

Emergence in CAAD Systems

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Abstract

Emergence is the process of making properties which were not explicitly represented in a computational system explicit. This paper presents two approaches to graphical emergence suitable for implementation in a CAAD system. It presents processes for shape emergence - the interpretation of shapes which were not intentionally placed there by the designer - and shape semantics emergence - the interpretation of patterns of shape into structures which were not intentionally there by the designer. Examples of both processes and their use are given.

Keywords: shape emergence, shape semantics emergence, shape representation

1. Introduction

Fundamental to any computer-aided design system is the need to represent the objects under consideration. When those objects are conceptual a strictly symbolic representation is sufficient. For example, the concept that a physical object has a particular behaviour which can be derived from it can be represented by algebraic expressions which represent the theory of the derivation of that behaviour from that object. However, much of the information our senses bring to us is visual and is shape oriented. Much of our knowledge about the physical world comes to us in the form of shape information. There has been considerable effort on developing representations for computer vision purposes. However, there is no consistent symbolic representation of shape because of the difficulty in developing such a representation. There is clear evidence that visual information is somehow treated differently by the human brain to many other forms of information. Coherent visual information has long been treated as either part of geometry or part of topology. Both of these have been represented and manipulated mathematically. The vast majority of shape representation schemes are concerned with the geometry and to a lesser extent with the internal topology of the shape. This is important since the object needs to be represented on the screen.

Current CAAD systems have not been used extensively during conceptual design for a variety of reasons, one of which is that they freeze the shape being represented and do not allow any other interpretations. Thus current CAAD systems are unable to aid the designer in the perception of figures, shape semantics and in the recognition of emergent structures. Furthermore current CAAD systems have limitations in the interpretation of shapes to capture visual patterns from shapes which are conceivable to human beings. This is one obstacle in using CAAD systems to provide significant assistance to human designers. Thus the major aim of this paper is to present computational models for shape emergence and shape semantics emergence to improve the capability of CAAD systems in order to support designers' creativity at the conceptual design stage.

2. Emergence in Design

A property that is not represented explicitly is said to be an emergent property if it can be made explicit. We will restrict ourselves to the domain of shapes in CAAD systems, although the underlying conceptual approach may well be applicable in other domains. Basically there are two types of emergence of interest here, shape emergence and shape semantics emergence.

We see design as the process by which artefacts are produced, in particular, the processes we will present relate to visual emergence. Two processes relate the notion of visual emergence in design: (i) shape emergence is the process of

discovering possible new shapes that were not explicitly represented in the primary shape nor initially intended; and (ii) shape semantics emergence is the process of discovering visual patterns from groups of shapes or a simple shape.

Working in some visual medium - drawing - the designer sees what is there, draws in relation to it, and sees what has been drawn, thereby informing further designing. In all this seeing, the designer not only visually registers information but also constructs and discovers new shapes and its meaning - identifies patterns. Shape emergence clearly plays an important role in those design domains which use shapes to represent concepts. Shape semantics emergence plays an important role in organising decisions, providing order, and generating the final form of design results from a designer's interpretation of drawings.

In general, emergence in design is divided into shape representation and the process to find emergent properties. Shape representation, as knowledge representation in general, is a partial view of the object it represents. From this partial view, we can infer some partial results, which depend on our intentions. Therefore, there is no particular representation which allows any type of reasoning. Our solution to this problem is to use multiple representations, each one targeting a particular problem [3]. The general schema for this is shown in Figure 1. In this figure, the representation R_1 is the basic computational representation, usually in numeric format. From this representation we can map the shape into other representations, usually in symbolic format.

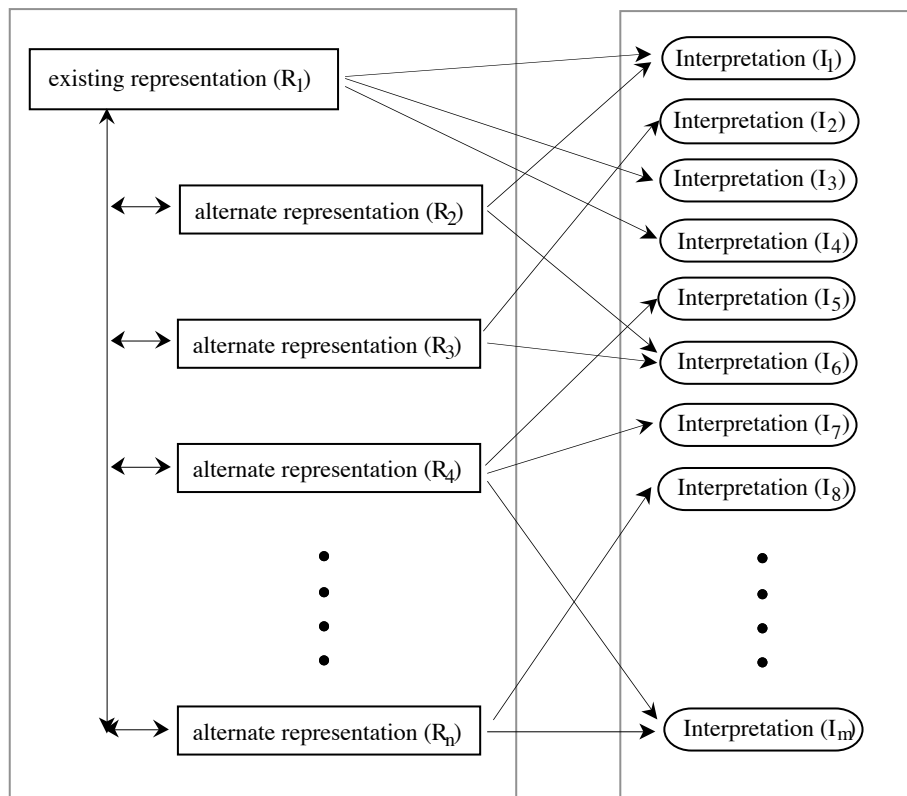


Figure 1: Framework for interpretations based on representations

From each representation, there are several *interpretations* which we can derive from it. Interpretation is the process of inferring results from a given shape in a particular representation. We use this concept of interpretation as the basis of emergence processes. Whenever we change the representation, it may be possible to find some emergent properties from that representation. In this article we use two different representations for processes to find emergent properties. For shape emergence we use halfplanes [5] and for shape semantics emergence infinite maximal lines [11]. These representations and the processes are outlined in the following sections.

3. Shape Emergence

3.1. Shape Emergence and Architectural Design

The previous section defined a general approach to emergence in design. Shape emergence is one type of emergence in design. It is concerned with the *structure* of the shapes, its component parts and geometric and topological constraints.

Designers are adept at reinterpreting existing shapes to derive new shapes. In the field of architectural design, shape emergence is an important way in which we conceptualise what has been drawn differently to what was intended to be drawn. Current CAAD systems use representations that do not allow for any other interpretations. This limits the use of such systems in conceptual design. We are pursuing a system that helps designers working at a conceptual level in this phase. Such systems ideally work in parallel with a CAAD system and produce results upon request. We see the following roles of a shape emergence process in design.

1. Extending the shape beyond its constraints by breaking the geometrical constraints of line segments. This gives an opportunity for designers to see the implications of the limitations in the shape and the possible utility of its extensions.
2. Presenting alternative shape configurations that are related to the current shapes. This allows the designer to see gradually some slightly different shapes from his/her original ones.
3. Finding schemas (well know patterns) in the drawing and/or its extensions. This allows the designer to find some more useful (from the designer's point of view) pattern during design. For example, from step 1 and 2 above some new pattern can emerge, such as a new n -sided shapes. This pattern could be interesting to explore, if it exists in the given drawing.

We can expect these roles could lead to more creative designs, headed by the designer, once the system produces novel situations for the designer.

Basically there are two classes of emergent shapes: embedded and illusory shapes. Embedded shape emergence occurs when the emergent shapes are part of the primary shape or input shape. That is, the emergent shape is composed of a sub-set of boundaries of the primary shape. Illusory shapes are related to extensions of the primary shape, and the boundaries of these shapes are not necessarily boundaries of the primary shape.

Figure 2(a) shows an architectural plan from the Catholic Church in Crailsheim, Germany designed by Fritz Vogt [12]. We can extend the major lines outlining the building as shown in Figure 2(b).

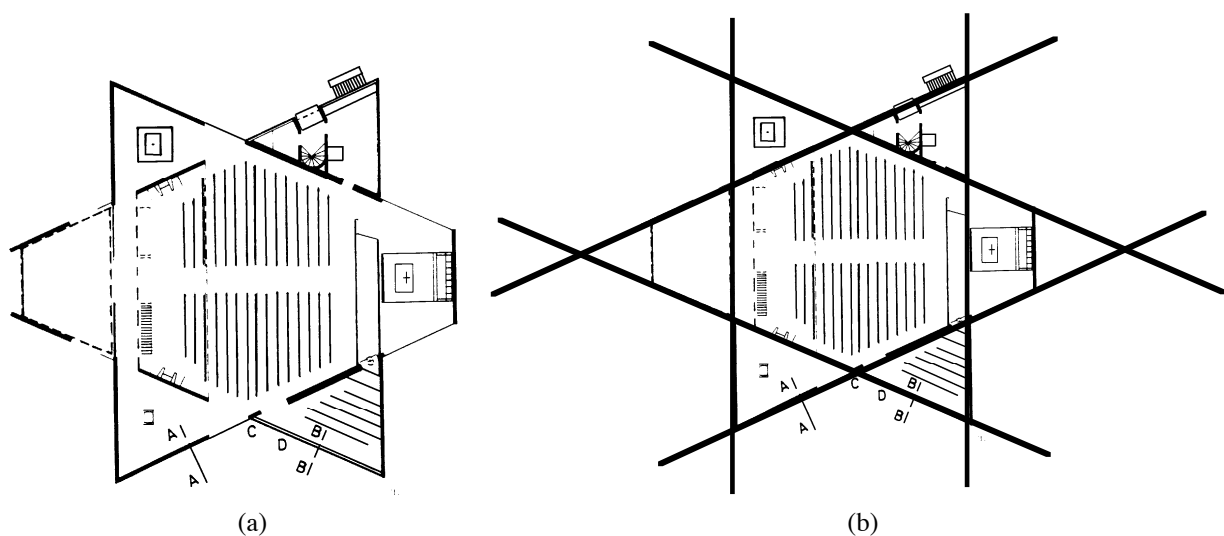


Figure 2. Catholic Church in Crailsheim, Germany (Fritz Vogt) (from Hoffman, K., Griese, H. and Meyer-Bohe, W. (1975) *Designing Architectural Facades*, Watson-Guptil Publications, New York, p. 63)

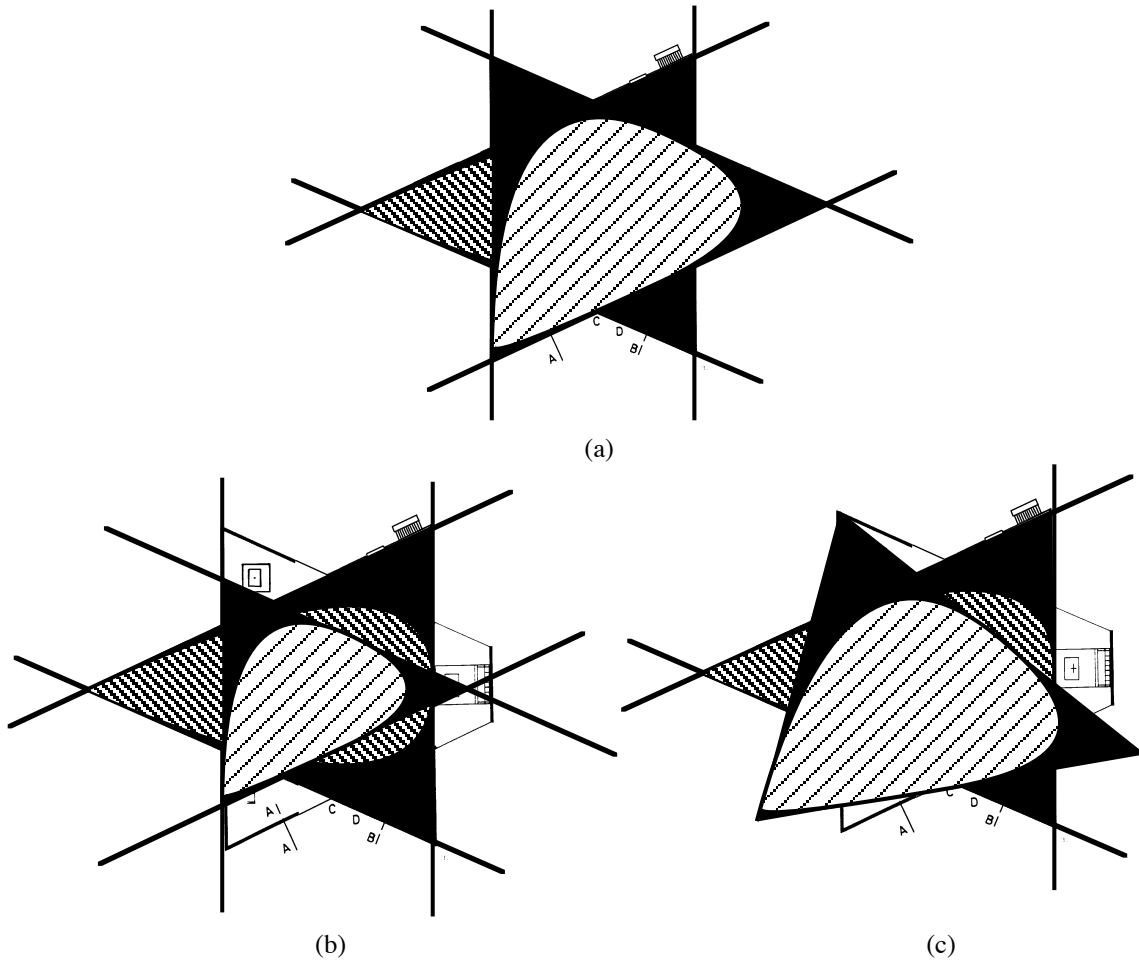


Figure 3: (a) The emergent triangle from Figure 2, (b) the emergent triangle scaled, and (c) the emergent triangle rotated.

Once the primary shape in Figure 2(a) is re-represented as infinite maximal lines [11] in Figure 2(b), there are two triangles that can be emerged, which are shown in Figure 3(a). Once the triangles were found they can be now used as entities for further designs. A entity can be scaled, as shown in Figure 3(b), rotated as shown in Figure 3(c), moved, etc.

3.2. Representation using halfplanes

In order to represent shapes symbolically we develop a system that re-represents infinite maximal lines into logic predicates. The basic concept is, from a given plan, any non-self-intersecting lines divides this plan into two halfplanes. The Figure 4 shows two examples of halfplanes, either bounded by straight lines in Figure 4(a), and non-straight lines in Figure 4(b).

Of particular importance in this representation in the consistency with which shapes can be represented whether they be bounded by straight line segments or curved line segments. Once we have the plane divided into two halfplanes, any shape can be expressed as a sequence of boolean operations among these halfplanes. For example, if the lines shown in Figure 2(b) were re-represented as halfplanes labelled hp1, hp2, ..., hp6 and one side of the halfplane as "+" and the other side as "-" we can represent the triangle in Figure 3(a) as the expression:

$$hp1^+ \& hp2^+ \& \neg hp3^+$$

where the symbol & means intersection between two halfplanes.

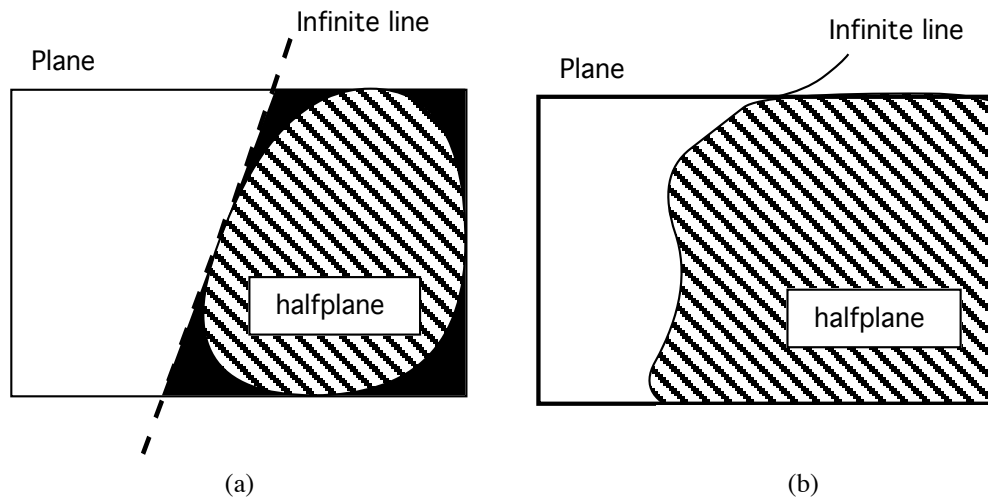


Figure 4. Halfplanes

The sides "+" and "-" of the halfplanes are mapped as truth values True and False for the predicate "hp" in logic. The symbol & is mapped into the logic "and". As a consequence it is possible to have the connector "or" and formulas with logical implication. The logical implications make the logic representation very interesting because it allows the expression of topological relation among the halfplanes. As a simple example, Figure 5 shows six halfplanes in a particular arrangement.

The topological expression can be written in logic using the following formula:

$$b^+ \& c^- \Rightarrow a^-$$

With a set of such formulas it is possible to express a drawing and all the shapes in it. There is a set of possible operations with such representation as adjacency, embedability, relative position, etc. [5].

This logic representation can be directly implemented in a computational language that works with a CAD system. The current stage of this research is the implementation of this representation in Prolog linked to AutoCAD via a C program. There is a mapping from the numerical to symbolic level, which is stored to be used to map back the symbolic results into the numerical and hence displayable level.

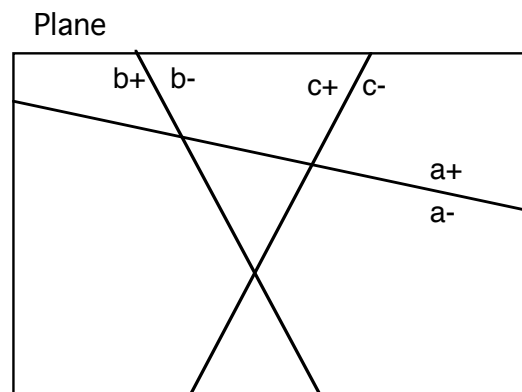


Figure 5. Six halfplanes: a+-, b+- and c+ -

3.3 Process for shape emergence

The representation using halfplanes mapped into logic uses two different steps to find extensional expressions of the shape, and therefore, emergent shapes.

The first step concerns the extension of line segments to become a halfplane. In a given drawing, it is always possible to define a two-dimensional plan where the process searches for emergent shapes. Inside this plan, every line segment must be extended in order to meet the definition of a halfplane. This extension itself plays a role in shape emergence, because usually it produces "closure" and "completeness" in the shape. For non-straight lines, the extension should follow the general equation of that curve. This is because human beings see the continuation of the line segment in terms of expectations (following the notion of familiarity in Gestalt perception). If there is no such mathematical equation defining the curve, there is no preferential way to extend the line segment and any type of extension is plausible.

The second step toward the generation of emergent shapes is using the combination of regions in the representation. Regions are the smallest portion of the shape and are formed by intersection of all halfplanes. So, any shape is a combination of these regions.

These two steps encompass the process of generating emergent shapes but not how to rank them. This ranking must follow a particular set of criteria, and there is not a general model that includes all possibilities. These criteria depend on the type of the drawing, the domain, the background of the people involved, the understanding of the cognitive process, etc. As in creativity, the result of what is the "best" or "most" emergent shape, depends on the subject. Some criteria based on visual perception of the form has been studied since the beginning of this century by Gestalt psychologists [19] and have been also applied in shape emergence [4, 7].

4 Shape semantics emergence

4.1 Introduction

Visual semantics emergence is the phenomenon of making explicit visual patterns, which were not explicitly indicated, by grouping explicit or implicit structures of shapes in certain ways. In psychology, Gestalt psychologists have studied this phenomenon by formulating perceptual laws governing figure perception [18]. Some principles contained in these laws of perception can be applied to architectural and graphic art design [15].

Our interest in visual semantics emergence is restricted here to the domain of shapes in architectural design nevertheless the conceptual approach of visual semantics emergence may well be adaptable in various design domains. From the earliest time man built dwellings, be they humble or elaborate, with materials that were closest at hand. Dwellings built in earth throughout the world demonstrate a unique richness of design [6]. These designs cover not only houses, but a great range of public and private buildings. Figure 6 shows the evidence of adaptation of various visual patterns in the Mosque of Djenné, in Mali. From the example, dominant visual pattern and/or embodied visual patterns are perceived. More technically, those visual patterns are captured by interpretations from given shapes in the design.

From seeing drawings, various visual patterns are perceived by the human viewers. In design, designers can find embodied visual patterns from what was intended to be drawn. The newly discovered visual patterns may play a crucial role in developing further ideas in the same design if the designer is willing to adapt the visual pattern which were not there at the moment of drawing. Regardless of adaptability, we define visual patterns from shapes as *shape semantics* when the patterns match the criteria for predefined labels, such as visual symmetry, visual rhythm, visual movement and visual balance. There are two types of shape semantics: (i) a *primary shape semantics* is regarded as a certain predefined visual pattern designers intentionally present and represented in the specific design, however, primary shape semantic is not well supported by current CAAD systems; and (ii) an *emergent shape semantics* is a visual pattern which was discovered after the designer has drawn. The emergent shape semantics can be discovered from only primary shapes and/or newly discovered shapes, emergent shapes.

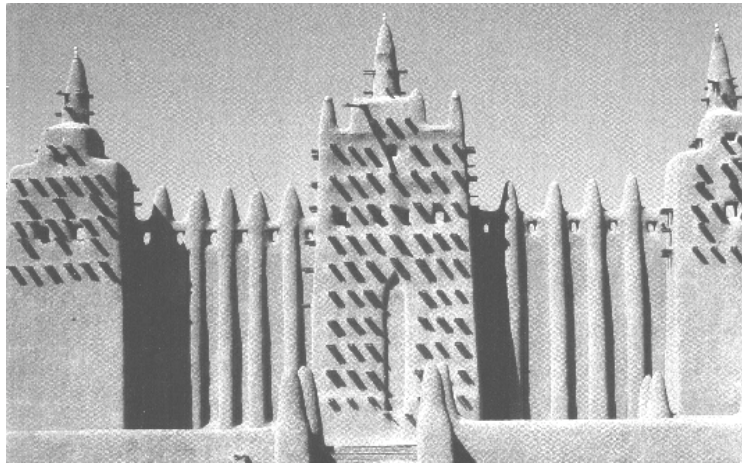


Figure 6: Various visual patterns can be perceived by the human viewer in the Mosque of Djenne, in Mali, rebuilt in 1905 (from Dethier, J., (1982), *Down to Earth*, Thames and Hudson Ltd, London, cover page).

4.2 Shape semantics in architectural design

The drawings being produced in architectural design would range from the rough and freehand to the formal and precise. The drawings would include early conceptions for a design, drawings developing ideas conceptualized in previous drawings and drawings representing developed ideas produced in such a way that they can be used by builders to realize the building. There are number of ways of looking at architectural drawings. We could see them as presentations, a language for communication or see what ideas each drawing embodies. To look at drawing in these ways is critical to any understanding of what a drawing is and what role it plays in the design process. In particular, the different ways of looking at architectural drawings at this conceptual design stage play a crucial role in discovering new visual semantics from previous drawings.

Visual similarities appear in many architects' works, independent of time, style, location, function or type of building. These visual similarities can be conceptualized and predefined into various architectural visual semantics which play a dominant role in generating building designs. There are many types of visual semantics in architectural design but here we deal with only four types of shape semantics of architectural design: visual symmetry, visual rhythm, visual movement and visual balance. Definitions for each of these four shape semantics will be presented in this section. Architectural examples are used to assist in understanding these shape semantics.

Visual symmetry

A shape or group of shapes is defined as symmetrical to the extent that it satisfies the symmetry operations of: reflection, rotation and translation. Various types of symmetries are adapted for various purposes by architects/or designers from ancient architecture to modern times. The facade of Mosque of Djenne as shown in Figure 6 shows reflectional symmetry around a central vertical axis. Reflectional symmetry is found in the plan of the Unity Temple as shown in Figure 7(a). The plan of Sepulchral Church as shown in Figure 7(b) reveals 120° rotational symmetry. Figure 7(c) shows an example from which another type of rotational symmetry can be found.

Visual rhythm

Visual rhythm is a pattern of relationships of equivalent shapes or groups of shapes such that the pattern contains repetition along one or more axes. Figure 8(a) illustrates that when the same pattern repeats visual rhythm emerges. The visual rhythm occurs along the curved direction as shown in Figure 8(b) in which the same plan is repeated.

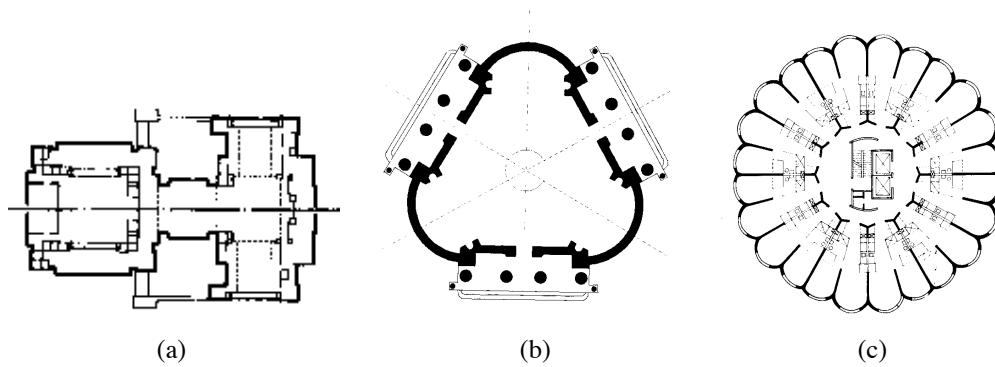


Figure 7: (a) reflectional symmetry: Unity Temple (Frank Lloyd Wright, 1906) (from Clark, R. H. and Pause, M. (1985). *Precedents in Architecture*, Van Nostrand Reinhold, New York, p.178); (b) self rotational symmetry: Sepulchral Church (Sir John Soane, 1796) (from Mitchell, W., Liggett, R. and Kvan, T. (1987) *The Art of Computer Graphics Programming*, Van Nostrand Reinhold, New York, p.444); (c) rotational symmetry: high-rise Flats in Chicago (Bertrand Goldberg Associates) (from Hoffman, K., Griese, H. and Meyer-Bohe, W. (1975), *Designing Architectural Facades*, Watson-Guptill Publications, New York, p.56)

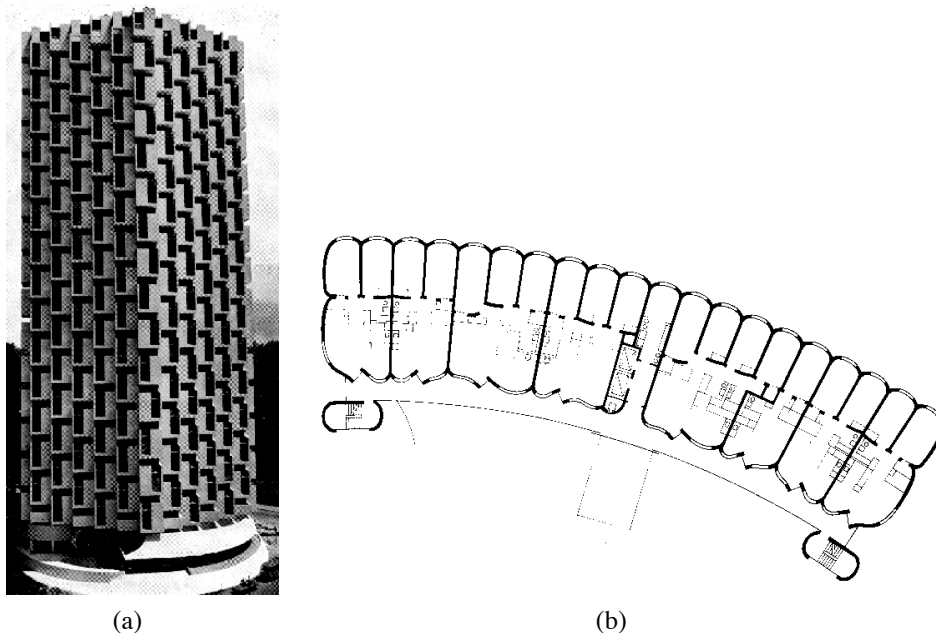


Figure 8: (a) High rise flats in Grenoble, France (R. H. Anger, Ch. Pivot and P. Pucinelli) (from Hoffman, K., Griese, H. and Meyer-Bohe, W. (1975), *Designing Architectural Facades*, Watson-Guptill Publications, New York, p.59); (b) high rise flats in Chicago (B. Goldberg Associates) (from Hoffman, K., Griese, H. and Meyer-Bohe, W. (1975), *Designing Architectural Facades*, Watson-Guptill Publications, New York, p.57).

Visual movement

Visual movement is a pattern of relationships of equivalent shapes or groups of shapes such that the pattern contains a transformed repetition along one or more axes. Size, interval and orientation are factors related to the perception of visual movement in architectural design. Sacred space to profane space establishes the hierarchy which reduces the size of spaces in Einsiedeln Abbey as shown in Figure 9(a) from which visual movement emerges. Emergent visual movement is seen in the Temple of Thebes where the movement towards the heart of the sanctuary can be perceived not only in the plan but also in section as shown in Figure 9(b).

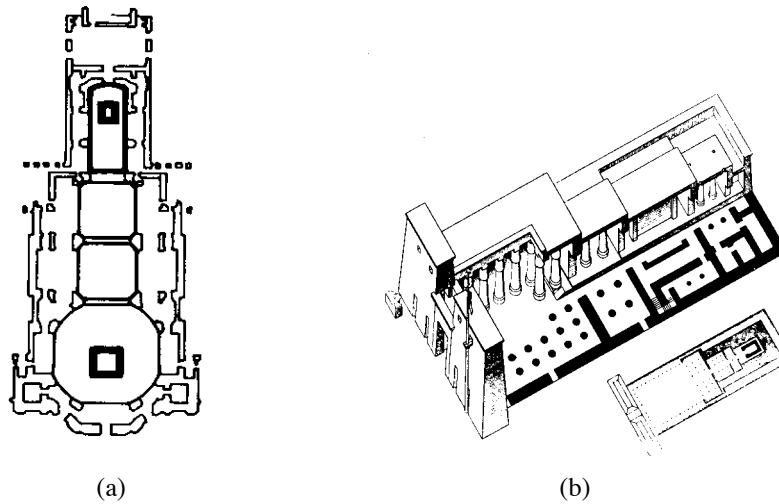


Figure 9: (a) Einsiedeln Abbey (Kaspar Moosbrugger, 1719-1735) (from Clark, R. H. and Pause, M. (1985). *Precedents in Architecture*, Van Nostrand Reinhold, New York, p.206); (b) Temple of Thebes (from Meiss, P. (1986), *Elements of Architecture*, Van Nostrand Reinhold, London, p.42).

Visual balance

Visual balance occurs when a shape or group of shapes have perceptually equivalent weight on both sides of an axis of balance. From Figure 10(a) can be seen how completely different simple geometries are balanced in the Paul Mellon Art Centre. The Vanna Venturi House as shown in Figure 10(b) exemplifies how reflectional symmetry is shifted to visual balance by changing the window patterns.

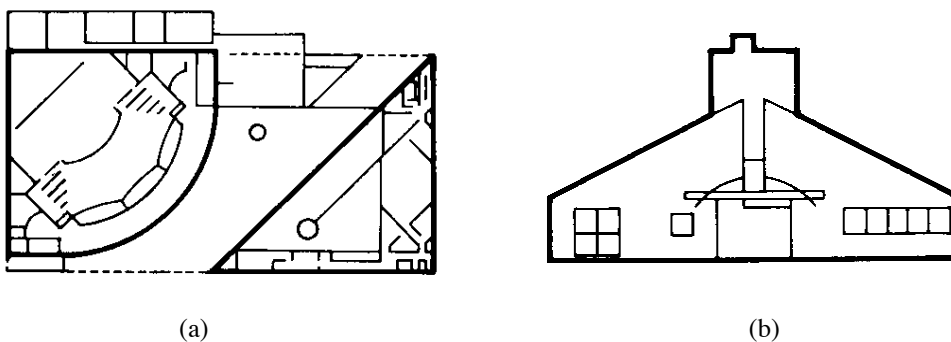


Figure 10: (a) Paul Mellon Art Centre (I.M.Pei, 1970-1973) (from Clark, R. H. and Pause, M. (1985). *Precedents in Architecture*, Van Nostrand Reinhold, New York, p.180); (b) Vanna Venturi House (Venturi, Rauch & Scott Brown, 1962) (from Clark, R. H. and Pause, M. (1985). *Precedents in Architecture*, Van Nostrand Reinhold, New York, p.179).

4.3 Representation and process of shape semantics

Various types of shape semantics can be represented at the symbolic level [9, 10]. Shape semantics are interpreted, from given two-dimensional shapes, by relying on constraints on shapes, which constrain behaviours or properties resulting from the representation of those shapes. The base representation is infinite maximal lines [11]. In particular, visual symmetry from given shapes are discovered in the system when constraints on shapes are regarded as isometric transformational constraints, such as translational constraints, rotational constraints, reflectional constraints, and glide reflectional constraints [8]. The general declaration for discovering symmetries is:

1. L is a set of infinite maximal lines, $(l_a, l_b, l_c, \dots, l_n)$.
2. I is a set of intersection, $(i_{ab}, i_{cd}, \dots, i_{mn})$, in which an intersection i_{ab} is obtained for each pair (l_a, l_b) in L when l_a and l_b intersect each other, denoted as $l_a \square l_b$.
3. K is a set of line segments, $\{(i_{ab}, i_{ac}), (i_{cd}, i_{ce}), \dots, (i_{ij}, i_{ik})\}$, in which a line segment (i_{ij}, i_{ik}) is obtained for

- each pair (i_{ij}, i_{ik}) in I when two intersections lie on a common infinite maximal lines, $i_{ij} \in l_i$ and $i_{ik} \in l_i$.
4. $d(i_{ij}, i_{ik})$ is a distance between two intersections, i_{ij} and i_{ik} .
 5. S_j is a shape defined by:
 - subset of L
 - subset of I
 6. l_g is the self symmetry axis, in which a shape has symmetry within it, defined by:
 - an infinite maximal line passing through a centre of gravity and midpoints of segments;
 - an infinite maximal line passing through a centre of gravity and intersections; and
 - an infinite maximal line passing through a centre of gravity and one midpoint of a segment and one intersection.
 7. C_l is a set of corresponding infinite maximal lines, $(l_a \in l_p, l_b \in l_q, \dots, l_k \in l_s)$, in which a corresponding infinite maximal line $l_i \in l_j$ is obtained when a number of line segments in two infinite maximal lines are equal and at least one of $d(i_{ij}, i_{ik}) \in l_i$ is equal to one of $d(i_{jp}, i_{jq}) \in l_j$.
 8. C_i is a set of corresponding intersections, $(i_{ab} \in i_{pq}, i_{cd} \in i_{rs}, \dots, i_{ij} \in i_{yz})$, in which corresponding intersections $i_{ab} \in i_{pq}$, are obtained when $l_a \in l_p$ and $l_b \in l_q$ and $l_a \in l_b$ and $l_p \in l_q$.
 9. K_e is a set of emergent line segments, $\{(i_{ab}, i_{pq}), (i_{cd}, i_{rs}), \dots, (i_{ij}, i_{yz})\}$, in which an emergent line segment is obtained for each corresponding intersections in C_i .
 10. P_m is a set of midpoints of emergent line segments, $(i_{(i_{ab}, i_{pq})m}, i_{(i_{cd}, i_{rs})m}, \dots, i_{(i_{ij}, i_{yz})m})$, in which $i_{(i_{ab}, i_{pq})m}$ represents the midpoint of an emergent line segment, (i_{ab}, i_{pq}) .
 11. L_b is a set of perpendicular bisectors of emergent line segments, $(l_{\frac{(i_{ab}, i_{pq})}{m}}, l_{\frac{(i_{cd}, i_{rs})}{m}}, \dots, l_{\frac{(i_{ij}, i_{yz})}{m}})$, in which $l_{\frac{(i_{ab}, i_{pq})}{m}}$ represents the perpendicular bisector of an emergent line segment, (i_{ab}, i_{pq}) .
 12. S_{\square} is a translational symmetry defined by:
 - a set of K_e when two pairs $\{(i_{ab}, i_{pq}), (i_{cd}, i_{rs})\}$ in K_e forms part of a parallelogram [1].
 13. S_{\square} is a reflectional symmetry defined by:
 - a set of K_e when two pairs $\{(i_{ab}, i_{pq}), (i_{cd}, i_{rs})\}$ in K_e form part of a trapezoid; when midpoints of emergent line segments in P_m are concurrent; and when perpendicular bisectors of emergent line segments are coincident [1, 13].
 14. S_{\square} is a rotational symmetry defined by:
 - a set of K_e when midpoints of emergent line segments in P_m are concurrent [1, 14].
 15. S_{\square} is a glide reflectional symmetry defined by:
 - a set of K_e when perpendicular bisectors of emergent line segments in L_b are collinear [1, 14].

The process of symmetry discovery involves two steps as shown in Figure 11: (1) searching corresponding structures of elements between shapes, so called shape correspondence; and (2) discovering possible symmetries, so called symmetry emergence. In addition, self symmetry axis inference is needed when symmetry is embedded in an individual shape.

For example, reflectional symmetry is discovered through the process of symmetry discovery in given two triangles as shown in Figure 12(a). Two given shapes are defined by a subset of L and a subset of I :

$$\text{where } L = \{(l_i, l_j, l_k, l_p, l_q, l_r), l_i \in l_j \in l_k \in l_p \in l_q \in l_r\} \text{ and}$$

$$I = (i_{ij}, i_{ik}, i_{ip}, i_{iq}, i_{ir}, i_{jk}, i_{jp}, i_{jq}, i_{jr}, i_{kp}, i_{kq}, i_{kr}, i_{pq}, i_{pr}, i_{qr}).$$

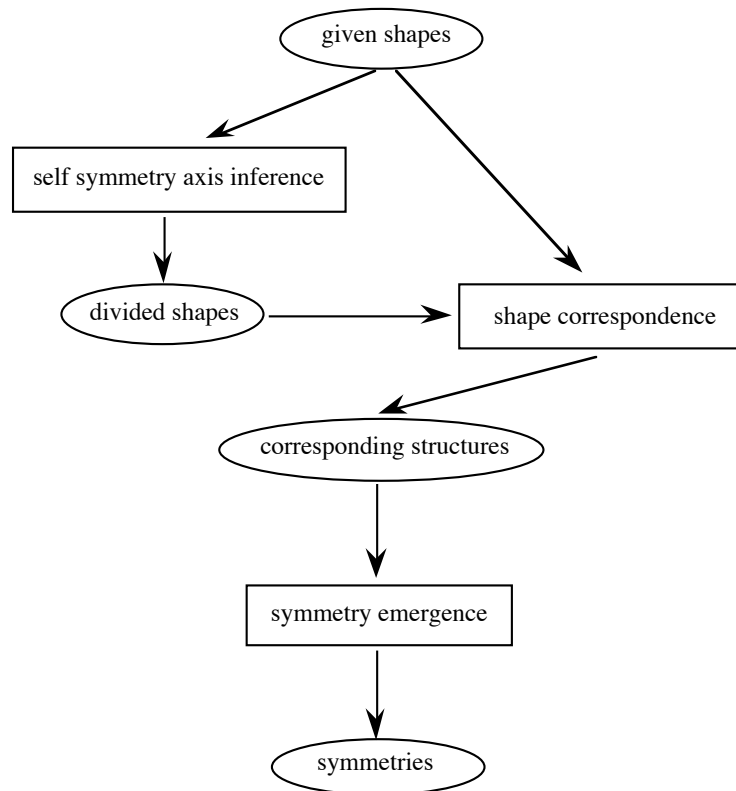


Figure 11: A process model for symmetry discovery [8]

S_i is defined by a subset L_i of L and I_i of I :

$$L_i = (l_i, l_j, l_k) \text{ and } I_i = (i_{ij}, i_{ik}, i_{jk})$$

$$\Rightarrow S_i = \{3; [i_{ij}, i_{ik}, i_{jk}]\}$$

where 3 is number of infinite maximal lines in L_i

S_j is defined by a subset L_j of L and I_j of I :

$$L_j = (l_p, l_q, l_r) \text{ and } I_j = (i_{pq}, i_{pr}, i_{qr})$$

$$\Rightarrow S_j = \{3; (i_{pq}, i_{pr}, i_{qr})\}$$

where 3 is number of infinite maximal lines in L_j

Figure 12(b) shows the representation of the two given shapes using infinite maximal lines.

Shape correspondence

Sets of corresponding infinite maximal lines and intersections are searched when the number of infinite maximal lines, number of intersections and dimensional constraints in each infinite maximal lines are equivalent. A set of corresponding infinite maximal lines, C_l , and a set of intersections, C_i , are found through this process.

Corresponding infinite maximal lines:

$$C_l = (l_i \square l_p, l_j \square l_q, l_k \square l_r)$$

Corresponding intersections:

$$C_i = (i_{ij} \square i_{pq}, i_{ik} \square i_{pr}, i_{jk} \square i_{qr})$$

Symmetry emergence

A set of emergent segments, K_e , a set of midpoints of emergent line segments, P_m , and a set of perpendicular bisectors of emergent line segments, L_b , are inferred from C_i :

$$K_e = \{(i_{ij}, i_{pq}), (i_{ik}, i_{pr}), (i_{jk}, i_{qr})\}$$

$$P_m = \{i(i_{ij}, i_{pq})_m, i(i_{ik}, i_{pr})_m, i(i_{jk}, i_{qr})_m\}$$

$$L_b = \{l(i_{ij}, i_{pq})_m, l(i_{ik}, i_{pr})_m, l(i_{jk}, i_{qr})_m\}$$

As a consequence, reflectional symmetry, S_{\square} is discovered as shown in Figure 12(c).

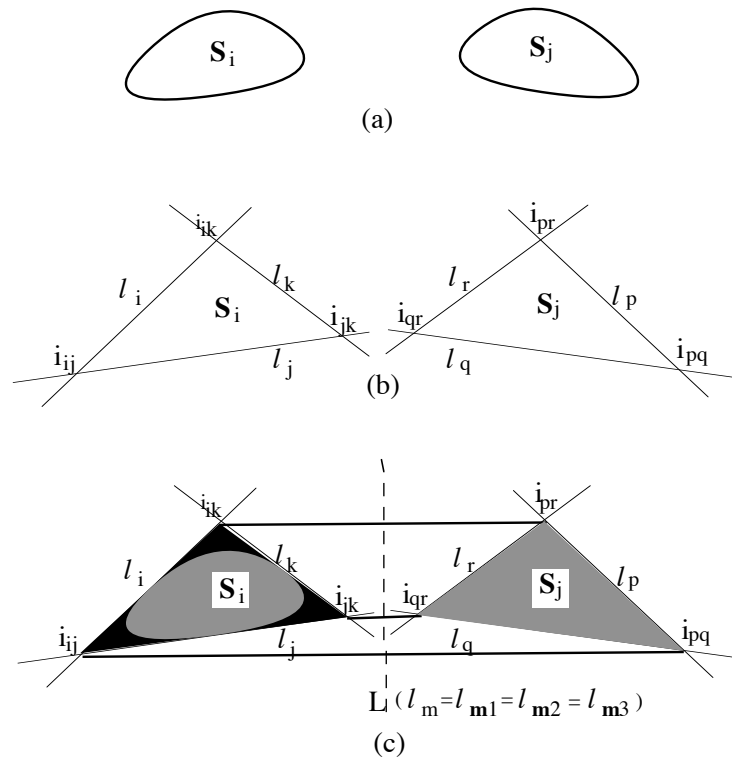


Figure 12 : Discovering reflectional symmetry: (a) two triangles as given shapes; (b) representation of given shapes using infinite maximal lines; and (c) discovering reflectional symmetry.

Other types of symmetries, such as translational symmetry, rotational symmetry and glide reflectional symmetry, are discovered when translational constraints, rotational constraints and glide reflectional constraints are satisfied respectively.

4.4 Using of emergent semantics in architectural design

Using the shape semantics for designing, particularly in architectural design, is an important potential for designers in practice. In this section we describe how designers may be able to use the shape semantics in their designing. The ideas are described through the following example.

Some of interesting reflectional symmetries from the facade of Casa Rotonda as shown in Figure 13(a) are discovered through the process outlined in Section 4.3 . The outline of the facade and the window are represented by infinite maximal lines. As a result, two reflectional symmetries are introduced in Figures 13(b) and 13(c) even though there are many other symmetries. Choosing some semantics from the many possible depends on the designer's interest and the requirements of the design.

Figure 14 shows two uses of the reflectional symmetries emerged from Figure 13. Operations on structures, such as moving, reshaping or rotating, provide opportunities for new designs to designers. If the designer wishes to keep an emergent shape semantics, reflectional symmetries in this example, the shape semantics is constrained to exist independent of other operations. If the designer wants to adapt the symmetry concept for his design in this example, the reflected structures are automatically reshaped when one part about the axis is reshaped by the designer. As a result, Figure 14(a) shows a new design of the facade generated by reshaping the brick part and Figure 14(b) shows a new facade which now has a new window shape.

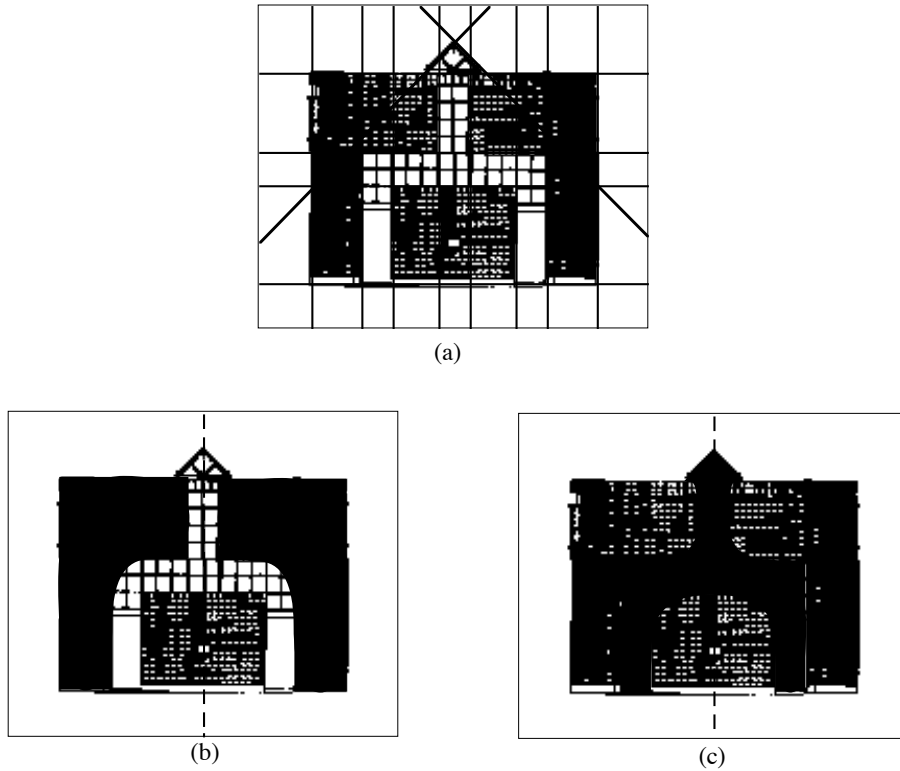


Figure 13: Emerging some of the reflectional symmetries from the facade of Casa Rotonda (Mario Botta, 1980-1981) (from Nicolini, P. (1984). *Mario Botta: Buildings and project 1961-1983*, Rizzoli, New York, p.45): (a) representation of the facade using infinite maximal lines; (b) one of emerged reflectional symmetries; and (c) one of emerged self reflectional symmetries.

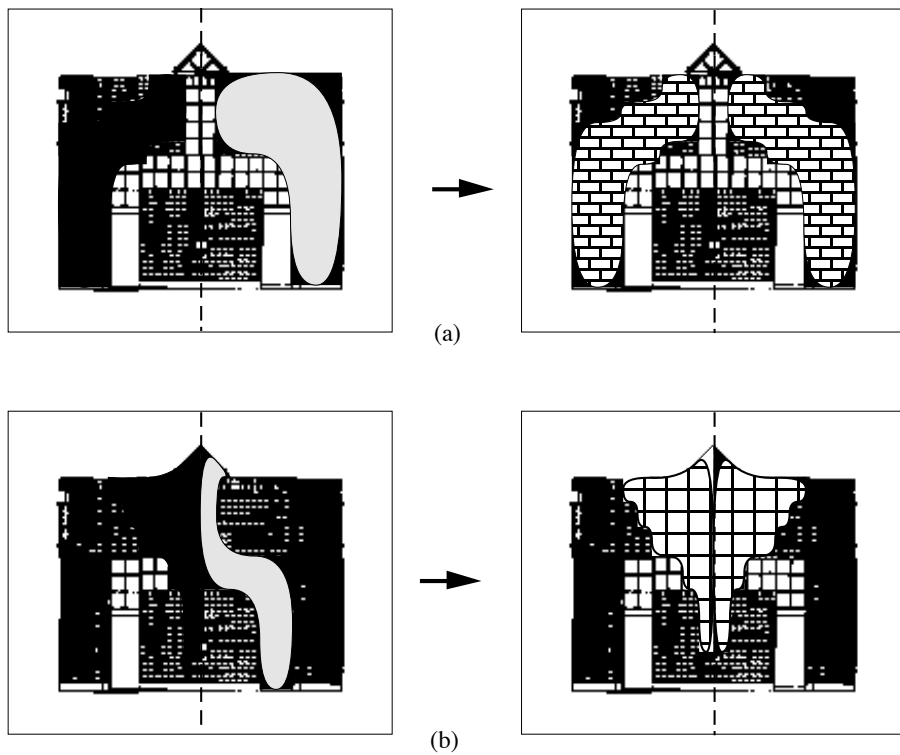


Figure 14: Use of visual symmetry in design: (a) generating new reflectional symmetry by reshaping one part of Figure 13(b) after choosing to maintain the reflectional symmetries; and (b) generating new self reflectional symmetry by reshaping one part of Figure 13(c) after choosing to maintain the self reflectional symmetries

5 Discussion

Current CAAD systems have been developed to represent well developed designs and have primarily been used to produce the graphic documentation of those designs. As a consequence they are not necessarily suited to document design concepts as they are developing. One area of weakness of current systems relates to the concepts of emergence and in particular graphical emergence. This paper has developed processes which support both shape emergence and shape semantics emergence capable of being implemented as front ends for traditional CAAD systems. The use of such emergence processes allows both the system and the designer to "see" the drawing differently from what was intended when the drawing was being produced. This novel "seeing" plays an important role in the design process as it allows a designers to construct new concepts from what has already been drawn. The computational processes described here allow these new concepts to form the basis of further designing.

Many other forms of graphical and non-graphical emergence than those described here may be possible. Of importance is not just the discovery of the emergent concept but its representation in the CAAD system to allow its use in the design process. Graphical emergence provides opportunities for computer-based design support at the conceptual stage of designing, opportunities currently not available.

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