The generation of Hepplewhite-style chair-back designs

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Abstract. A parametric shape grammar is given for the generation of Hepplewhite-style chair-back designs.

Introduction

"To unite elegance and utility, and blend the useful with the agreeable, has ever been considered a difficult, but an honorable task. How far we have succeeded in the following work it becomes us not to say, but rather to leave it, with all due deference, to the determination of the Public at Large" (Hepplewhite, 1794).

The great epoch of English cabinetmaking reached its zenith during the last half of the eighteenth century. Yet, the aesthetic appeal and functionalism of a Chippendale, Hepplewhite, or Sheraton, for example, is still compelling and being imitated nearly two centuries after the original designs were created. Interestingly though, the formulations of furniture designs in the eighteenth century were based on design standards quite different from those embraced today. During the late 1700s, guide-books or catalogs were published by the more prominent and influential cabinetmakers for the purpose of providing other cabinetmakers and designers with a wide variety of formal models on which to base their own designs. As Greenberg (1977, page 72) notes:

"The drawings in the handbook explore interrelated series of formal variations based on a given set of themes .... Each aesthetic theme has a base model, the simplest form of the model, and by using different degrees of formal, ornamental, metaphorical, and structural complexity, an appropriate design solution could be developed. Rather than justify the base models, the handbooks document a few design variations."

Thus,

"Design was understood as a process of refinement requiring the development of increasingly rich and complex solutions based on accepted models .... Innovation is largely restricted, therefore, to the development, in ever more brilliant designs, of already stated themes" (Greenberg, 1977, page 75).

The result of this type of design methodology is a highly developed language based on a particular model or paradigm. Creativity is expressed not by innovation of new paradigms or novelty as is so often encouraged and rewarded today. It is expressed by elaborations on the given paradigm within the context of the language which defines it. Good design, therefore, is a reflection of the designer's ability to fully understand this language and to develop its potentialities in an articulate and refined way.

In this paper, three examples of the Hepplewhite-style shield-back chair are studied, in particular the design of the back itself, and traced to a common base model or paradigm. Given this paradigm, a *parametric shape grammar* (Stiny, 1977) is developed which defines its unique characteristics and constraints. The grammar specifies shape rule schemata which generate not only the three designs in the original corpus, but also a wide range of new designs within the constraints of the paradigm.

Like the guidebooks of the eighteenth century, the grammar is the design tool by which new solutions can be developed based on a given model. The language of Hepplewhite-style chairs defined by this grammar can be seen as an extension of the catalog of designs compiled by Hepplewhite himself.

The shield-back or heart-shaped chair was the design which brought Hepplewhite his greatest reknown. The pattern of the back is invariably composed of smooth, unbroken curves richly ornamented with familiar neoclassical motifs such as urns, medallions, and festoons of drapery; the seats are usually square and the legs tapering. It is the design of the backs however, which allows for the greatest variation in style, while at the same time adhering to easily discernable and well-defined regularities which uniquely identify a chair as being 'Hepplewhite'. In fact, it is the design of the chair-back alone which so strongly differentiates a Hepplewhite chair from a Sheraton chair, for example; the legs and the seat being almost identical.

The three examples of a Hepplewhite-style shield-back chair (figure 1) shown below are attributed to the American architect and furniture designer, Samuel McIntyre, a close contemporary of Hepplewhite and a leading exponent of his work. With the exception of slight differences in ornamentation, the chair-backs shown in figures 1(b) and 1(c) are direct copies of chair-backs designed by Hepplewhite. As will be shown, all three chair-back designs can be said to exemplify a particular design paradigm within the Hepplewhite style.

In the following sections, this paradigm will, first, be analyzed and described by distinguishing certain characteristics common to and expressed by the three chair-back designs. These unique characteristics will then form the basis for development of a *parametric shape grammar* which defines the paradigm and gives schemata to construct new examples of it by generating simple rectilinear patterns. Finally, a procedure is given which translates these basic rectilinear patterns into curvilinear designs consistent with the Hepplewhite style.

The chair-back designs generated by the grammar and procedure give only a partial description of a Hepplewhite shield-back chair. The design of the seat and the legs and the carved ornamentation, also uniquely 'Hepplewhite', is not dealt with here although equally amenable to definition by a grammar.
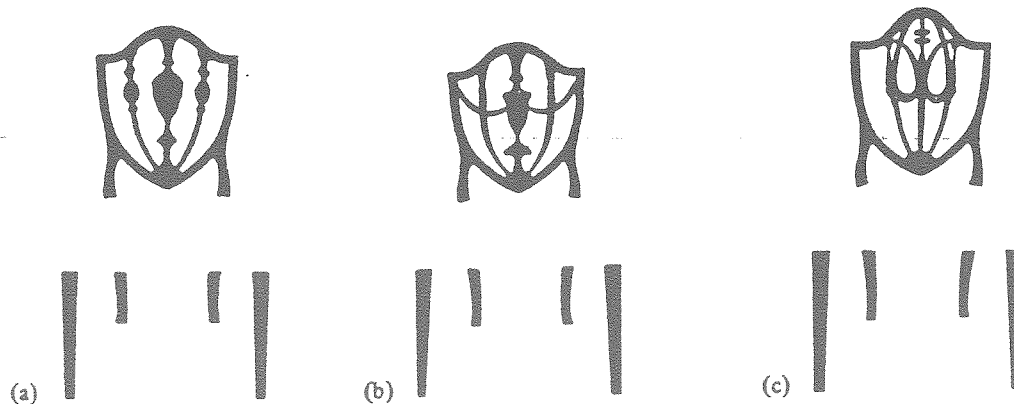

Figure 1. Three Hepplewhite-style shield-back chairs attributed to Samuel McIntyre.

An analysis of the chair-back designs
Examination of the three chair-back designs in the corpus reveals first, a division of the back into two equal parts and second, a division of these two halves into two approximately equal parts. This elementary subdivision constitutes a *basic curvilinear shape* from which a series of new and more complex designs can be developed.

The top border, side borders, central axis, and intermediate axes of the *basic curvilinear shape* are defined as in figure 2. Observe that the chair-back design in figure 1(a) is simply the *basic curvilinear shape* with the addition of ornamental motifs along the central and intermediate axes. Elaborations of the *basic curvilinear shape* are produced by the addition of curves[1] interlacing the borders and axes of this shape; they are uniquely determined by rules which specify how these curves are connected, their frequency, and the approximate angle of their curvature.

The addition of curves to the *basic curvilinear shape* must adhere to the following constraints:

(1) Curves must be symmetric about the central axis.

(2) Curves may be added between the central axis and an intermediate axis. Each of these added curves must connect at some point with another added curve. No more than three such curves may be added, and if three occur two of them must intersect at one and only one point in the area between the central and intermediate axes (figure 3). As is readily seen, more than three curves would unnecessarily perplex the central area of the chair-back and contradict the light and airy quality characteristic of the Hepplewhite style.

(3) One and only one curve may be added between a side border and an intermediate axis and it must connect with a curve between the central axis and an intermediate axis (figure 4). In other words, this curve cannot be added unless a curve has been previously added to the central area of the chair-back. Thus, the central motif predominates over a side motif.

(4) The angle of any curve cannot be so small that the curve appears discontinuous or abrupt. Aside from this aesthetic consideration, too acute an angle would make the task of carving the curve in wood a near impossibility.
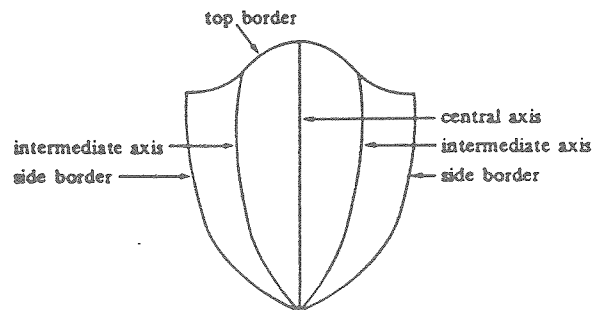

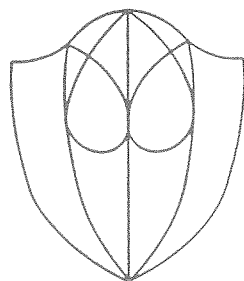
Figure 2. Basic curvilinear shape.

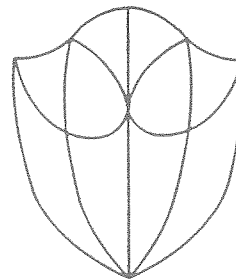Figure 3. Three curves are added between the central and intermediate axes.

Figure 4. A curve is added between the intermediate axis and the side border.

[1] For the purposes of this paper, the terms *curve* and *curved line* are loosely defined as any line that deviates from straightness in a smooth and continuous fashion.

A parametric shape grammar for generating chair-back designs

The constraints determining the design of a chair-back, as given in the preceding section, can be more succinctly and rigorously expressed by the use of a *parametric shape grammar*.

First, the *basic curvilinear shape*, defined earlier, is translated into a *basic rectilinear shape* (figure 5). Since chair-back designs are symmetric about a central axis they can be minimally represented by only half of the design divided along this axis. Thus, the initial shape of the grammar (figure 6) is half of the *basic rectilinear shape* cut along its central axis. More exactly, it is a labelled shape composed of a quadrilateral, and a triangle with vertices at the fixed points p_1, p_2, and p_3. The label A is attached to one vertex of the quadrilateral and the label * is attached to a point at the centroid of the triangle. All of the shape rule schemata as indicated (figure 7) are applied to the initial shape and to labelled shapes produced from it, under similarity transformations.

Schema 1 of figure 7 states that any triangle of a constant area can be divided into a quadrilateral and a triangle by placing a line between its two longest sides.

More specifically, the left side of the schema consists of a triangle with vertices at the fixed points p_1, p_2, and p_3 and the label * attached to the point at its centroid. The right side of schema 1 consists of a triangle identical to that on the left side, divided by a line with parameterized endpoints (x_1, y_1) and (x_2, y_2). The label B is attached to the point (x_1, y_1), and the symbol * to the parameterized point (x_3, y_3).
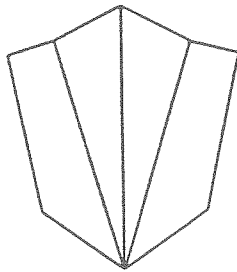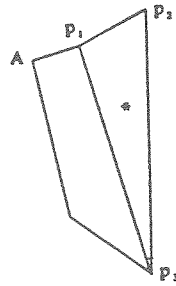

Figure 5. Basic rectilinear shape.

Figure 6. Initial shape.

4a $\langle s_\phi, \{(0, 0): A\}\rangle \rightarrow \langle s_\phi, \varnothing\rangle$
4b $\langle s_\phi, \{(0, 0): B\}\rangle \rightarrow \langle s_\phi, \varnothing\rangle$
4c $\langle s_\phi, \{(0, 0): *\}\rangle \rightarrow \langle s_\phi, \varnothing\rangle$
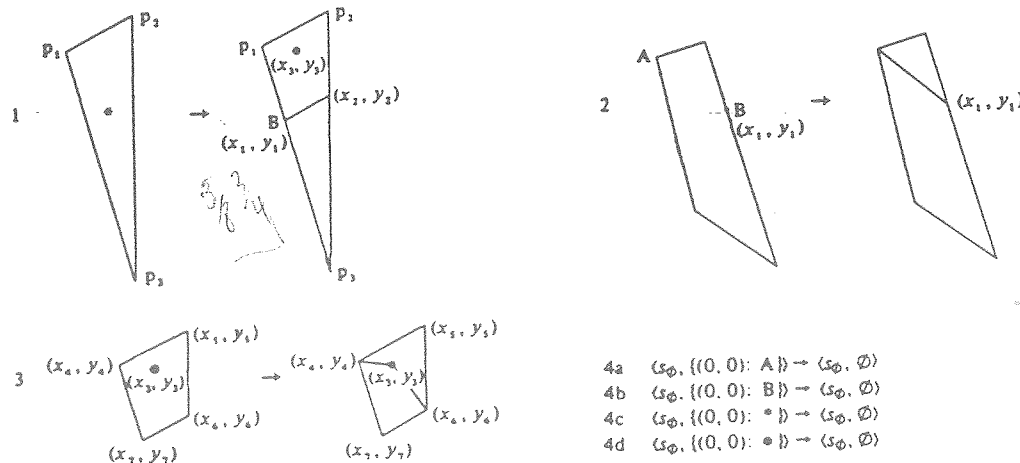4d $\langle s_\phi, \{(0, 0): *\}\rangle \rightarrow \langle s_\phi, \varnothing\rangle$
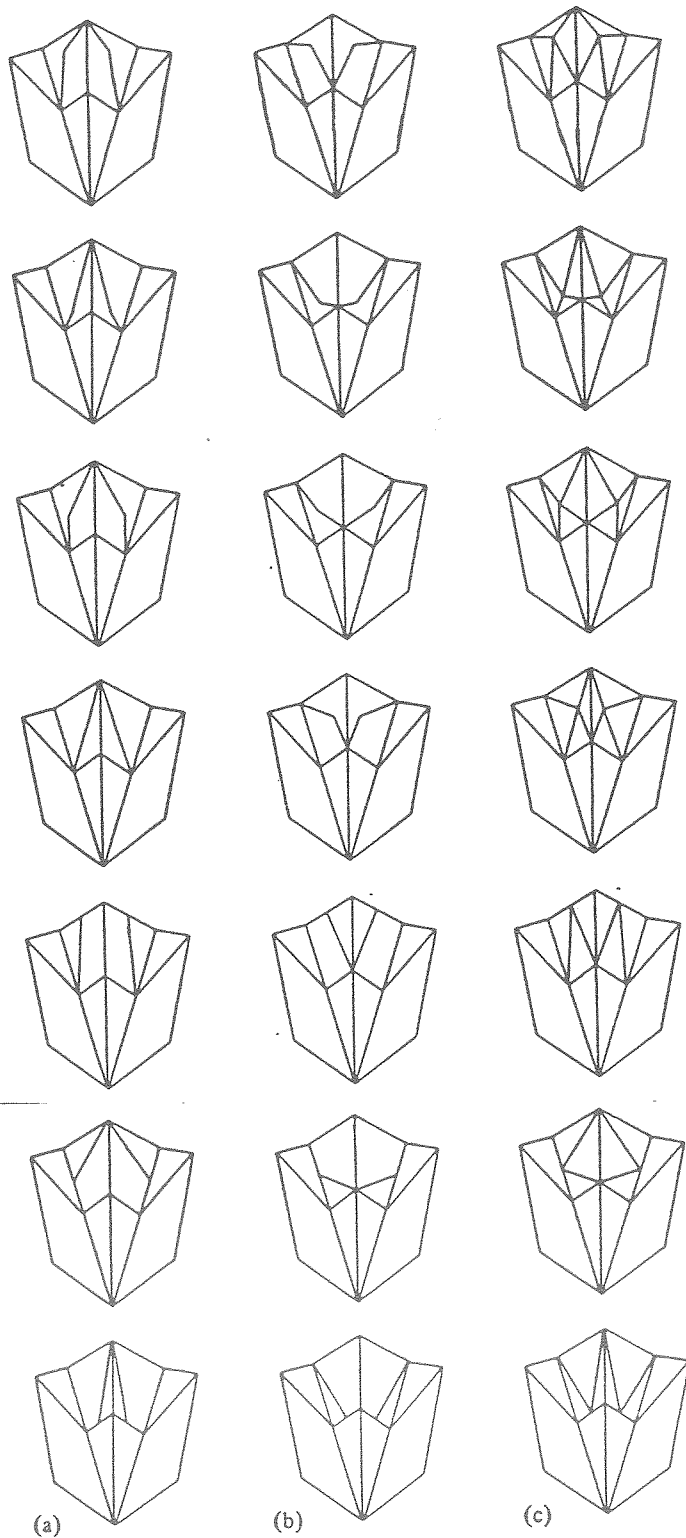
Figure 7. Shape rule schemata.

Figure 12. Rectilinear designs generated by the shape grammar. In (a) and (b) schema 3 is used once. In (c) schema 3 is used twice.

Values assigned to the parameters x_1, x_2, x_3, y_1, y_2, and y_3 must satisfy all of the following conditions:

(1) The point (x_1, y_1) is any point between five eighths and three quarters the distance from point p_3 to point p_1.

(2) The point (x_2, y_2) is any point between five eighths and three quarters the distance from point p_3 to point p_2.

(3) The angle θ (figure 8) formed by drawing a line with endpoints (x_1, y_1) and (x_2, y_2) must be greater than or equal to $90°$.

(4) The point (x_3, y_3) can be any point on the lines with endpoints p_1 and p_2, or p_1 and (x_1, y_1), or (x_1, y_1) and (x_2, y_2) in the intervals m units away from the endpoints of these lines where m is a fixed constant (figure 9).

The point (x_3, y_3) can also be any point within the area defined by constants c_1 and c_2. This area is inside the quadrilateral with vertices at (x_1, y_1), (x_2, y_2), p_2, and p_1, and its boundaries are parallel to the boundaries of the quadrilateral (figure 10). The constants c_1 and c_2 are fixed distances along the lines which bisect opposite sides of the quadrilateral; c_1 is a constant distance from each side of the quadrilateral, and c_2 is a constant distance from the intersection of these lines.

The above conditions prevent lines defined by the point (x_3, y_3) from coming too close to the sides of the quadrilateral, and, in most cases, they prevent these lines from forming straight or approximately straight lines.

Schema 2 of figure 7 states that given a quadrilateral with the label A attached to one of its vertices and the label B at the point (x_1, y_1), a line may be drawn between these two points. At the same time, the label A and the label B are erased.

Note that this schema can only be applied after schema 1 has been used since the point (x_1, y_1) with the label B attached to it is defined by schema 1. For this same
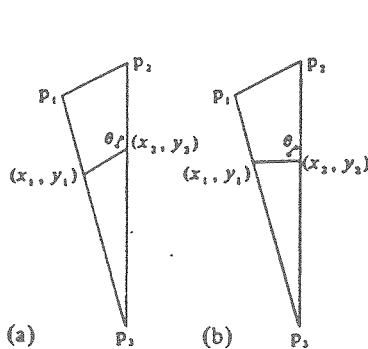

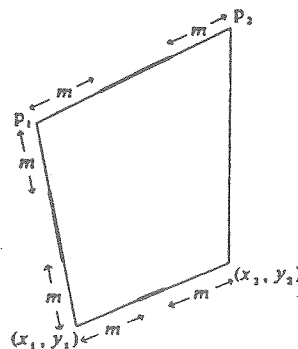**Figure 8.** Possible placements of the line with endpoints (x_1, y_1) and (x_2, y_2).

Figure 9. The point (x_3, y_3) can be coincident with any point on the bold lines indicated in the figure.
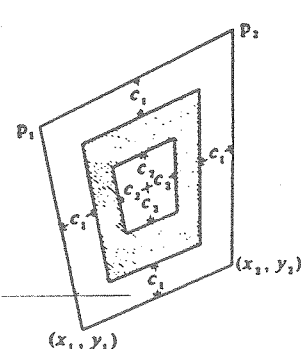
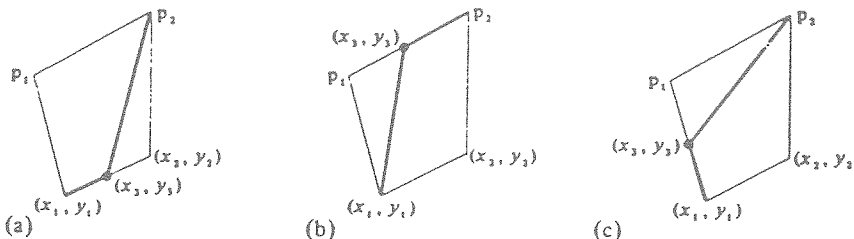**Figure 10.** The point (x_3, y_3) can be any point in the shaded area.

Figure 11. Lines may overlap a line previously generated as in (a) or a line in the initial shape as in (b) and (c).

reason, no additional conditions need be given for the parameters x_1 and y_1 as they automatically satisfy the conditions given for schema 1 when schema 2 is applied.

Schema 3 of figure 7 states that given a convex quadrilateral with a parameterized point (x_3, y_3) with the symbol • attached to it, a line may be drawn from any vertex of the quadrilateral to the point labelled by •, and another line may be drawn from this same point to the vertex diagonally opposite the first vertex.

In some cases these lines may overlap a line previously generated by schema 1 [figure 11(a)], or a line in the initial shape [figures 11(b) and 11(c)]. Again note that application of this schema is only possible after schema 1 has been applied as the point (x_3, y_3) labelled by • is defined by schema 1.

Values assigned to the parameters x_4, x_5, x_6, x_7, y_4, y_5, y_6, and y_7 must satisfy the following condition:
(x_4, y_4), (x_5, y_5), (x_6, y_6), and (x_7, y_7) are vertices of a convex quadrilateral, such that $(x_4, y_4) = p_1$ and $(x_5, y_5) = p_2$, or $(x_4, y_4) = p_2$ and $(x_5, y_5) = p_1$.
No special conditions need be given for the parameters x_3 and y_3 as they automatically fulfill the conditions specified for schema 1.

Schemata 4a, 4b, 4c, and 4d allow for the symbols A, B, •, and • to be erased. When all symbols have been erased from a labelled shape generated at any stage in the application of the shape rule schemata, the shape generation process terminates as no schemata in the shape grammar can now be applied. Any shape with no symbols attached to it is a member of the language defined by the grammar.

To produce a complete rectilinear design for a chair-back, reflect any shape which is a member of this language along an axis coincident with the points p_2 and p_3.

In figure 12 a diversity of rectilinear designs are shown. They are produced by different placements of the point (x_3, y_3) in schema 1 of the grammar and by applying schema 3 once [figures 12(a) and 12(b)], and by applying schema 3 twice [figure 12(c)]. In all the designs the points (x_1, y_1) and (x_2, y_2) are kept constant although different assignments given to these parameters would also result in differing designs. Also note that schema 2 has been applied in all the designs. In each case, different designs would have been generated had this schema not been applied.

A procedure for replacing straight lines with curves in a chair-back design

The final stage in the generation of a chair-back design is the replacement of straight lines, in any previously generated rectilinear design, with curved lines. The following is a general procedure which specifies how straight lines are replaced by curved lines in a manner which preserves the original pattern of the straight lines, follows the logic of the grammar which generated them, and conforms to the standard of elegance and fluidity of line associated with a Hepplewhite chair.
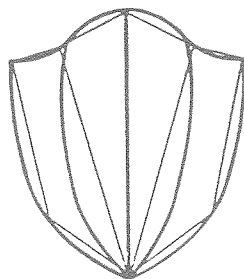
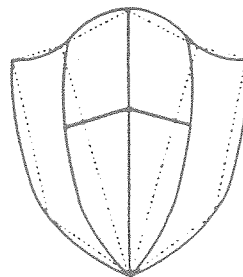Figure 13. Basic rectilinear shape is replaced by basic curvilinear shape.

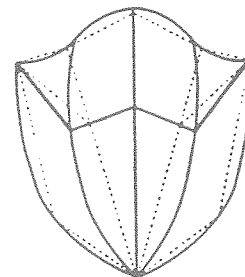Figure 14. Lines generated by schema 1 are extended.

Figure 15. Lines generated by schema 2 are repositioned.

A basic requirement governing this procedure is that all curves drawn must be symmetric about the central axis in the chair-back design. More specifically, lines which are reflections of each other across the central axis must be replaced by curves which are reflections of each other.

Step 1 Replace those lines that coincide with lines in the *basic rectilinear shape*, defined previously, with curves as in the *basic curvilinear shape* (figure 13). The top border, side borders, central axis, and intermediate axes of this curvilinear shape are as defined earlier in figure 2.

Step 2 Extend any lines generated by schema 1 of the grammar to intersect with the intermediate axis of the *basic curvilinear shape* (figure 14). Reposition any lines generated by schema 2 of the grammar to intersect with the newly extended lines (figure 15). Lines generated by schema 3 of the grammar are repositioned in the same manner as above.

Step 3 Replace any lines generated by schema 3 of the grammar with a curved line which follows the angle defined by these lines (figure 16). Special cases arise when the lines generated by schema 3 of the grammar overlap lines previously generated (see figure 11) as in figures 16(b) and 16(c). In cases like these, the new curve must still follow the angle defined by the lines generated by schema 3, even if one of them has already been replaced by a curve.

If the angle defined by the two lines generated by schema 3 is such that the lines form a straight line or an approximate straight line, the curve which replaces this line is determined by using the same convention adopted for schema 1 of the grammar (see figure 10). The curve must intersect any boundary of the area defined by the constants c_1 and c_2 twice and only twice (figure 17). In addition, any curve replacing

(a)   (b)   (c)
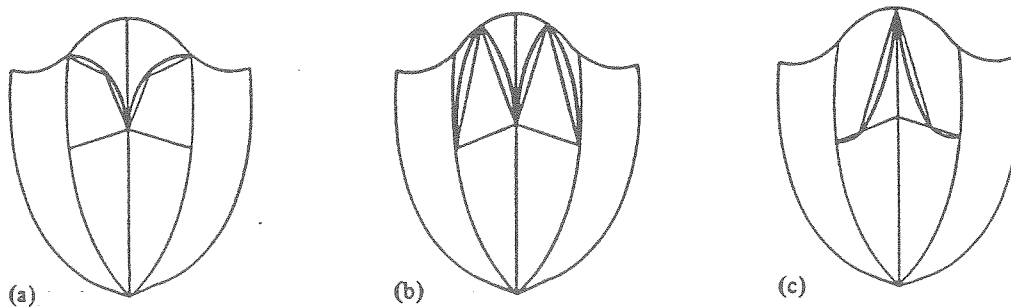
Figure 16. Lines generated by schema 3 are replaced with curves.

Figure 17. The curve replacing a straight or approximately straight line must intersect any boundary of the shaded area twice and only twice.
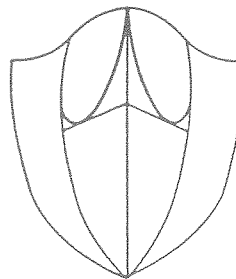
Figure 18. Adjustment of a curve which intersects the intermediate axis.

a line generated by schema 3 which slopes downward and intersects the intermediate axis should connect smoothly with this axis. This may require a slight adjustment of the curve at the point of intersection (figure 18).

Step 4 If a line has been generated by schema 2 of the grammar it must be replaced together with a line generated by schema 1 of the grammar, with one continuous curve. (Recall that an application of schema 2 is contingent upon a previous
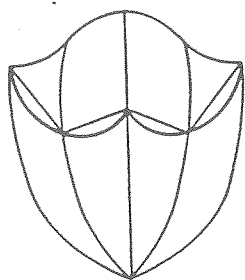
Figure 19. One continuous curve replaces a line generated by schema 2 and a line generated by schema 1.
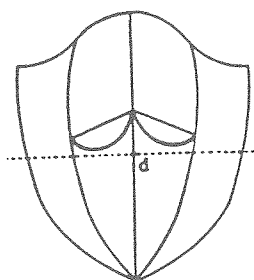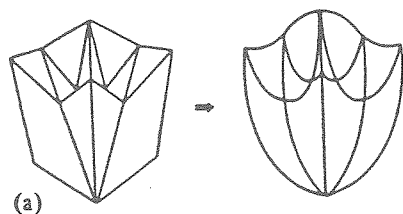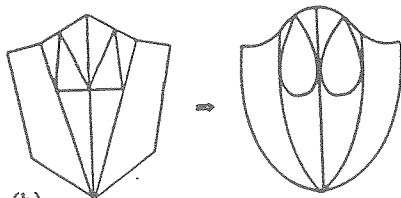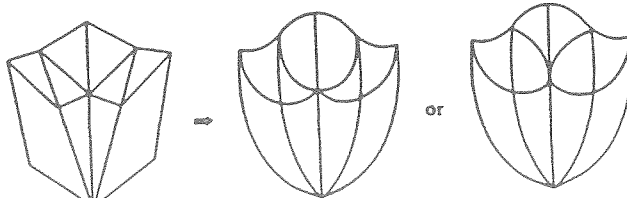
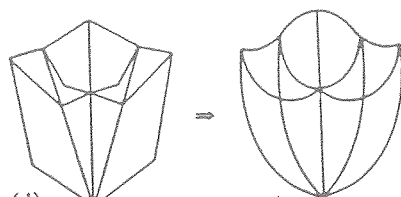Figure 20. The curve cannot intersect the broken line defined by the point *d*.

(a)

(b)

(c)   or

(d)

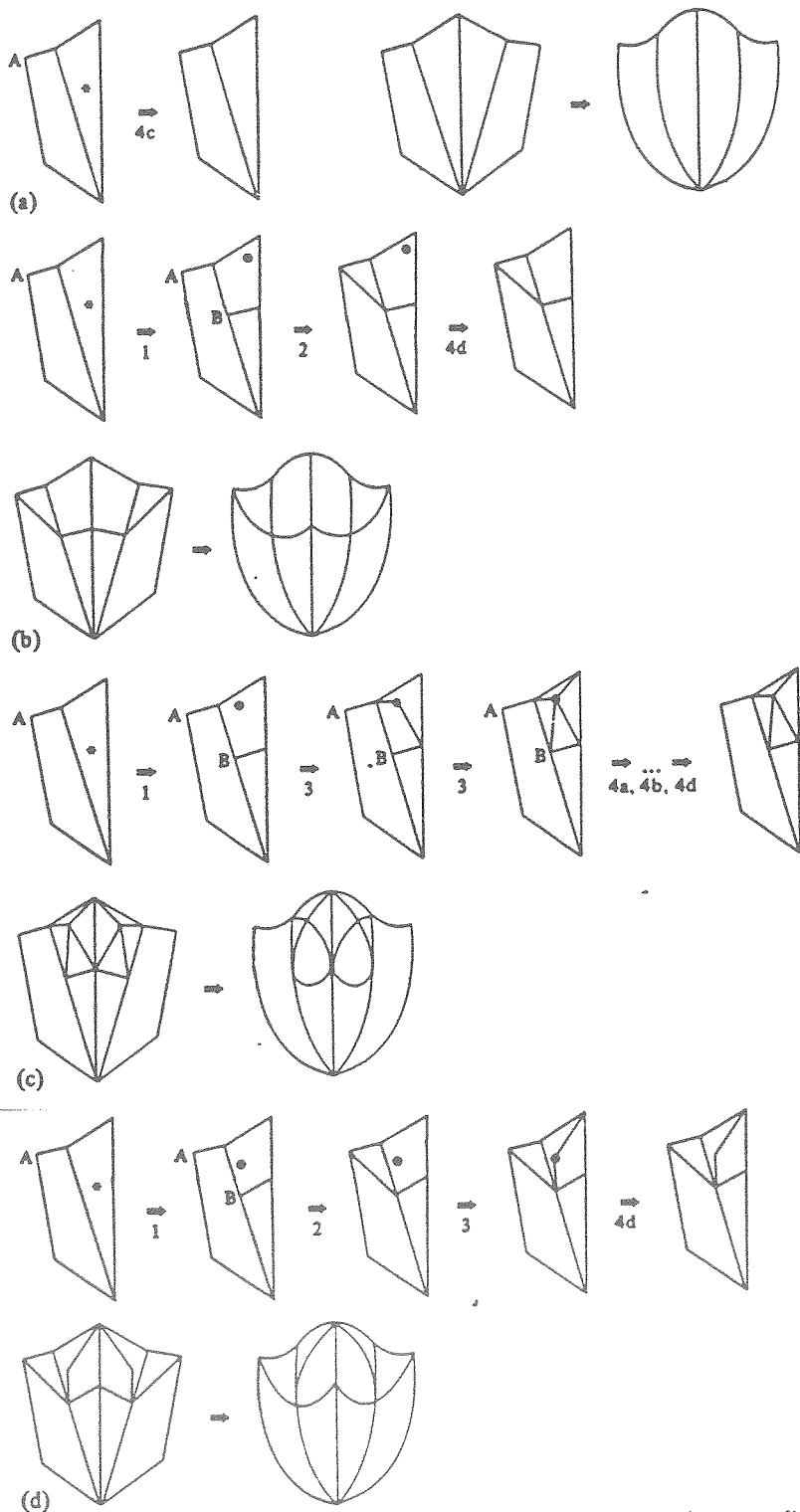Figure 21. Rectilinear designs are translated into curvilinear designs.

Figure 22. Chair-back designs generated by the grammar. The schema applied in each step is indicated by the number beneath the double arrow (⟹). A complete rectilinear design and its corresponding curvilinear design are shown. Chair-back designs (a)–(c) are for the chairs shown in figures 1(a)–(c); chair-back design (d) is new.

application of schema 1.) This curve must slope downwards and should follow the angle defined by the line generated by schema 1 and the line generated by schema 2 (figure 19).

Step 5 Any line or part of a line generated by schema 1 of the grammar, not already replaced by a curve, must be replaced by a curve which satisfies the following conditions:

1. The curve must slope downwards.
2. The lowest point of the curve must not fall below a line which is perpendicular to the central axis and which intersects it at a fixed point d along the axis (figure 20). As described in *step 3* above, this curve should also connect smoothly with the intermediate axis.

Examples of rectilinear designs and their curvilinear counterparts produced by application of the preceding procedure are shown in figure 21. Note that a rectilinear design can sometimes have more than one corresponding curvilinear design. The converse is also true—identical curvilinear designs may be generated from different rectilinear designs [compare figures 21(c) and 21(d)]. In both cases this occurs when the lines generated by schema 3 of the grammar form a straight line or an approximate straight line and are replaced by a curve which does not follow the angle defined by these lines (see figure 17). This curve is identical with a curve which follows the angle defined by lines drawn by a different placement of the point (x_3, y_3) in schema 1 of the grammar.

Generations of chair-back designs

By means of the preceding grammar and procedure, the generations of the three chair-back designs in the original corpus plus one new example in the same style are given in figure 22.

In figure 23, a complete Hepplewhite-style chair is drawn from the design for the chair-back generated in figure 22(d). The grammar and the procedure specified here give a definition for only one design paradigm for a Hepplewhite-style shield-back chair. Other design paradigms based on different subdivisions of the chair-back were used by Hepplewhite. These paradigms can also be simply and explicitly defined by grammars and procedures similar to those given here.
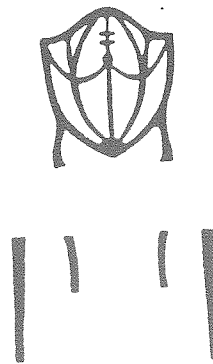

Figure 23. A new Hepplewhite-style chair.

Conclusion

The following is an excerpt from the preface to Hepplewhite's *The Cabinet-Maker and Upholsterer's Guide:*

> "... we designedly followed the latest or most prevailing fashion only, purposely omitting such articles, whose recommendation was mere novelty, and perhaps a violation of all established rule, the production of whim at the instance of caprice, whose appetite must ever suffer disappointment if any familiar thing had been previously thought of; we say, having regularly avoided those fancies, and steadily adhered to such articles only as are of general use and service, one principal hope for favour and encouragement will be, in having combined near three hundred different patterns for furniture in so small a space, and at so small a price. In this instance we hope for reward; and though we lay no claim to extraordinary merit in our designs, we flatter ourselves they will be found serviceable to young workmen in general, and occasionally to more experienced ones."

Clearly, the precepts governing the compilation of designs in the guide are comparable to those which govern the formation of the parametric shape grammar given here and the language of designs it defines.

Hepplewhite's selection of designs according to compliance with "established rules" and avoidance of "novelty" produced by lack of rules or "whim" is analogous to the language of designs which are generated by the shape rules of the grammar. His conciseness and economy in collecting the designs ("near three hundred different patterns ... in so small a space and at so small a price") is rivaled only by the grammar which generates enumerable designs by application of only four schemata. And, finally, the serviceability of the guide either to the inexperienced or to the experienced workman can be equated with the usefulness of the grammar either to the inexperienced or to the experienced designer and its ease of application.

References

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