論文の内容の要旨

A Generative Approach to Architectural Form using Design Constraint Systems
－Case Studies in Vernacular Compounds in Burkina Faso

（設計制約条件を用いた建築形態への生成論的アプローチ
－ブルキナファソの伝統的なコンパウンドを事例にして）

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The invention of the computer caused profound transformation in most fields of human activity. Architecture is not an exception. Computer aided architectural design programs, for example, make it possible to calculate all plans and sections as well as three-dimensional models from a single digital model. This model can easily be edited, evaluated and optimised before the actual construction, thus greatly simplifying the work process. However, even though architects use the computer extensively, its use in many aspects only mirrors the functionality of traditional non-digital tools, like the drawing board, or wood and paper models. The most central and difficult parts of architectural design, in other words, the decision process concerning the structure of an architectural entity, or the design of the actual shapes used to realise it, are in most cases still accomplished without the help of computers.

This thesis addresses the limits of present computer use in architectural design cited above from an interdisciplinary point of view, and offers the application of methods from artificial intelligence, formal linguistics and computational geometry as problem-solving strategies for architectural design. It proposes design constraint systems (DCS) as a grammar-based approach for the formalisation of the structural and morphological knowledge underlying architectural 'design families' (for example, buildings of a certain function, architectural style, or type). The grammars resulting from this approach can be seen as formal theories of these design families.

In addition to being of interest as theories of design families, these formal theories can also be used in combination with strategies of evolutionary computation to generate new instances of the design families, and thereby become a tool to support the architect in the difficult task of solving design problems. Other examples of their application include parametric house designs, and the manipulation of architectural structures and shapes on an abstract level, facilitating their evaluation, and therefore the solution of complex problems. In combination with methods of digital simulation and fabrication, this creates an interesting range of possibilities for the architectural practice.

DCS, the approach to grammar-based generative architectural design introduced in this thesis, are based on three different levels of abstraction connected by two subsystems mediating between them. The *design* level corresponds to the actual three-dimensional shape; the *design structure* level represents an abstract description of the design; finally, the level of the *design grammar* encompasses the rules and constraints that define the design structures in a generative way. The component responsible for the generation of the design structures from the design grammar is modelled as a type constraint system (TCS) and inspired by formal linguistic approaches such as the well-known head-driven phrase structure grammar (HPSG). The component used for the translation of the design structures into the visual models of the designs, on the other hand, is implemented as a formal language with a three-dimensional semantic, and is referred to as the design description language. This component is part of the architectural model and depends on the design family modelled.

To demonstrate the developed DCS, and their application to complex architectural examples, the theoretical description of the system is followed by a case study. The case study used a family of traditional architectural compounds from Burkina Faso, characterised by irregular circular shapes, which are difficult to model with conventional computer-based design approaches. Four representative compounds of different sizes and structures were selected for the case study. A design description language based on methods from computational geometry was developed for the description of their shapes. Bezier-curves were used to model the irregular circular shapes of the compounds; Boolean operations were used to calculate overlapping and adjacent areas; and the extrusion of two-dimensional

ground plans into three-dimensional structures was used to generate the final models. Making use of the abstract descriptions defined by this language, a design grammar was then written, to generate the design structures, which describe the compounds in terms of the design description language. Finally, the design grammar was constrained to generate structures similar to the compounds in the corpus to prove the viability of the model.

Outline of the thesis structure

The thesis is in four main parts: an introduction to grammar-based architectural design, a description of DCS, a case study where a DCS is used to model a family of traditional compounds from Burkina Faso, and a conclusion.

I. Introduction

The field of grammar-based generative architectural design is introduced, together with other research and literature related to the current research. The main differences between the symbolic approach introduced in this thesis and other related fields are explained.

II. The formal description framework

A short overview of the formal description framework is followed by a detailed description of its components. The first chapter introduces type constraint systems, and explains type hierarchies, typed feature structures, type constraints, resolution, random and evolutionary resolution strategies and numeric constraints.

Chapter 2 introduces design description languages by explaining their function in the system, their general concepts and some simple examples for their application to the description of different domains.

Chapter 3 gives a more detailed example of a minimal DCS, which models simple towers composed from stacked cubes, to illustrate through a concrete example how design grammar and design description language work together to define a design family.

III. Case study: A model of traditional compounds from Burkina Faso

Following the introduction of DCS in Part II, Part III shows how such a system can be applied to the description and modelling of a group of traditional African compounds from Burkina Faso.

In Chapter 4, the compounds selected for the corpus are briefly introduced, while Chapter 5 explains the design description language for their structure and morphology, which are both characterised by overlapping irregular circular shapes, organised in several hierarchical levels. Chapter 6 gives a general grammar for the generation of design structures for this kind of circular morphology. Finally, the general grammar is customised and further constrained to mirror the individual settings corresponding to the four example compounds, thus proving that the rules and constraints constituting the system are able to generate models similar to the original compounds in the corpus.

IV. Conclusion

The findings of the research are summarised, followed by a section on future directions, which discusses the limits and possibilities for further research and development.