Building Form Modelling in Architectural Design Education

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Abstract

The paper describes an approach to architectural design education within the tradition of grammatical studies. It exploits certain attributes of computer modelling and computer graphics programs as an environment to convey architectural knowledge. The formal representation of designs and the manipulation of these representations are proposed as architectural knowledge and one of the foundations of design. Computer-based three-dimensional formal analysis of designs is employed as a technique for the acquisition of knowledge of classes of designs. Through formal analysis certain general models of building form are postulated. The classes of building form models in architecture are elaborated, and their relation to the concept of architectural syntax is discussed. The computational significance of building form modelling is considered, and the relevance of formal modelling in design education is discussed.

Architectural Knowledge as a Foundation of Design and Design Education

At the workshop meeting of ECAADE '87 in Zurich (Kramel, 1987) a significant topic of discussion was the emerging role of the computer in design education within the architectural curriculum. At this meeting, as well as at subsequent meetings of ECAADE and ACADIA, it had become apparent that a new role was emerging for the computer in architectural schools as an environment for the study of design. What was crystalizing in the late Eighties was the intensive development of computer-based architectural formal studies related to the teaching of design *per se.* From its research-oriented origins in universities such as UCLA and Carnegie Mellon, the use of the computer as a vehicle for the teaching of architectural design principles has now become well-established as a significant part of the curriculum in many architectural schools (McCullough, Mitchell, Purcell, 1990).

Most of this work has retained its design research orientation. It is generally based upon grammars and formal languages, and deals with studies in areas such as composition and transformational operations (Schmitt, 1988; Radford and Stevens, 1987). Recently the work has been collectively referred to as 'grammatical approaches in design education' (Woodbury,1991). Because of the analytical and rigorous orientation to design research which is characteristic of the approach, the dual functions of design education, and the generation of knowledge through design research are both satisfied.

Certain of the teacher/researchers in the field have recently begun to change emphasis from *ad hoc* studies of specific works to the formalization of general formal knowledge in design (Flemming, 1990; Madrazo, 1990; Oxman and Oxman, 1991). In this paper we present an approach to the formalization of general models of building form in architecture. The formulation of the knowledge of building form models is the result of student research within a course which employed computer-based three-dimensional formal analysis in the study of architectural form. The explicit goal was to analyze a range of classes of building form according to instances of these classes in the work of specific architects. Through the analysis of a range of specific instances, we have attempted to define the design principles of the class.

The concept of models of architectural representations is itself a research subject of significance in CAAD (Eastman, 1990). In the current research we present a preliminary proposal for classes of general building form models. The particular emphasis has been to establish models which may be useful in design computation.

The Computer as an Environment for the Acquisition and Formalization of Architectural Knowledge

Underlying the development of these approaches and their successful integration into the architectural curriculum has been an implicit critique of the conventional design studio as a venue for architectural design education. Design studio orientation rarely makes explicit the methodological aspects of designing or the knowledge employed in design. The teacher generally acts as design critic rather than directly teaching the knowledge and methodological aspects of designing.

If the progressive acquisition of design knowledge is what design education is about, why not make design knowledge the explicit content of design education. At least in the sense of the formal knowledge of designing, such as composition and spatial organization, this is exactly what is achieved through computerbased grammatical approaches to design education. We have defined architectural knowledge as the knowledge of representations of architectural and urban form. and design knowledge as the knowledge of the manipulation of these representations in processes of design such as generation, refinement and adaptation (Oxman and Oxman, 1989, 1990). Grammatical approaches to design education exploit a syntactic paradigm in order to make this knowledge explicit. The transformational representation of grammars are frequently used to represent the formal characteristics of architecture and their generative operations in design (Stiny, 1980a; Mitche11, 1990).

Computer graphics programs provide an environment in which the modeling of formal representations of architecture can he made to effectively convey the basic principles of architectural composition. The computer, given the ability to execute complex design operations such as operations of symmetry, scaling, substitutions, parametric and geometric transformations, can employ analysis to simulate the synthesis of designs. The analytical reconstruction of element vocabularies and generative operations conveys considerable explicit knowledge about architectural design. In working with computers. the representations, the principles underlying classes of representations and the operations are the content of rigorously formalized knowledge.

Formal analysis and the formalization of knowledge may he seen to serve two purposes. The first is the pedagogic function of computer-based design studies. In the electronic processing of designs, the resultant image is the product of building the representations and procedures of electronic processing. It is the interaction with the computer in preparing the processing which is the source of design knowledge. In the architectural curriculum, the acquisition of this knowledge base may becomes one of the objectives of computer graphics-based design studies. This is particularly the case with configurative and compositional aspects of architectural design, which can be most effectively modelled grammatically.

If the computer fulfills a pedagogical function by providing access to the knowledge structures and operations of design, it fulfills the complementary role of generating knowledge for design computation. Grammars themselves are an example of the modeling of designs through a formalism which can be employed in the computation of formal generation. In the current research we have explored the syntactic representation of general classes of building form as a type of knowledge in design and design computation. Through analytical studies, we are attempting to formalize these classes of design, their compositional characteristics and their characteristic design operations.

Architectural Principles in the Computer Age: Building Form Models as Architectural Knowledge

Building modelling is a significant research field in architectural computing (Eastman, Bond and Chase, 1991). Among research areas in modelling are geometric modelling (Kalay, 1989), component modelling (Harfmann and Chen, 1990) and performance modelling (Clarke and Maver, 1990). The present research is an approach to modelling principal classes of building form based upon compositional and organizational principles. Building form models are distinct from other approaches to building modeling in computers. Rather than the modelling of physical building elements, or simulating performance, this is modelling the design principles of general, recurrent classes of building designs, models which formalize knowledge of characteristic design operations within classes of designs.

Building form models formalize basic compositional principles as well as the design procedures which generate, refine and adapt form according to these principles. For example, within the class of centralistic layered plans we can identify certain principles of composition and massing. Furthermore, we can establish models of the design refinement sequence which can generate such designs within the class (Oxman and Oxman, 1991). Such models can formalize bodies of architectural knowledge including plan types, massing, the syntax of elevations, etc. for classes of building form. We assume that compositional principles of building form are among the important types of knowledge in building design and that one of the purposes of education is to convey these principles in a coherent way. The remainder of the paper provides an introduction to building form models as fundamental classes of knowledge, and to an educational approach which utilizes computer-based formal analysis to formulate such models.

Grammars are widely known as a representational formalism for formal languages in design. The concept of building form models assumes the possibility to formalize certain general three- dimensional languages of building form. The formalization of general languages of form in architecture can be based upon the definition of general compositional principles which are of fundamental and recurrent significance in the history of architecture. We have attempted to identify languages of form as sets of three-dimensional design principles which characterize a class of designs.

The modelling of classes of designs in architecture has been undertaken through formal analysis. The work described in this paper is an approach to the exploration of building form models in architecture through three-dimensional formal analysis in the computer. The objectives of the formal analysis were:

- define fundamental and recurrent compositional and organizational principles of architectural design through the analysis of instances;
- establish general models of classes of architectural building form through the definition of characteristic sets of formal principles;
- employ three-dimensional formal analysis as a computer-based technique to acquire knowledge of general three-dimensional languages of designs;
- formulate the underlying rules of composition which can be employed to generate form within these languages;
- utilize transformational descriptions (shape grammar formalism) as a basis for formalizing and representing the rules;
- learn to work within these languages in the computer as part of learning design.

Flemming (1990) has proposed a classification of a range of basic architectural syntactic types. The current research attempted to reconsider the basis of this classification within the framework of syntactic descriptions of design and to explore standardized rule sets. Flemming's syntactic classes are:

- **Wall Architecture:** a language of planning in which the wall is the basic element and the rules determine how the walls relate physically;
- **Mass Architecture:** hollowed out space, or figurative space as positive solids,
- **Panel Architecture:** vertical and horizontal planes are the basic elements; the rules determine how planes relate relative to an ordering system;
- **Layered Architecture:** vertical layers are the datum for composition;
- **Structure-Infill Architecture:** an expressed three-dimensional frame is the basic element;
- **Skin Architecture:** non-structural elements are independent of the structural frame.

However, this classification is based primarily upon types of physical elements (interior walls. external wall, structure-infill relationship), but also includes spatial characteristics (hollowed out space), and morphological principles (layered architecture). In working with this classification of types, we have attempted to stress the consistent use of compositional and organizational principles as the basis for the classification of models which can he employed in form generation. Types of physical elements become part of the rule sets within the class. The physical elements of the design are then ordered according to basic morphological principles of composition.

In the application of the grammar formalism to building form descriptions, there is generally a need for multiple rule sets (Stiny and Mitchell, 1978) in order to represent a complete building form. It appears desirable to attempt to establish standard rule sets for three-dimensional building modelling. Through precedent analysis we have postulated categories of standard rule sets for building form modelling. These categories will be refined in future analyses.

The following groups of rule sets appear to be among those required to model a building according to a grammar formalism:

- **Plan Type-principles** of plan morphology
- **Mass** - vocabulary of exterior volumes, roof-shape, skyline;
- **Exterior Wall** - modulation of the wall, its articulation, openings, motifs, materials;
- **Structure** - vocabulary of elements, and the relationship between structure, enclosing wall and partitioning system;
- **Interior** - vocabulary of elements and their rules of relationship.

For each rule set the steps of definition of the set generally include: underlying principle of order (e.g. a grid or axial system): syntactic sub-division of design area (e.g. the syntactic scheme of an elevation); or, definition of element vocabulary; and then rules which generate compositions within the sub-area(e.g. plan, elevation, etc.) of the building model. The goal of establishing standard rule sets is eventually to arrive at general grammar formalisms for major languages of architectural form.

In addition to syntactic knowledge, what other kinds of knowledge must he encoded in a representation of a class of building form ? The syntactic paradigm in form modeling is accomplished as a rule-based description through transformation rules. Can the modelling of building form classes be based exclusively upon syntactic, rule-based descriptions or must process descriptions and other forms of knowledge also be encoded ? Syntactic descriptions represent the finished design, but do not necessarily encode the process and logic of its generation, or the principles and strategies of adaptation which a designer learns through experience. It appears that such design processes are characteristic of classes of designs. For example, adaptive operations in one class of designs are probably different from such operations in another class of designs. In a related research (Oxman and Oxman, 199 1), we have explored the representation of design processes such as refinement and adaptation within classes of building form. A rule-based approach has been employed to formalize the operations of refinement and adaptation which appear to be characteristic to classes of designs.

A Computer-Based Approach to Three- Dimensional Modelling of Building Form Languages

The work in building form modelling was introduced by presentations on the tradition of formal studies in architecture, works and techniques in formal analysis, and the role of the computer in two and threedimensional formal analysis. This provided the theoretical background and philosophical introduction to the work. Grammars were introduced as a descriptive formalism, and the types of grammars which have been employed in building descriptions were reviewed.

Having achieved an understanding of theory and methods. the first module of study involved experimentation with a grammar-based transformational description in the three-dimensional analysis of an object in order to characterize the compositional principles which can generate objects in the class. In this case (we employed Rietveld chairs), it was possible to use well-defined compositional principles from the literature, isolate the elements vocabulary and model the composition.

It is significant to note that modeling is based upon the analysis of selected instances. This means that many instances must be analyzed before -principles" can he generalized. Consequently, examples selected for analysis were usually of designs in which systematic principles had previously been established in the literature. Another source of material was the work of architects in which a series of buildings constituted an ensemble of works within a compositional approach. Complex building types frequently required two stages of work, one of decomposition (Seebohm, 1990) and then the stage of rule formation for three-dimensional design generation which was the methodological goal of the research.

The objectives of the course were as follows:

- Explore formal analysis as a method of knowledge acquisition in design studies. Accomplish this in a computer environment employing existing two-dimensional graphics programs and three-dimensional modelling software. Explore these programs in order analyze and then rigorously describe formal operations which underlie composition in architectural design. This is done through the analysis of instances of designs in order to establish principles of composition. Explore the use of rule-based representations to describe the processes of generation.

- Simulate generation through dynamic representations (animation programs) in the computer. The sequence of steps acts as a statement of the rule system.

- Attempt to analyze prime instances as a basis for modeling the class of designs. As a research team, we attempted to work in areas which appeared to represent general, recurrent compositional principles in architecture which could he considered the basis for classes of building form. We had the advantage of beginning with Flemming's classes. We would attempt to work towards general classes of building form models.

- An eventual goal is to encode the formal knowledge of composition in a design support system in which the designer could work within the rules of the system.

The Building Form Models

The following brief description introduces some of the building form classes which we have modeled, or are currently modelling. Generally, these classes of building form were introduced to the student through lectures and literature study in which we attempted to postulate the characteristic elements and high-level principles of the class.

Architecture of Element Vocabularies

The simplest class of built objects can be described through one rule set which defines a simple element vocabulary and the configurative principles of its structuring (Stiny, 1980b). An additive architecture of basic elements.

- Planar architecture: this is a sub-class including e.g. early Miesian architecture or de Stijl, in which elements of the vocabulary are planar.

Zoned Structures of Organization

Building organizational systems in which an organizational principle is introduced in order to develop the additive or subtractive principles which operate with the zones in design.

- Circumferential layered zoning: a major architectural sub-class in which zones are layered about a core of space. Common in Ledoux' plans (Middleton,1982), in Loos' villa designs (Resselada,1987), in Kahn's civic buildings (Scully, 1962). We have done a considerable number of analyses in this class of designs. A selection from an analysis of a Kahn project is illustrated in figure 1.

- Frontal layered zoning: another major sub-class in which the zones are two-directional rather than rotational as in the previous class. Common in housing design (Habraken, et.al. 1976), and in the villas of Le Corbusier. Transformational space in frontal layered zoning is characteristic of Terragni where spatial shifts are suggested in the thick zone of the exterior wall. In figure 2 we have illustrated an analysis of rules in a frontal layered elevation of Eisenman.

Mass Architecture - the composition of elements

A major class of architectural design in which building masses are the element vocabulary which generates the composition. These masses are frequently disposed in plan according to a zoning scheme. The masses may reflect the spatial scheme of order on the interior of the building, as common in the Ecole des Beaux Arts (Middleton, 1982).

- Primary, or prismatic, mass: an important sub-class of simple volumetric architecture, with a simple exterior wall expression. Botta is an interesting contemporary example.

- Articulated Mass Architecture: organization of spatial volumes and masses according to an axial or zoning system, or both. High level of articulation of masses. Common in historic architecture. Interesting variations in the civic buildings of Kahn. There are many compositional sub-classes incorporating principles such as hierarchical order and dual order. Both are common in Kahn, as are special rules for the articulation of masses in his highly articulated elevations.

Grids and Lattices-the regularity of systems

A large family of architectural sub-classes are based upon the grid as an organizational and expressive element.

- Expressed grid architecture: the expressed grid is a physical element which organizes the design. A contemporary example is the work of Ando. One example of an analysis of grid architecture in Ando is illustrated in figure 3.

- Modularity: the volumetric module of the grid becomes the organizational and expressive element of the design. Common in Dutch Architecture, for example the work of Hertzberger. Sub-classes may he established on the basis of modular system, number of modules, etc.

  Open lattice systems: the grid is a three-dimensional lattice in which functions are flexibly introduced. The Free University of Berlin, by Candilis, Josic and Woods is the classic example.

  Isotropic space: the open plan and the grid matrix. The expressed grid-matrix in Le Corbusier is part of the language of the open plan, itself, a sub-class of designs. Another expression is the grid matrix in Miesean buildings.

- Syntactic architecture: grids as a basis for syntactic order. Certain of the principles identified in this class may be employed in other classes, such as the use of syntactic, grid-based principles in the analysis of the elevation of Eisenman. Syntactic architecture in the work of Eisenman might he considered a three-dimensional approach to the open plan.

Figurative Architecture and Combinations

We are currently exploring other languages based upon figurative elements and patterns, e.g. in the work of van Eyck and Portoghese, the hybridization of languages in Siza, organic metaphors in Aalto, and the architecture of PostModern space.

6. Conclusions: the Relevance of Formal Analysis and Building Form Modelling in Architectural Education

Computational formal analysis has provided an effective means to analyze design instances using two and three-dimensional graphics software. The objective of modelling classes of building forms was an intellectual and research challenge beyond the scope of undergraduate design education. However, this conceptual framework contributed to the quality of the work as well as to the accumulated knowledge produced by the research. Furthermore, computational formal analysis has proved to be an effective method for knowledge acquisition in design research as well as a medium for teaching concepts of design by means of computer modelling.

The computer programs employed (geometrical modelling and animation) have enabled a dynamic representation of sequences of design steps. This has provided a unique medium for representing design principles and for simulating generation processes in design.

The concept of building form models appears to be a powerful formalization of design knowledge. From the work which we have accomplished so far, compositional and organizational classes of building form appear to he an area of knowledge which bears upon the way in which we generate architectural form in design, and the way we work with form in complex design processes such as adaptation. The research component of the work will in the future incorporate more rigorous descriptive methods. Furthermore we will attempt to undertake a more systematic coverage of the classes which we have so far proposed. One of the most challenging questions from a computation point of view is what might he the design computational implications of the concept of formal knowledge encoded in computer programs.

One conception of the human-computer partnership arrangement would represent and encode design knowledge and make it available to the human designer in CAD programs. The missing link in the development of generative knowledge in computers appears to be less technological than due to a lack of formalization of the knowledge underlying design in architecture and of the processes involved. We, therefor, believe that the kind of research represented by our formal modelling effort and that of others is fundamental to the advancement of design computing.

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