Logical models for rule-based CAAD

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Summary

The aim of this paper is to present the basic results of a theoretic approach to represent architectural individual forms in CAD systems. From the point of view of design methodology and problem solving these descriptions might be conceived as parts of possible environments satisfying the laws of some design theory in logical sense. This paper describes results in a series of logical studies towards rule and knowledge based systems for design automation.

The effective use of programming languages and computers as design aids in architecture presupposes certain cababilities to articulate built environment logically. The use of graphic languages in the description of environmental items e.g. buildings might be theoretically mastered by formal production systems including linguistic, geometric, and spatio-material generation.

The combination of the power of formal mechanisms and logical individual calculus offers suitable framework to generate arbitrary e.g. free spatial compositions as types or unique solutions. In this frame it is natural to represent in a coherent way very complex hierarchical parsing of buildings in explicit form as needed in computer implementations.

In order to simulate real design work the individual configurations of possible built forms should be designed to satisfy known rules. In the preliminary stage partial solutions to design problems may be discussed in mathematical terms using frameworks like lattices, graphs, or group theoretical considerations of structural, functional, and visual organization of buildings.

The capability to produce mathematically sophisticated geometric structures allows us to generalize the approach further. The theoretical design knowhow in architecture can be partly translated in to some logic and represented in

a knowledge base. These rules are used as selection criteria for geometric design candidates in the sense of logical model theory and mathematical optimization. The economy of the system can be developed by using suitable conduct mechanisms familiar e.g. from logic programming.

The semantics of logic offers a frame to consider computer assisted and formal generation in design. A number of semantic and pragmatic problems, however, remain to be solved. In any case conceptual analyses based on logic are applicable in order to rationally reconstruct architectural goals contributing to the quality of environmental design, which should be the main goal in the developement of design systems in near future.

The formal language analogy in architecture

Introduction: The mathematical theory relevant to architectural studies consists of the algebraico-logical, geometrico-topological, and numerico-analytical branches. Although some of these areas may seem quite fictive and avantgarde, it is evident that in architecture mathematics has always played a considerable role. Traditionally many fields like symmetry theory, descriptive geometry, and calculus of proportions have been applied. A truly revolutionary influence has been seen as a result of application of discrete and structural mathematics to environmental analysis and design. In the sequel we discuss some of the principal algebraico-logical questions in architectural computing.

The hierarchy of architectural forms: In architecture one may differentiate forms of varying level like building blocks, constructions or spatial units, buildings and possibly higher order constellations such as districts or styles and finally the whole architecture as a cultural totality. A single item may be parsed to its constituents with respect to practical requirements in reference of some principal hierarchy of values and objectives. For exact studies the complex situation may be uniquely formalized as follows. Building blocks are defined as elements in a building relation defined between a certain space and materials. It is convenient to use as space a part of parts of the usual linear space and as materials some real repertoire. From the basic building blocks we are capable of forming composed structures, called constructions, with the aid of composition operations. In designing buildings we might, instead of a building block repertoire, use some higher order repertoires. The formal architecture can be defined as a subset of all structures or constructions obtainable by generation using the basic sets and operations available. The subsets in an architecture might be interpreted as a style, a set of desired attributes etc. (Oksala, 1977, 1978, Stiny and Mitchell, 1978)

An algebraic structure in architecture: The particular structures of interest, namely constructions, were formed with the aid of composition operation 'o from building blocks. We are now capable of making indefinitely new constructions of constructions within a given architecture. Mathematically the composition operation is associative and one may apply the theory of semigroups if needed. A semigroup of constructions is an algebraic structure or system. It is possible to form other similar algebraic systems and to study other operations like joinings and juxtapositions. From this point of view practical CAD systems may be conceived as complex systems with many operations defined on geometric units. In order to master the possible generations in a mathematical system corresponding to some CAD-system we may use equivalence and part relations. By applying the theory of equivalence and ordered sets we might consider the items as making up classes and class hierarchies, and manipulate the classes of objects on higher abstraction levels. Theoretically the formation of solution libraries in CAD-work is based on such notions. The production of architectures of complex objects is mastered by means of grammars and object-oriented techniques.

Building and design grammars: In reverse direction to the parsing of an item one can also use formalisms to produce new items. For this purpose it is convenient to use combinatoric and generative systems. Based on the kinds of before mentioned libraries of units we may use production rules, which tell us which unit is replaceable by an other and denote such a rule with an arrow. The contextual composition knowhow is expressed by explicit rules regulating the generation. In order to define a building grammar we need the following kinds of entities: a building block repertoire, an auxiliary repertoire, a base stone and a set of production rules and constraints. For much a grammar an architecture produced by it becomes associated (Oksala, 1977). The execution of productions is conveniently represented by derivation trees. Analogous formal productions may be performed in design by using graphic configurations (Stiny and Mitchell 1978) or linguistic concatenations in symbolic descriptions (Coyne et al. 1987). The results achieved by formal production are transformable as Well as potentially acceptable by special devices like transducers and acceptors.

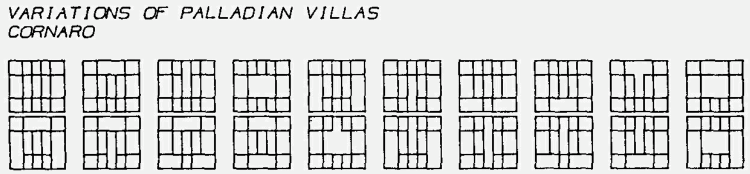

Figure 1 Palladian villas generated by a grammar as compositions of walls.

An individual model of a natural building

Introduction: In order to apply formal production in architectural design in a more advanced way the basic problem is typically the modelling of a building. Then the first task is to master its individual constituents. In the case of natural planning we do not use one universal repertoire of building blocks, but rather a set of appropriate repertoires. Compositional knowhow then corresponds to the build up of a house. This is a minimal package of knowledge to design the building and to generate all states of affairs of deeper knowledge structures. Next we discuss basic location relations to which special subarchitectures like mass, space, interior architecture etc. are associated. These correspond in typical subproblems in building design familiar e.g. in expert system implementations of today (e.g. Navinchanda and Marks, 1987).

The design of shape units: A site for a building may be interpreted as a location relation between a given place and landscape elements. This basic relation, when manipulated compositionally, leads to the concept of formal landscape architecture. In a similar way the site as a new space and the variation range of mass units as the material one can define mass architectures. Then certain mass units are composed and some subset of alternative mass formations is a formal architecture. Building designs at this stage are parsed e.g. like site o roads o mass etc. In further studies one may restrict oneself to the mass and the repertoire of alternative room spaces. Some acceptable subset of all room compositions formed out of the resources available is a formal space architecture. Typical parsing of space graphs includes formulae like: outside walls o interior walls o system of natural lightning etc. Design studies in a building map should be further restricted to rooms. For a room as the space and alternative equipment as the material one can derive interior designs. A subset of alternative compositions is an interior architecture accepted by the recognizer used. Parsings at this stage are of the form: walls o equipment o furniture etc. (Oksala 1978)

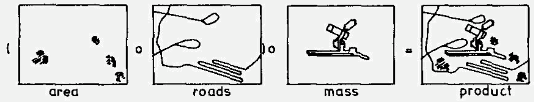

Figure 2 A possible parse of the Sanatorium at Paimio (A.Aalto)

The design of material structure: Above we have characterized the quite abstract design of architectural forms in their shapes. In order to build up an accurate design corresponding to the sketches we now define some more tangible forms. With the aid of underlying space of building and the available material we specify the location function of real building blocks. At this level one may define alternative material architectures by making legitimate combinations of material units available. Based on the materialized places of a building and known detail solutions one can form a detailed distribution map. This leads to the concept of detail architecture in which the knowledge about functional performance of details define our possibilities. Detail architectures may be conceived as derivations of the material ones. Analoguous to the constructions before mentioned, but at quite a high level of abstraction, on detailed building parts one may form a distribution map of known work routines and compose actions of workers (compare Coyne et al. 1987 (6)). Some subset of possible compositions is then a controlled work phase.

The planning of use: When defining the shape and detailed structure of a building one has to make preliminary decisions about its use under the constraints of client's briefing. Although the concretization of use is difficult due to the dynamic character of events, the problem will be considered in order to allow for a coherent treatment. Between the parts of building one imagines and the activities intended one may define a space action map and represent the spatial distribution of activities. A subset of possible action compositions is acceptable as a basic idealization of the shape of space needed. On higher levels one may consider the whole spatial structure with activities. Then one associates the structured set of activities with the space unit structures and obtains an activity architecture as an acceptable subset of possibilities. A building offers spatial resources for events and one may assign to it qualities that are appropriate for desired perception conditions. Then one may compose labels of quality knowledge fixed for given places. Such entities include well known norms of decibel, k-value, Q-value, load, light values etc. Some subset of all possible labellings is an acceptable solution set for further work. (Oksala 1978b)

How to use individual models: The word architecture has been used somewhat methaphorically in order to view architectural solutions as compositions. Our approach allowed us, however, to consider generation at different abstraction levels after modularizing the apace, filtering properties and using groups of units. The design sequence used was also a standard convention and in order to simulate real planning, manufacturing, and use of buildings one can start from any partial locational decision. In our approach it is at the same time possible to consider real and desired structures and compare them. The satiafiability of special design theories in individual structures is a key question and in this context visual geometric relations, physical constraints, and activity networks are typical.

Algebraico-logical models in architecture

Introduction: By means of formal language theory applied to architecture one can produce, transduce, and accept basic sets of architectural items. Such a mini-theory is applicable to natural design. On the other hand the theory might be extended from space of things to cover the space of states of affairs or even to allow discussion of events and actions. Next v consider some relevant algebraic models in architecture satisfying algebraic theories and conditions of formal optimality. Then we discuss some logical extensions.

Units and properties in design: Although the time-sequential and procedural thinking in construction is central, we might for many purposes forget the knowhow of built up order. The richness of parts in a completed spatial design is mastered by means of individual calculus (see Oksala, 1977 and Stiny, 1982). Then we introduce, as is customary, a basic relation 'have a common part' for environmental items and define relations like 'is separate', 'is part' and 'is identical with' etc.. These basic relations lead us to the notions of operations like 'complement', 'common part product', 'compositional sum', 'difference' etc.. The definitions allow us to associate to every item a lattice of its parts and to apply top down or bottom up parsing as is used in CAD. In an individual lattice the chains from zero to one correspond to constructions in the theory of formal architectures. In applications one can define filters and ideals and consider properties of parts. In fact the lattice theoretic structure is applicable in the case of properties and events as well.

Relations in design: In order to analyze various types of relations in the spatio-temporal universe, special attention should be focused first of all on binary relations and corresponding theory of graphs as a part of general theory of relations (e.g. Earl, March, 1979). In a more accurate analysis of constructions one may consider the production action graph. In certain cases it may be embedded in parsed lattices of the item concerned. If we consider the ready product, a lot of graphs are associated to the cell tissues of the building. Similarly the building in use contains networks associated with actions, which are analyzable by graph theoretic means. Functional connection graphs are often in an interesting dual relation with the cellular ones. Many higher order relations can be considered in analogous ways when necessary.

Transformations in design: The operations and functions hidden in a design product and in its production sequence can be investigated with theories concerning algebraic structures. E.g. in the case of binary operations and transformations, group theory is at hand. In fact the theory of formal architectures is based on the theory of semigroups. We are dealing, so to speak, with compositional construction semigroups. To this basic structure one can associate a number of special joining operations and transformations for building blocks, constructions and architectures. An important set of transformations is associated with building products in the form of symmetry groups acting on architecture as is well known from historical context (Weyl, 1952). Also the additive groups of individuals have certain connections to classical formal analyses in the history of art and artifacts. In this part of architectural design CAD systems are really an excellent aid in formal manipulation.

Mathematical versus practical knowledge: Although the analyses of individual forms, geometric graphs, groups, etc. have direct relevance to natural architecture, such a formal approach can offer only accidental material in practice. Our design at this stage are only satisfying mathematical requirements or goals formulated with partial optimization techniques. A highly developed generative theory contains semantics of description language, which leads to the notions of architectural semantics and to the possibility to interpret real architectural theories in buildings in an exact way. The specific results, which are obtained trough formal algebraic models can be collected and integrated into a comprehensive logical approach appropriate to formalization of general and specific theories of planning and design. In principle we have a set of unique experiences about environmental phenomena. By means of our perception and description capabilities we can start to build up, more or less universally, the logical structure of our domain i.e. the logical architecture of architecture. (Oksala, 1977)

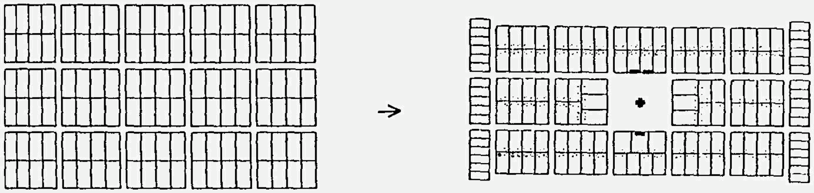

Figure 3 A mathematically defined product and a transformed product of a rewritten procedure in a form of a town plan of old Jyväskylä (C.L. Engel) satisfying classical composition rules.

Methods based on natural knowledge and rules

Logical preliminaries: Architecture as a product of action is conceivable as an articulated field consisting of individuals, relations and mappings or transformations of parts of the world. For an experiencer with capabilities of conduct or for a designer accepting states of affairs or events in architecture an experiment dealing with building corresponds to a filter in the solution space and, in the complete case, an ultrafilter. In order to model architecture the decisive point is what is selected, where and when in view of realizing the objectives. For that articulation a logical description language can be developed in terms of built or drawn form or by purely symbolic means, corresponding the range of predicate calculi. It is worthwhile to notice that in purely technical situations the first order languages containing no names of relations of relations are adequate. Even elementary artistically relevant relations are, however, of higher order type. Similarly in many actual developement projects in logic programming a variety of extensions of first order techniques are under work (e.g. Porto, 1982). The choice of planning language is free and a creative phase in the design process. All representations are, in fact, only partial and there always exists a 'real background'. The interpretations of logically expressed theories in reality are called models for our theories. For design preliminaries a number of special logics are available. In the case of spatio-temporal construction one may develop a temporal logic involving concepts like 'base stone', 'start, end of', 'preceeding' etc. (see Karlsson, 1986). For spatial relations like 'besides-', 'above', 'behind' etc. spatial logics are available. The need of such special logics for experts in design is many splendored and we can only mention here the variety of notational knowledge representations and design languages familiar in practice.

Design rules and knowledge: Since the conception of systematic methodologies there has been extensive discussion about the possibility of producing designs by starting from requirements abstracted in one way or another from the acceptable reality. This ides is comparable to the use of declarative rules in problem solving and the rule-based design ideology. Such theories are connected to the early views of Wittgenstein especially to his picture theory of language (e.g. March, 1976 pp. 2 ff). The idea to use reverse logical descriptions in planning is, however, overoptimistic. Sentences expressing desires, requirements, laws, and other natural planning rules are in their logical form not objective and isomorphic pictures of reality, but rather subjective and partial receipts guiding the production process whithout a well understood 'background'. A set of rules describing a design object, can be understood in a process, in which one constructs all alternative partial but complete object descriptions into which the rules are embeddable. In a more general context these sets of descriptions are the so called Hintikka model sets (see e.g. Oksala, 1977). Thus from a purely logical point of view the transformation of rules into a design is not a simple and easily mechanizable process. There is always a part, which we are not cabable of formalizing and it should be left to a creative architect in order to find new solutions and create real background for buildings, where the checklist requirements are satisfied on their own level of value. Such a work presupposes rule-relaxations based on value systems. Thus design proposals are normative and not directly derivable from facts.

Intuitive versus systematic expertice: By logical means one may study the satisfiability of design theories, which allows building up a variety of expert systems. This presupposes an extensive study of design process and criteria. We know that the formalization of real goals and principles is tedious if we think of motivation, impression and success in design. E.g. in architecture we master rules guiding some technical or functional performance. At the same time experienced quality and architectural principles are quite problematic to reconstruct. In any case the amount of alternatives and rules to be investigated for systematic approach is astronomous. What then makes it meaningful to develop design systems at the same time when in intuitive design an expert directly sees a solution and can explain its advantages? A rational reconstruction of the design theories allows us to construct simple devices and at the same time to understand more deeply the etheric aspects of architecture. Artificial and human intelligence may proceed hare in hand.

Fuzzy future: By using architecture as a language in a way analogous to using language as a model, we can extend our discussion to cover architectural semantics and pragmatics. The theory of architectural production can be developed by introducing probability and information measures for fictive and empirical targets. In such a frame it becomes meaningful to analyze such fuzzy aspects like the use of themes in a cultural field of artifacts, to develop, stylistic indices, or to discuss design goals by means of utilities in social context. To understand architecture deeply in connection with future possibilities one might apply modal logic. Logical approaches offer many tools to develop design technology, but it also shows its own limits. In that it paves way for human creative abilities to better master intentionally the art of design with technical aids. Thus we should master the rules and conduct in design with the same accuracy as we today master some single solutions.

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