbe. A Spatio-Semantic Query Language for the Integrated Analysis of City Models and Building Information Models. In A. Abdul-Rahman, editor, *Advances in 3D Geoinformation*. Springer International Publishing, 2016.

12   S. Daum, A. Borrmann, C. Langenhan, and F. Petzold. Automated generation of building fingerprints using a spatio-semantic query language for building information models. In *eWork and eBusiness in Architecture, Engineering and Construction: ECPPM 2014*, Vienna, Austria, 2014.

13   Katrin Jahr and André Borrmann. Semi-automated site equipment selection and configuration through formal knowledge representation and inference. *Advanced Engineering Informatics*, 38:488–500, 2018. `doi:10.1016/j.aei.2018.08.015`.

14   P. M. Kielar and Borrmann A. Spice: A Cognitive Agent Framework for Computational Crowd Simulations in Complex Environment. *Autonomous Agents and Multi-Agent Systems*, pages 1–30, 2018. `doi:10.1007/s10458-018-9383-2`.

15   Peter M. Kielar, Daniel H. Biedermann, Angelika Kneidl, and André Borrmann. A unified pedestrian routing model for graph-based wayfinding built on cognitive principles. *Transportmetrica A: Transport Science*, 14(5):406–432, 2017. `doi:10.1080/23249935.2017.1309472`.

16   Peter M. Kielar and André Borrmann. Coupling Spatial Task Solving Models to Simulate Complex Pedestrian Behavior Patterns. In *Proc. of the 8th Conference on Pedestrian and Evacuation Dynamics*, 2016.

17   Peter M. Kielar and André Borrmann. Modeling pedestrians' interest in locations: A concept to improve simulations of pedestrian destination choice. *Simulation Modelling Practice and Theory*, 61:47–62, 2016. `doi:10.1016/j.simpat.2015.11.003`.

18   C. Preidel and A. Borrmann. Towards code compliance checking on the basis of a visual programming language. *ITcon*, 21:402–421, 2016.

19   C. Preidel, S. Daum, and A. Borrmann. Data retrieval from building information models based on visual programming. *Visualization in Engineering*, 5(18):1–14, 2017. `doi:10.1186/s40327-017-0055-0`.

20   R. Sacks, L. Ma, R. Yosef, A. Borrmann, S. Daum, and U. Kattel. Semantic Enrichment for Building Information Modeling: Procedure for Compiling Inference Rules and Operators for Complex Geometry. *Journal of Computing in Civil Engineering*, Vol. 31(Issue 6 (November 2017)), 2017. `doi:10.1061/(ASCE)CP.1943-5487.0000705`.

21 C. Schultz, M. Bhatt, and A. Borrmann. Bridging qualitative spatial constraints and feature-based parametric modelling: Expressing visibility and movement constraints. *Advanced Engineering Informatics*, 2015. `doi:10.1016/j.aei.2015.10.004`.

22 Dominic Singer, Maximilian Bügler, and André Borrmann. Knowledge based Bridge Engineering - Artificial Intelligence meets Building Information Modeling. In *Proc. of the EG-ICE Workshop on Intelligent Computing in Engineering*, Krakow, Poland, 2016.

23 S. Tuttas, A. Braun, A. Borrmann, and U. Stilla. Acquisition and Consecutive Registration of Photogrammetric Point Clouds for Construction Progress Monitoring Using a 4D BIM. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 85(1):3–15, 2017. `doi:10.1007/s41064-016-0002-z`.

24 S. Vilgertshofer and A. Borrmann. A Graph Transformation Based Method for the Semi-Automatic Generation of Parametric Models of Shield Tunnels. In *Proc. of the EG-ICE Workshop on Intelligent Computing in Engineering*, Krakow, Poland, 2016.

25 S. Vilgertshofer and A. Borrmann. Using graph rewriting methods for the semi-automatic generation of parametric infrastructure models. *Advanced Engineering Informatics*, 33:502–515, 2017. `doi:10.1016/j.aei.2017.07.003`.