SCHEMA EMERGENCE IN COLLABORATIVE DESIGN

RIVKA OXMAN, EZEKIEL GOLAN*, EYAL NIR**, and DANIEL BRAININ**
Faculty of Architecture and Town Planning, Technion, Haifa, Israel 32000
**Faculty of Computer Science, Technion, Haifa, Israel, 32000*
***Faculty of Architecture and Town Planning, Technion, Haifa, Israel 32000*

Abstract In this paper, we report on work in which media environments are developed to support *schema emergence* in collaborative design. We present a conceptual framework to support the cognitive phenomena of emergence in CAAD environment. First, we introduce and present a cognitive conception of schema emergence in design. We then discuss our computational model of schema emergence. Based upon this model we propose a conceptual framework to support emergence in collaborative design. Finally, the potential of the present implementation and the computational tools which support the approach are discussed .

1. Introduction

Reinterpretation and restructuring of design representations is a fundamental property of visual reasoning in design thinking. This reasoning is generally facilitated by the interaction between the designer and the visual representations of the design (Schon and Wiggins 1992). The process of recognizing new emergent properties within existing representations characterizes what is termed, emergence.

Most current research on emergence in design computation deals with graphical emergence in shape interpretation. Stiny's work, (Stiny, 1993) formalized emergence through shape grammars. A general framework for the emergence of shapes has recently been proposed by Soufi and Edmonds (Soufi and Edmonds, 1995). They have developed a formulation of categories of emergent shapes and a mechanism for the isolation of those shapes based upon a computational framework. Another development in the theory of shape emergence is work based on the recognition of implied shapes within line drawings as in the work of Liu (Liu, T.Y.,1995). Interpretations of shapes and the interpretation of patterns of shapes into graphical structures are an important advance in the area of shape interpretations and their semantics, since it begins to introduce concepts of higher level structures in emergence. Work in this area has recently been advanced by Gero and Damsky and Jun (Gero, et. al., 1995).

In our work, rather than dealing with specific classes of shape emergence, we have attempted to understand and model how the emergence of structures of higher level semantics can be supported by the syntax of shapes within generic representations. Our theoretical assumption is that knowledge of design classes

and their generic representations is one of the forms of knowledge of the experienced designer. Furthermore, we propose that such class knowledge underlies design emergence (Oxman, R. E., 1988a). Therefore, rather than dealing with specific classes of shape emergence, we have been attempting to understand and to model how, emergence operates in design schema. In previous papers (Oxman, R. E., 1998b) we have proposed a cognitive approach through which generic knowledge, a well formalized body of specific knowledge, can contribute to the emergence of new schema by shape manipulation and re-interpretation. We have attempted to study and model how the exploitation of generic knowledge of typological representations operates in the emergence of new schema in visual reasoning in design.

In applying current research on emergence to CAAD, an underlying assumption exists that the cognitive phenomenon of emergence in a design process occurs in the mind of the individual designer. However, we know that emergence also is a characteristic of collaborative design (Cross at. el., 1996). The emergence process may also function as a cognitive basis for collaboration when the design idea of one designer is exchanged with another. We will propose how in collaboration a design idea may be conveyed along with its structure of emergent properties. This appears to facilitate the mutual development of designs in collaboration.

In this paper we report on experimental work towards the support of emergence in computer supported collaborative design. In the study *of emergence in collaboration*, we have investigated how emergence can be utilized and supported in a distributed workplace. In this case the two designers, or teams, do not share the same workplace (either in space or in time), but may share and participate in a common representational environment. Within this representational environment knowledge of design schema may be represented in a manner which enhance the possibility of collaborative work on the emergence of new schema.

In the following sections, conceptual issues in schema emergence in CAAD are discussed. On the basis of these a conceptual framework to support emergence in collaborative design is presented. The suggested framework is generic and, as such, may be applicable in a variety of design problem types. Following this theoretical presentation, a computational approach is presented which can support emergence in collaborative design. Implementation of the media environment is proposed and its exploitation as part of a collaborative design support system is discussed and presented.

2. Schema Emergence in CAAD

2.1 SCHEMA EMERGENCE AND GENERIC DESIGN

Developing and manipulating generic knowledge is one of the most significant forms of cognitive behavior of the designer. Generic design demands knowledge handling properties related to the schema and variables of the type which are manipulated in generic design (Oxman, 1998a, 1998b). The emergence of new schema is a fundamental cognitive capability of creativity in the human designer. A paradox of creative design is how the human designer can discover new schema while working with the generic content of existing schema. An early recognition of this phenomenon appeared in Dickemann, (Dickemann, 1930) who illustrated how a transformation process can occur in which specific prototypes (of chairs) can be transformed and thus result in other types.

His and subsequent work demonstrates two important phenomena in design thinking. Firstly, design transformations within types are the result of formal operations upon the class variables of the type. Secondly, new schema may emerge through the transformation process of the original type. A new schema may be a substantive modification of the class variables, or in their relationship. This and other works raise an interesting question regarding creativity in design: how can typological knowledge which is specific contribute to the emergence of new types in creative thinking? For example, figure 1. Illustrates a schema and a related sub-schema which may emerge through the operations of transformation.

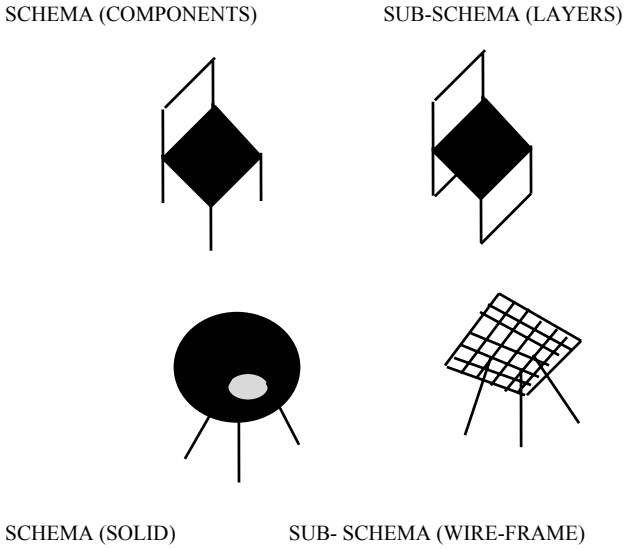

Figure 1. Schema and its sub-schema

Schema emergence appears to be a unique, and highly significant, form of emergence. Our previous research has attempted to model this class of emergence (Oxman, 1998b). The cognitive model of emergence is based upon an interpretation of typological knowledge in design and of the generic

processes which are associated with the exploitation of typological knowledge. We employ the term typology as domain knowledge of classes of design problem types. Typological knowledge may be graphically formulated as a series of generic representations which are associated with specific design problem types. The knowledge of the variables of the type is organized in a hierarchical order of representations of which the highest level is that of the schematically represented class description. Generic design is the exploitation of this structured knowledge in design reasoning.

Typologies are also well known in the context of evolutionary design. However, exploration process in which new types emerge, and the employment of generic design in these processes is not yet well understood. In our modeling of this process, we have proposed that the designer can graphically explore how to reformulate, or re-structure, the graphical representation. We have found that this occurs in design, and that in creative design evolutionary processes are often supported cognitively by knowledge of existing schema (Oxman, R. E., 1997).

We can now demonstrate by an example how the concepts of design typologies, generic representations, and schema emergence are related. For example, in the case of chair design, the typology of the chair can be represented by diverse combinations of sub-components (two are illustrated). Within each particular element of the generic structure of the components of the type, modification is also possible as a means to differentiate the design image, and eventually to result in the emergence of new sub-types. Transformations may be achieved through parametric variations, substitutions and other formal operations. Figure 2 illustrates analyses of possible schema emergence of a chair which is derived from the same graphical presentation of components. In the first case, transformations are achieved through parametric variations on components. In the second case, a sub-scheme of the first case, transformations are achieved through various formal operations upon the graphical components. The generic of the type is the knowledge of its design family characteristics, e.g. the set of design components of each of the chair schema, the underlying structure of these characteristics, their transformational properties. Emergence may be said to occur in design when the underlying structure is modified.

2.2 SCHEMA EMERGENCE IN CAAD

This typological model of schema emergence has been a basis for the development of a computational medium which supports graphical emergence. The computational environment provides a graphical interactive design medium which is supportive of the cognitive capabilities of the designer. Schema emergence is supported by providing an interactive interface which assists in the construction of new design structures which can be derived from existing ones. The representational system operates through the maintenance of the schema

while enabling modifications within the type. The generic knowledge acts in the background while the designer interacts with the representation dynamically to achieve transformations. Once the limits of transformation within a typological schema have been explored by the designer, it is possible to discover a new structure, and its design generics. The designer can then interact with the new current schema and explore variations within the new typological framework.

We may illustrate this through figure 2. As the legs of the chair are extended in the width dimension, they are transformed from a "leg" type to a "plane" type system. The designer then explores the generics of this second sub-type. We are currently developing a graphical interface to support human emergence, as well as continuing experiments into the cognitive validity of the model. The work is extending our knowledge of schema representations and of how generic knowledge of design classes contribute to creative thinking in design. It also demonstrates how the interaction with, and re-representation of, schema enables a significant form of emergence in design. Generic knowledge in design appears to be one of bases of interacting with and transforming graphic representations, and thus, one of the significant classes of visual design thinking.

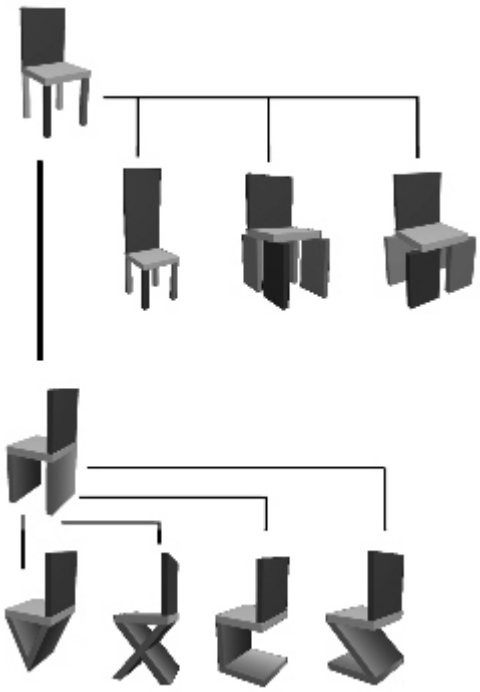

Figure 2. Analyses of schema emergence in a chair design which is derived from the same generic representation.

2.3 ISSUES

In order to support schema emergence in CAAD several problems and issues are currently explored:

One. *Representation of class knowledge behind the geometrical object:* how can typological knowledge of the experienced human designer be represented in a CAAD system? Current CAAD systems describe object attributes which do not include typological knowledge of the geometrical object represented and associated variables. In order to do so, we need a theoretical basis to provide a knowledge-based representation of an object which would underlie the geometric properties of an object.

Two. *Interpretation of generics within types and re-representation of new types:* how can a computational system *interpret* the generics within a current representation and re-represent a new representation of an emergent type once it has emerged?

Three. *Graphical support for interactive exploration of the type:* how can the associated modification of the new type be supported in a graphically interactive environment?

3. A conceptual framework for schema emergence in CAAD

We propose a framework which supports the visual representation of typological knowledge as defined by the three conditions above: knowledge representation; interpretation and exploration for emergence. The conceptual framework contains the following components as illustrated in figure 3:

a. CAAD interactive graphical interface
The environment which enables the designer to graphically manipulate the design object and to create instances within its own generic structure of representational possibilities.

b. Linkages to the typological structure (s)
The typological definitions are those that support emergence in the CAAD system, and the objects that implement the structure of the type class represent their generic definitions of elements, relationships and variables.

c. Interpreter
Our proposal is that the CAAD objects should be linked to a mechanism which knows how to interpret the geometrical object as a typological schema. A generic schema of one chair design type in our example, is defined by a set of components such as : back, seat, support and arm. Its typological schema can provide for the development of designs within this generic schema. Its associated typological operations are descriptions of transactions and operators

on the component set and their structure.

The interpreter also can identify the emergence of new types. This component of our graphical environment still requires additional work and has not yet been fully implemented. We are currently working on a simplified interpreter which activates a new type and its generics once one element of a different typological class has been instantiated in an exploration process. For example, in figure 2, when the legs of the chair have been extended to the point in which they join to become planes, the new type emerges as a graphical representation which can be manipulated according to a new set of generics.

d. Typological Interface

Currently, we have built a VRML interface that allows us to see a structured instance in a *visual mode* as a VRML model. In fact, through the VRML interface we will allow the user to interact with the presentation, re-represent and define attributes and parameters including their associated dynamic operations.

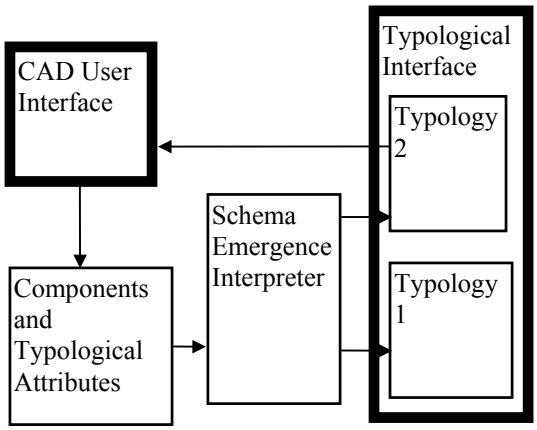

Figure 3. A Conceptual Framework for Schema Emergence

4. Supporting Emergence in Collaborative Design

In our approach to design collaboration a basic assumption is that the collaborating designers may share a common design language such as typological structures (Oxman, 1994). We propose that one such design language may be conveyed through a library of types, and that the units of this language can be conveyed by a graphical modeling language. We also assume that the content of a *structured graphical library of types* could be a collection of types or part of a more general design language. As an example, we are working on a design language for chair design as a general design language. Within the overall objective of a general design language, we are also attempting to implement the system with a semi-automatic process) and interactive mechanism

for generating instances within the type.

Figure 4. illustrates in an extended diagram how schema emergence may operate in collaborative design. The difference between this diagram and the previous diagram of schema emergence in the individual designer, (see figure 3) is that here, emergence is achieved cognitively by the human designer. Since we currently do not yet know how to implement an automatic mechanism to support schema emergence, we propose a system architecture which allows the designer to make interpretations of a new schema, represent them and send them to the collaborator by using the interface. Figure 5 and figure 6 illustrate our current *typological interface*. It shows a scheme of the entire *extended emergence process* between two designers. Figure 5 shows how one designer may carry out a part of the process and passes the result to the other. Figure 6 shows how the collaborator, in turn, carries out the same process and passes the result back to his colleague.

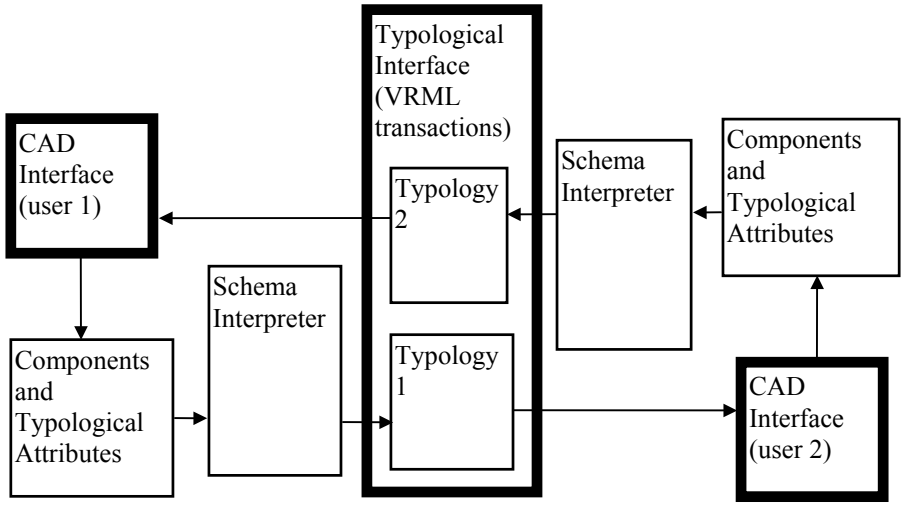

Figure 4. A computational support medium for schema emergence in collaborative design

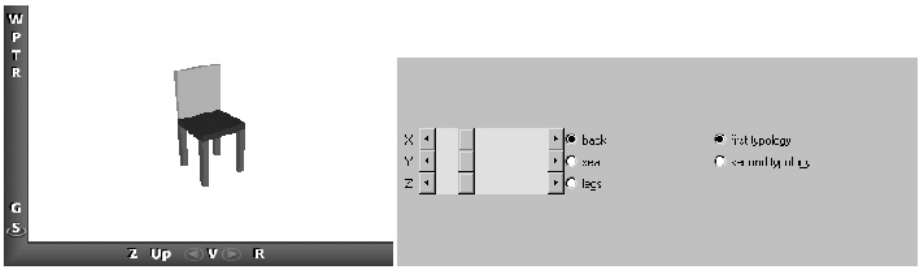

Figure 5. A typological Interface
(working with current typology: typology no. 1)

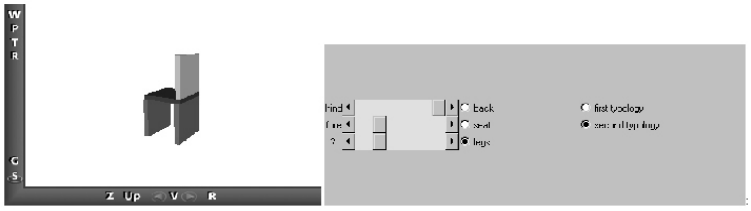

Figure 6. A typological Interface
(interpretation of a new typology: typology no. 2)

5. Conclusions

On the basis of a proposed cognitive model of schema emergence in design we have presented a computational framework to support schema emergence in collaborative design. Our basic assumptions regarding the design process assumes that designers share common forms of design knowledge, that this knowledge can be formalized and represented graphically, and can be employed as the basis for communication in collaborative, distributed design sessions. With the elaboration and expansion of our design language for chair design, we hope to test these basic assumptions in collaborative computer-mediated design sessions with our research partners. The construction of a small typological library; the provision within the library of a medium for graphical, interactive design exploration; its use as medium for visual reasoning in schema emergence, these are the three main operative objectives which will be the operational framework for the collaborative design sessions. Beyond this set of research objectives we have identified two important computational problems for which research will be continued.

One. Systems for supporting graphical interactive explorations *within design types* appears to us, on the basis of the work already accomplished, to be an achievable objective. It appears to be completely feasible to provide for three-dimensional "sketching" of design instances within the generic possibilities of types. Thus the dynamic three-d computational representation of design objects can become the basis upon which the designer reasons visually as he interacts and dynamically modifies the representation. However, automatically "switching" between types, or supporting real emergence, has not yet been achieved. What we have referred to as the "interpreter" would perform this function, as does the human designer. We are continuing to work on this problem, and are currently experimenting with the graphical "cueing" of new sub-types when a common design element emerges.

Two. Another central problem is the presentation of typological knowledge as part of the underlying and support knowledge behind the geometrical representation of the CAAD model. That is, can so-called intelligent CAAD

tools provide typological knowledge or precedent knowledge which can be called up by the presence of certain geometrical conditions in the CAAD model ? Certainly CAAD as a design medium should enable such linkages between a geometrical model and a knowledge model. We will attempt to link our typological libraries to a CAAD modeling system.

It appears to us that design media which can support schema emergence are feasible. Such cognitively responsive and dynamically interactive design environments must constitute one of the major objectives of the CAAD design community. We see the functioning of computer-mediated design environments as one of the foundations of collaborative design also to be a related task and an important future objective of research in *design cognition and computation*.

Acknowledgments

This work is supported by the DFG grant from the German. Professor Bernd Streich and Oliver Fritz are our German counterpart. Our discussions and meetings have been stimulating for the development of our thinking.

References

Cross N. Christiaans, H. and Dorst, K. (eds) Analyzing Design Activity, Wiley, Chichester, UK

Gero J.S., Damsky J, and Jun H. (1995) Emergence in CAAD systems, in CAAD Futures ’95 National University of Singapore, Tan M. and The R. (eds.) pp.423 - 438

Liu T.Y. (1995) Problem decomposition on restructuring shapes in terms of emergent sub-shapes, in CAAD Futures ’95 National University of Singapore, Tan M. (eds.) pp.455-468

Oxman Rivka E. (1997) “Design by Re-representation: “A model of Visual Reasoning in Design” Design Studies, Butterworth-Heinemann, October Vol 18/4, pp. 329-347

Oxman Rivka E. (1998a) Beyond sketching: visual reasoning through re-representation in cognitive design media, in CAADRIA ’98 Sasada T., Yamaguchi S. Morozumi M. Kaga A. and Homma R. (eds.) Kumamoto University, pp. 337-347

Oxman Rivka E. "Precedents in Design: a Computational Model for the Organization of Precedent Knowledge", Design Studies Butterworth-Heinemann, (1994) Vol. 15, No. 2, pp. 141-157.

Oxman Rivka E. (1988b) “Schema Emergence in Design” in AID 98’ workshop on Design Emergence Chase S. (ed.) Portugal, Spain.

Stiny G., (1993) Emergence and continuity in shape grammars, CAAD Futures, ’93, in Flemming U. and Van Wyk (eds.) Elsevier, Amsterdam, pp. 37-54

Soufi B. and Edmonds E. (1995) A framework for the description and representation of emergent shapes, in CAAD Futures ’95 National University of Singapore, Tan M. (eds.) pp. 411-422

Schon, D.A. and Wiggins G.: 1992, “Kinds of seeing and their functions in designing, Design Studies, Vol. 13