A COMPUTATIONAL SYSTEM FOR ENRICHING DISCOVERY IN ARCHITECTURAL DESIGN

RABEE M. REFFAT
Architecture Department,
College of Environmental Design,
King Fahd University of Petroleum and Minerals,
Dhahran 31261, Saudi Arabia
rabee@kfupm.edu.sa

Abstract. This paper presents a computational system for enriching design discovery in the external 2D representation of architectural plans. Enriching discovery is achieved through an interpretative search process that involves emergent findings. The developed computational system employs a twofold discovery process, generative phase and an interpretative or explorative phase. In the generation phase the system allows designers to depict an initial building design in the form of 2D plans as a set of lines. The system recognizes possible components of the initial design by generating different forms of bounded shapes that are both explicit and implicit using the Hamiltonian circuit approach. In the interpretation phase the discovery process using the quest mechanism is invoked by selecting a geometrical semantic identified in the recognized shapes to generate possible alternative interpretations of the complete representation of initial design. This plays an important role in enriching discovery in the architectural design of buildings and provides a set of new moves and directions for the designer to pursue.

1. Introduction

Design can be viewed as a purposeful, constrained, decision making, exploration and learning activity. Decision making implies deciding the values of a set of design variables. Exploration refers to changing the problem space within which decision making occurs while learning implies a restructuring of knowledge. Designers operate within a context which partially depends on the designers' perceptions of purposes, constraints and related contexts. These perceptions change as the designer explores the emerging relationships between putative designs and the context and as the designer learns more about possible designs (Gero, 1996).

Although designers have always managed with pencil, paper and imagination, computers could help them in conceptual designing. Through shapes designers express ideas, present elements of design and abstract concepts. Hence, the role of constructing shapes in designing is significant and the formation and discovery of relationships among parts of a design composition are fundamental tasks in designing. The ability to provide useful computational designing support at the conceptual stages is important to accommodate the situated and fluid nature of early schematic designing and to allow new design solutions to emerge.

For computers to support human creative thinking, they must be able to keep up with human recognition of emergent ideas. This implies that the system is not based upon a well ordered object set but has pattern recognition capability that can find the new objects, as they emerge, with minimum human guidance. Emergence is fundamental to creative thought in the sense that we find it hard to qualify an idea as creative if it is clearly implied by the preceding conditions. The creative thought introduces something new (Edmonds, 1995). This paper introduces a computational system that can be used to support one of the primary designing activities at the conceptual stages, that is discovering various design compositions of architectural shapes. This system provides a medium for designers to explore the design space and to enhance the perceptual interaction with design elements.

2. Emergence and Creativity in Architectural Drawings

Drawings in architecture are valuable precisely because they are rich in suggestions of what might be (Mitchell, 1990). Drawings hold the potential of 'talk back' to their makers in a series of empirical experiments with both novice and experienced designers (Goldschmidt, 1999). Designers step back momentarily from the making process and reflect on the drawings, and that in this reflection, or re-examination, designers see patterns that stimulate the next cycle of designing (Schön and Wiggins, 1992). An evolving design may thus have alternative descriptions that may change from time to time in unanticipated ways; it may be decomposed and manipulated in this way and in another way later without difficulty.

The term "*emergence*" has been used in many different contexts within various research fields including artificial intelligence and artificial life. This paper adopts emergence as the process of making features explicit that were previously only implicit. Emergence is defined relative to a conceptual model of the observed phenomena held by an observer. In view of this definition of emergence any computational model of design emergence should include a means of observing not just the products of designing but also the process of designing in order to monitor significant changes in the representations used.

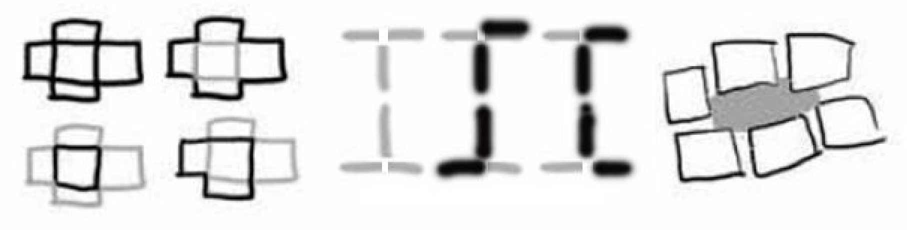
2.1 SIGNIFICNCE OF MULTIPLE REPRESENTATIONS IN EMERGENCE AND DESIGN CREATIVITY

Oxman (1997) demonstrated the significance of the concept of multiple representations in designing. Oxman observed that the designer appears to be capable of exploiting various underlying representational structures using multiple representations. Designers construct explicit representational structures that were implicit in a particular design form, during their moves as the design evolved. Designers were found to be able to extract various abstracted explicit representations of the existing design based on their own domain of knowledge. These abstractions include typological, organizational and morphological principles and functional relationships. They were able to externalize and categorize their graphic manipulations conceptually despite the fact that drawings tend not to provide explicit representational information to support such decomposition. Multiple representations serve the designer as supportive representations for design manipulations. It is the structuring quality of these multiple representations which appear to support design manipulation.

Some of the roles that multiple representations play in designing include: interpretation, transformation and emphasis. The complexity of a situation is hard to grasp when only a single representation is available. This is particularly true if a rich representation of the situation is required. The multiple representations approach is a cognitive strategy that designers and solvers of ill-structured problems adopt, because it facilitates the intricate process of creating links (Goldschmidt, 1997). Designers engage in “graphical conversation with the design” (Schön, 1983), and “the designer has a conversation with the drawing” (Lawson, 1980). These transactions with the external representation illuminate the visual mental process of designers. In the process of conceptual designing, various moves by designers are encountered and expressed in graphical design development in the form of different representations reflecting transitions of states from one representation to the other.

2.2 TYPES OF EMERGENCE IN ARCHITECTURAL SHAPES

Emergence is used for perceiving implicit and unintended patterns in an external representation. Emergent shapes might be viewed as multiple readings of a diagram. Sources of multiple readings include intersecting figures, alternative configurations, and figure-ground reversals (Gross, 2001). Intersecting figures occur when two or more figures intersect to create recognizable new figures that were not initially intended. For instance, in Figure 1(a), three figures are created as a side effect of drawing two intersecting rectangles, one horizontal and one vertical. Alternative configurations occur when grouping configurations' parts in several ways and reading them as belonging to a new configuration. For example, the designer has drawn a plan diagram with two tee-configurations as depicted in Figure 1 (b)-left; when juxtaposed differently twice as shown in Figures 1(b)-right alterative two configurations are created. Figure-ground reversal occurs when a new figure is formed by the edges of several drawn figures that define a recognizable shape. For example, in drawing the floor plan or footprint of building blocks (Figure 1(c)), the designer might create a plaza or street between the blocks. While drawing the blocks the designer might be also thinking about the space between. This emergent shape is not inadvertent but intended, although its boundaries comprise the edges of other shapes.



(a) (b) (3)

Figure 2. Three forms of visual emergence: (a) intersecting figures,(b) alternative configurations, and (c) figure-ground reversal (after Gross, 2001).

3. Computational Support for Enriching Discovery in Architectural Design

Supporting discovery in architectural design through shape emergence has been implemented computationally through various approaches. These approaches include: using replacement rules to recognize emergent shapes (Stiny, 1993); using data driven search to generate a set of emergent shapes wherein extending line segments in a figure is utilized to generate new intersections (Gero and Yan, 1993); extending segments in a drawing to make construction lines and finding intersection points with other similarly constructed lines to generate a set of candidate emergent shapes (Tan, 1990); using shape recognition and transformation for a directed search to identify specific subshapes in a drawing (Nagakura, 1990); and using neural networks to recognize emergent shapes in simple drawings (Liu, 1995).

This paper introduces a new computational system that employs a twofold discovery process as depicted in Figure 2, generative phase and an interpretative or explorative phase for enriching design discovery in the external representation of architectural two-dimensional plans of buildings. Enriching discovery is achieved through an interpretative search process that involves emergent findings. The computational system has a quest mechanism wherein quest refers to the act of seeking or pursuing something; therefore it is a type of search where the search space and the goal may be modified as a result of the process. In the generation phase the system allows designers to depict an initial building design in the form of 2D plans as a set of lines. The system recognizes possible components of the initial design by generating different forms of bounded shapes that are both explicit and implicit using the Hamiltonian circuit approach. In the interpretation phase the discovery process using the quest mechanism is invoked by selecting a geometrical semantic identified in the recognized shapes to generate possible alternative interpretations of the complete representation of initial design as detailed in the following sub-Sections.

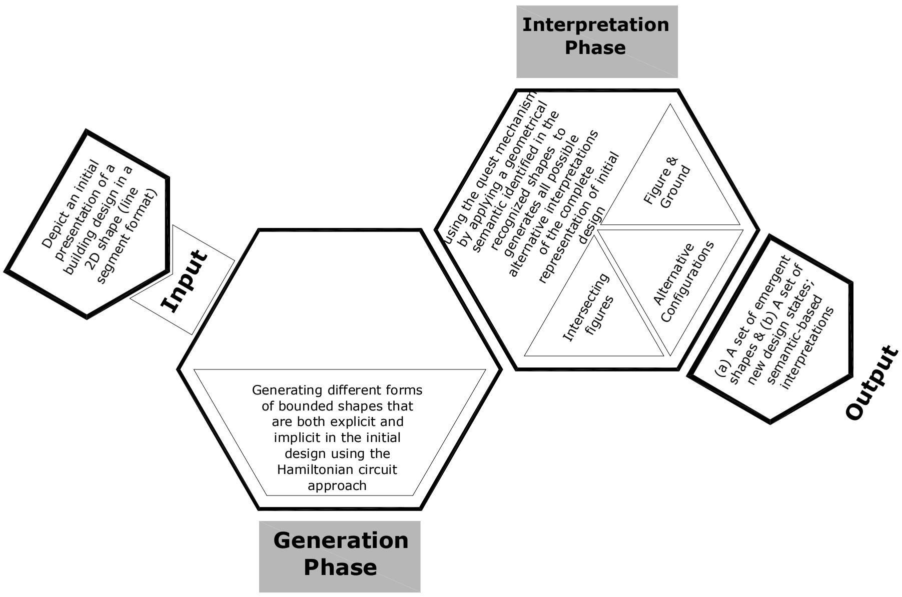


Figure 2. The framework developed computational system for enriching discovery in architectural design.

3.1 DIGITAL BOARD FOR DEPECITING INITIAL DESIGN

The developed computational system provides a digital drawing board that enables the designer to trace rectilinear representations of a design, save them, and open previous designs. The 2D representation of the design will be depicted in a form of line segments to be drawn as two-point segments in a 10 x 10-pixel grid where the mouse would have 'snap to grid' behavior as in most advanced drawing software. The snap behavior ensures that vertices are easily created, i.e. that two points are located on the same coordinate. Drawings are thus created by pressing the mouse left button to create the initial line point and after dragging the mouse by releasing the button to generate the final line point. These points are then stored in pairs of two-dimensional coordinates that can be saved into a generic file. While drawing, the designer can undo to discard the last line drawn with the availability of several 'undo'. Figure 3 shows a screenshot of the digital board showing the grid and menus available along with a depicted initial 2D representation of a design.

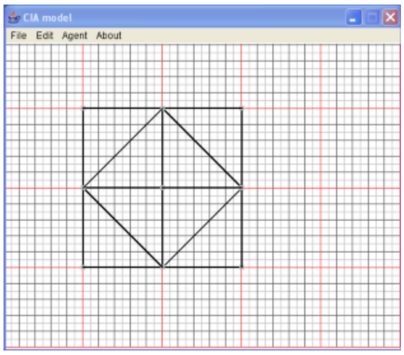


Figure 3. The interface of developed computational system showing the digital drawing board and a depicted initial presentation of a design to be explored using the developed system.

3.2 GENERATION PHASE

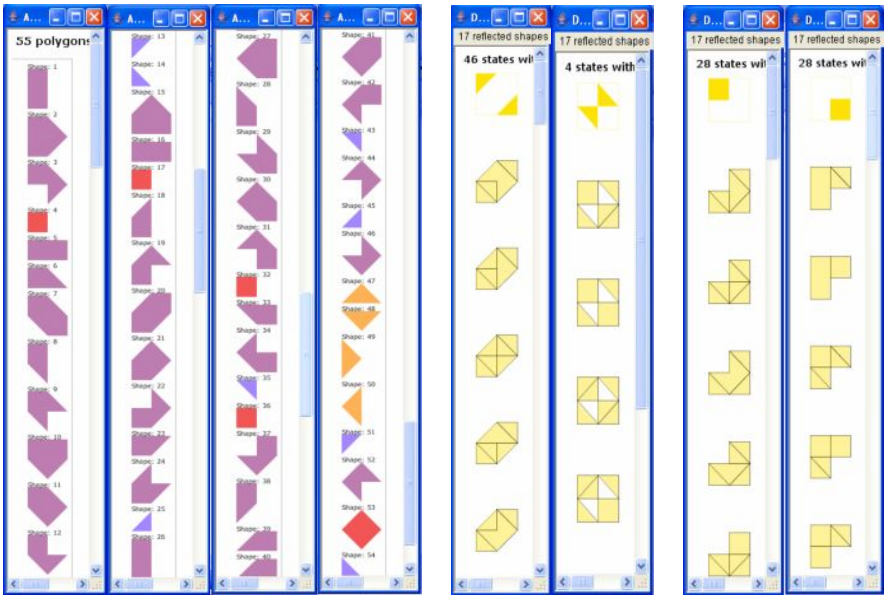
Once the designer reaches a certain stage with the design, the designer can run the system to find emergent shapes (not explicitly represented in the initial design). This is achieved by using a shape-recognition algorithm that searches exhaustively the line segments in the drawing and recognizing bounded shapes (explicit and implicit). A bounded shape is a closed circuit formed by more than two line segments. In general, the problem of finding a Hamiltonian circuit is NP-complete (Garey and Johnson, 1983), so the only known way to determine whether a given general graph has any particular closed circuit is to undertake an exhaustive search. This is implemented in a breath-first graph search using all vertices as starting points. A Hamiltonian circuit is defined as a graph cycle (i.e. closed loop) through a graph that visits each node exactly once. Because this search is conducted starting from every existing point in the drawing, shapes are recognized the same number of times as their number of vertices. Consequently, a process is added to discard these redundancies. Figure 4(a) shows an exemplary case of a design and the type of bounded shapes recognized by this procedure. In this particular case the system generated 55 bounded shapes (8 explicit and 47 implicit) from the initial design as depicted in Figure 3 without specifying a maximum number of line segments (sides) in recognizing and identifying bounded shapes. However, with more complicated designs it becomes necessary to determine a maximum limit of sides of bounded shapes since the algorithm may require extreme computational processing to complete the search. This limit can be set in the program through defining a side limit which discards any sequence of lines that exceeds that number of segments before a closed shape is found.

3.3 INTERPRETATION PHASE

Within the entire set of recognized shapes from the generation phase, the discovery process using the quest mechanism is invoked by selecting a geometrical semantic identified in the recognized shapes and the system generates all possible alternative interpretations of the complete representation of initial design (explicit and emergent) that can be encountered using the three types of emergence. This process is conducted to find pairs of shapes that exhibit a specific shape semantic, e.g. reflective symmetry. Such pairs are considered as a "focus-of-attention" and are used to generate "new design states", i.e. re-constructions of the original design representation by combining and arranging all the different shapes recognized without overlapping shapes. Figure 4(b) shows a typical pair formed by two reflected triangles representing the focus-of-attention. In this example, these pairs are formed by reflected shapes while other shape semantics could be used to form other focus-of-attention, e.g. rotation, translation, scaling, repetition, etc. Alternatively, other new design states can be created using the Figure-Ground reversals wherein a single bounded shape can be considered as a focus-of-attention and the system develops a set of new design states that consist of various sets of Grounds for the selected focus-of-attention as shown in Figure 4(c). These new design states create a rich source of creative designs that can be pursued by the designer. These design states are quite useful for design exploration and reflect different perspectives of what might be perceived from the initial design. Furthermore, they provide the designer with different design moves that were not accessible to the designer in initial design representation.

4. Conclusion

Develop computational systems to support conceptual designing is quite important especially to produce alternative possibilities to assist designers in exploring and discovering new design states and situations where differences make a difference. The developed computational system presented in this paper forms a key stone for developing computational tools for enriching discovery in architectural design to support design exploration and creativity especially within the domain of architectural shapes. This has been achieved by discovering emergent new shapes and utilizing them to develop new sets of design states that designers can pursue to develop creative solutions.



(a) (b) (c)

Figure 4. (a) A set of 55 recognized bounded shapes (8 explicit and 47 implicit) from the initial design presentation depicted in Figure 3; (b) and (c) Sets of new design states reinterpreted from the initial design using reflective symmetry as a focus-of-attention and figure-ground reversals respectively.

Acknowledgements

The author would like to acknowledge and thank KFUPM for supporting this research. Also, thanks are due to the Australian Research Council for supporting the development of this research through a Discovery Project grant.

References

Edmonds, E.: 1995, Creativity: Interacting with computers, (panel session), *CHI 95 Conference Companion*, pp. 185-186.

Garey, M.R., and D.S. Johnson: 1983, Crossing Number is NP-Complete, *SIAM J. on Algebraic and Discrete Methods,* 4:312-316.

Gero, G. S.: 1996, Creativity, emergence and evolution in design, concepts and framework, *Knowledge-Based Systems*, 9(7): 435-448.

Gero, J. S. and M. Yan: 1993, Discovering Emergent Shapes Using a Data-Driven Symbolic Model, *in* van Wyk S. and U. Flemming U. (eds), *CAAD Futures '93*, Springer, Pittsburgh, USA, pp. 3-17.

Goldschmidt, G.: 1997, Capturing indeterminism: Representation in the design problem space, *Design Studies*, 18: 441-445.

Goldschmidt, G.: 1999, The Backtalk of Self-Generated Sketches, *in* Gero J. S. and Tversky B. (eds)*, Visual and Spatial Reasoning in Design*, Key Centre of Design Computing, Sydney, Australia, pp. 163-184.

Gross, M.: 2001, Emergence in a Recognition Based Drawing Interface, *in* Gero J., Tversky B. and Purcell T. (eds), *Proceedings of the 2nd International Conference on Visual and Spatial Reasoning '01*, Key Centre of Design Computing and Cognition, University of Sydney, Australia.

Lawson, B.: 1980, *How Designers Think*, Architectural Press, London, UK.

Liu, Y.-T.: 1995, Problem Decomposition on Restructuring Shapes in Terms of Emergent Subshapes, *in* Tan M. and The R. (eds), *Sixth International Conference on Computer-Aided Architectural Design Futures*, Singapore, pp 439-451.

Mitchell, W. J.: 1990, Introduction: A New Agenda for Computer Aided Design, *in* McCullough M., Mitchell W., and Purcell T. (eds), *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era*, MIT Press, Cambridge, MA, pp.1-16.

Nagakura, T.: 1990, Shape Recognition and Transformation: A Script-Based Approach, *in* McCullough M., Mitchell W., and Purcell T. (eds), *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era*, MIT Press, Cambridge, MA, pp. 149-170.

Oxman, R.: 1997, Design by re-representation: A model of visual reasoning in design, *Design Studies*, 18: 329-347.

Schön, D. A. and Wiggins, G.: 1992, Kinds of seeing and their functions in designing, *Design Studies*, 13(2): 135-1

Schön, D.: 1983, *The Reflective Practitioner: How Professionals Think in Action*, Basic Books, New York.

Stiny, G.: 1993, Emergence and Continuity in Shape Grammars, *in* van Wyk S. and U. Flemming U. (eds), *CAAD Futures '93*, Springer, Pittsburgh, USA, pp. 37-54.

Tan, M.: 1990, Saying What It Is by What It Is Like - Describing Shapes Using Line Relationships, *in* McCullough M., Mitchell W., and Purcell T. (eds), *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era*, MIT Press, Cambridge, MA, pp. 201-213.