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A blend of different tastes : the language of coffee makers

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0. Abstract

Shape grammars, utilizing function labels, are shown to be applicable to product design. A grammar that describes a language of coffee makers is presented and shown to generate a large class of coffee makers currently on the market, as well as new designs that could be introduced to consumers.

1. Introduction

Established consumer products take on different shapes and features to fill various market niches and distinguish themselves among their competition. However, many of these product classes have essentially the same functional breakdown. One example is that of coffee makers. Although there exist many different brands of coffee makers, and much variety even within a given brand, most coffee makers function based on a single procedure: Water is first poured into and stored within a container; it then flows through a heating element, turns to steam and rises through a tube where, at the top, it expands, condenses, and flows into a filter. The hot water mixes with the coffee grounds within the filter (which also controls the amount of time the mixing occurs based on its shape). The coffee is then released into a coffee pot below where it is kept warm on a burner that

is heated either by the same heater that turned the water to steam, or, in more expensive models, by a separate heating element. Most major brands of coffee makers (Krups, Black & Decker, Proctor Silex, Braun...) follow this basic principle even if augmented by digital control features, exotic materials and colors, and avant garde shapes.

With coffee makers, this basic functionality drives the requirements of the form of the product: the water heater must be below the water storage unit, the filter unit must be above the heater (but not so high as for the water to condense prematurely), the coffee pot must be below the filter unit, and the burner must be below the coffee pot. Even with these requirements on function and form topology, the market has demanded and supported a wide variety of coffee makers, from the simple to the sleek. In Figure 1, a variety of common makers are shown: Proctor Silex (1a), Black & Decker (1b), Braun (1c), and Krups (1d). Note that, although some appear more contemporary, smooth, and costly, each of them have the basic forms discussed above: water is poured into the water storage unit found in the back, in the front is a coffee pot that rests on a burner and above which is the filter unit that is attached to the top of the water storage unit. Each of these models are single burner units which means that a single heater resides in the burner, tubing leads from the bottom of the water container to the heater and from the heater to the filter unit. Beyond these similarities these models are quite unique, based on the shape of the unit as a whole and in particular the shape of the water storage unit. The filters, too, take different forms with the less expensive models having filters that slide out and the more expensive models having filters that rotate out and also a lever that prevents coffee from flowing if the pot is not properly seated beneath.

The different shapes of the coffee makers are driven by corporate image and market niches. The chief designer at Braun, Dieter Rams, in particular has a philosophy of design that includes the principles that good design is innovative, enhances the usefulness of a product, displays the logical structure of a product, enduring, honest, minimal, and

consistent right down to details (DMI, 1990). These principles are consistent with the consumer impression of Braun, and, in the authors[9] opinion, the coffee maker illustrated in Figure 1c; the Braun gives the impression of being of high quality and reliability, simple yet contemporary form, lasting, and expensive. The other coffee makers in Figure 1 are most likely consistent with consumers[9] impressions of the other corporate identities[1]: the Proctor Silex is simple, inexpensive, but works well; the Black & Decker is hardy, reliable, and of good value; the Krups, like the Braun, is of high quality and cost, of contemporary form, and lasting.

The various coffee makers fill different market niches: the Proctor Silex and Black & Decker models shown here are inexpensive and disposable, while the Krups and Braun are more costly and will satisfy the customers[9] needs for an extended period of time. As one examines the variety of coffee makers on the market one recognizes many different features from which consumers may choose.

Companies must react to the various markets while maintaining their corporate identity. One could even consider the trend toward one-of-a kind design and rapid time-to-market as the limit of the multitude of designs that consumers may desire.

The coffee maker product is not unique. Many classes of consumer products such as blenders, toasters, ovens, flashlights, telephones, and more, vary from their competition by shape and features, but are based on the same functional principles and the same breakdown of form topology as their competitors.

In this paper we propose that shape grammars, whose application has mostly been within the field of architecture, are ideal for modeling such classes of consumer products.

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[1] All subjective comments about the coffee makers are solely the opinions of the authors unless otherwise noted.

Within shape grammars, products can be partitioned into different topological regions which are often built around a given shape (for example, the Frank Lloyd Wright Prairie Houses grammar (Koning and Eizenberg, 1981) builds the houses off the fireplace). Labels can be used to connect the different regions together and make functional decisions about product features. We illustrate these ideas by introducing a parametric shape grammar for the design of coffee makers. An initial shape representing a coffee pot is used to partition the form into three regions: the base, the water storage container, and the filter unit. Each of these regions is individually designed and then blended together into a final form. The choice of one or two heating elements, sliding or rotating filter, flat or conical filter, fixed flow or variable flow, and continuous flow or stop-lever-design features are determined via function labels. The grammar is used to generate a variety of coffee makers including those designs currently on the market as illustrated in Figure 1, and new design concepts.

We propose that shape grammars for product design such as the one presented here can be used to support the conceptual design of these products. They allow the designer to explore different shape options through modification of a single rule or parametric value. They allow a company to maintain certain rule or parameter value choices to model their corporate image, to learn about their corporate image by identifying what rule/parameter choices they tend to use, and to learn about their competitors' image. They allow for the rapid generation of design concepts to improve the time-to-market cycle and increase one-of-a-kind design capabilities. However, we recognize, too, the limitation of design conceptualization potentially imposed by such a grammar; the grammar is best used for the generation of standard products within the routine form and function framework already discussed. Radical changes to the design will most likely occur outside of the given grammar, although creative forms are still achievable from the grammar[2]. An important feature of shape grammars is that they are easily adaptable by adding and

[2] Brown and Cagan (1996) formally define the creative solution capabilities with grammars as *bounded creativity:* if an agent behaves in a manner that is within limits specified by the grammar but beyond its standard practice for the current goal, then the solution approach is considered creative.

removing shape rules, and thus new design characteristics can be incorporated into the language.

In the next section related literature will be discussed. Next, the coffee maker grammar will be presented and then a detailed example shown. Finally a variety of coffee makers generated by the grammar will be presented before concluding.

2. Shape Grammars

Shape grammars (Stiny, 1980) have successfully been used to generate a variety of architectural designs including villas in the style of Palladio (Stiny and Mitchell, 1978), Mughul gardens (Stiny and Mitchell, 1980), prairie houses in the style of Frank Lloyd Wright (Koning and Eizenberg, 1981), Greek meander patterns (Knight, 1986), suburban Queen Anne Houses (Flemming, 1987), and windows in the style of Frank Lloyd Wright (Rollo, 1995). A shape grammar derives designs in the language which it specifies by successive application of shape transformation rules to some evolving shape, starting with an initial shape (I). In particular, given a finite set of shapes (S) and a finite set of labels (£), a finite set of shape rules *(R)* of the form a -» j$ transform a labeled shape a in $(5,I)^+$ into a labeled shape p in (5,1)°, where $(5,I)^+$ is the set of all labeled shapes made up of shapes in the set *S* and symbols in the set *L* and *(S,L)°* is the set that contains in addition to all of the labeled shapes in the set (SI)* the empty labeled shape <s^<|». Shapes themselves can be transformed with Boolean operations. Parametric shape grammars are an extension of shape grammars in which shape rules are defined by filling in the open terms in a general schema. An assignment *g* which gives specific values to all the variables in a and (5 determines a shape rule g(oc) —»g(P) which can then be applied on a labeled shape in the usual way to generate a new labeled shape. This work takes advantage of labels and parametric shapes in the derivation of a concise shape grammar for coffee makers.

There has been limited application of shape grammars to engineering design. Fitzhorn (1990) and Longenecker and Fitzhorn (1991) present shape grammars specifying the languages of constructive solid geometry and boundary representations (i.e., realizable solids). Brown, McMahon, and Sims Williams (1993) present a manufacturing-oriented shape grammar which specifies the language of all axi-symmetric objects manufacturable on a given lathe. Reddy and Cagan (1995a&b) and Shea, Cagan and Fenves (1996) present a parametric shape grammar for the design of truss structures that uses the shape annealing technique of Cagan and Mitchell (1993) to generate optimal truss structures. This work is the first to apply shape grammars to a class of individual products.

3. A shape grammar for coffee makers

This section presents a shape grammar for the design of coffee makers as an example of the applicability of shape grammars to product design. The function and form topology breakdown has already been discussed. Due to the lack of functional coupling, the design procedure can be decomposed into function design and form design. The function drives the form in the product and in the application of the grammar rules; function labels are designed to maintain the proper function-to-form sequence. The grammar is a parametric, labeled 2-D shape grammar that through three views of the product — top, side, front — creates a 3-D shape. Figure 2 shows the notation for the three views, separated by hairlines, as used within the shape grammar. In general, any rule in the grammar manipulates these three views. By default, if only one view is illustrated then only that view is manipulated; unless otherwise noted, if only one view is shown then that view is the side view. The grammar is shown in Figures 3-7. The coffee maker is considered to be made up of three main parts: the filter unit, the water storage unit and the base unit. These three units are arranged around the space for the coffee pot which acts as the initial shape for the grammar.

The first set of rules, called initial shape rules as shown in Figure 3, distinguish between two main classes of coffee makers, those with one heating element and those with two, and break apart the basic form into the three regions. Rules 1 and 2 take as an initial shape a rectangular side cross section of the boundary of the space in which the coffee pot fits and distinguish between the two classes; a square label is associated with the initial shape to indicate a one heater design and a triangle label is used for two heater designs. In addition labeled points (indicated by solid dots and the associated label) p and z are added to define the right-most bounds on the design. These two points are constrained by:

$$x_z \simeq x_p \, .$$

Arbitrary points along the top, left side, and bottom of the initial shape are given the labels F, W and B, respectively, indicating the Filter, Water storage unit, and Base regions.

Next the basic cross-sectional shapes of the filter and base regions are designed using parametric rules 3-5 for the top, bottom rear, and bottom front, respectively. The position of the labeled points in rule 3 for the top of the unit are restricted based on the following constraints:

$$|x_{f'} - x_d| = |x_{t'} - x_b|,$$
$$|V - x_d| = |x_{s'} - x_b|,$$
$$|V - x_d| = |x_{r'} - x_{b'}|,$$
$$y_r = y_d = y_f = y_{b'} >$$
$$y_{s'} = y_{s'} > y_t <>$$
$$y_{p'} = y_1 > > y \cdot$$

The first three constraints ensure a symmetric filter unit formed by line r' s' t' b' a't" s" p' r'. The next three constraints ensure that there are no re-entrant corners in the filter. Note that in the right-hand side, labeled point a goes to labeled point a', and b goes to b'.

Rule 4 generates the shape of the bottom rear of the unit restricted by the following constraints:

$$x_{c'} \geq x_{y'} \geq x_{w'} \geq x_{v'} ,$$
$$y_{c'} \geq y_{y'} \geq y_{w'} \geq y_{v'} ,$$
$$y_{v'} = y_z ,$$
$$y_{c'} = y_{y'} ,$$
$$V = x_{v'} ,$$
$$y_{y'} \neq y_{w'} .$$

The first two constraints ensure no re-entrant corners. The third constraint ensures a horizontal base. The tubing into the base, if required, enters between points labeled w' and y'; the last three constraints ensure that the line w' y* lies on the common boundary between the water storage unit and the base.

Rule 5 specifies the bottom front of the unit restricted by constraints:

$x_{Z'} \wedge x_{ri} \geq x_{rri} \geq x_{d}$,

v > v > v > v .

3V = Xn' »

The first two constraints again ensure no re-entrant corners while the last two place restrictions on the form of the unit for desired design characteristics.

Next each of the three units are designed separately. In each of these units, functional requirements are considered first, driving the form decisions later. First the filter unit is designed. Shape rules 6-15 are used to address its functional requirements through the manipulation of labels. All labels specified in these shape rules are associated with the point previously labeled F. The labels 1,2,3,4 and 5 are used to generate the functional specifications of the filter unit. The label F is changed to F' to ensure that the function design rules cannot be reapplied. The presence of a label implies that the functionality associated with that label has not yet been addressed. Label 1 is used to decide between a rotating and a sliding filter; FMi refers to a sliding filter while FM_2 refers to a rotating filter. After the functionality associated with label 1 is designed, the label is changed to 1' and it plays no other part in the functional design of the filter unit. This process is then repeated for the labels 2,3,4 and 5. FTj refers to a conical filter, while FT_2 refers to a flat filter. FI refers to the inlet tube which is present in all coffee makers. FF| refers to a fixed flow coffee maker while FF_2 refers to a variable flow coffee maker. FSi refers to a mechanism to stop the coffee from dripping when the pot is not in place, and FS_2 is used when the mechanism does not exist. After all five labels 1-5 have been removed and the new labels 1'-5' created, the functional design of the filter unit is complete. The grammar is readily extendible for added functionality through the addition of labels and resulting shape rules.

Once the functionality of the filter unit is specified, its form is designed using rules 16-26. The form design is governed by the labels generated during the functional design stage.

First rule 16 removes unnecessary labels. Rule 17 then partitions the filter unit into a top portion and a movable bottom filter, and generates a top view. Rules 18 and 19 produce either sliding or rotating filters (the rotating hinge is indicated by the vertical dotted line). In the top view of these rules the center point is specified through a ^ notation and the extreme left-most points on the top and bottom of the filter unit are specified through points labeled C_1 and C_2 (the labels C_1 and C_2 correspond to points that lie on the planes containing r" and s\ respectively). These extreme points are used to define horizontal transition planes that will be used later to permit a transition in the shape of the water storage unit in the vertical direction. Rules 20 and 21 generate either conical or fiat filters. Rule 22 adds water tubing to the filter unit. Rule 24 adds in the variable flow mechanism (while rule 23 indicates that no such mechanism is present). Rule 25 adds in the optional water stop (rule 26 states that no water stop exists). Rules 25 and 26 also change the label s' to s'" to allow the water storage unit to be later designed. Again, the labels are associated with the unit in such a way that the form design can be carried out only in a particular order so that all functional requirements may be met (e.g., the water tube (rule 22) can not be applied until the top view is generated (rule 17)).

After the filter unit is completed, the base unit is designed using rules 27-37. First unnecessary labels are removed (rule 27) while function labels 6 and 7 are added. Also the label B is changed to B' to prevent the reapplication of the function design rules. The basic ideas used in designing the base unit are similar to those used in generating the filter unit. But here the designer chooses either rule 28 which designs a polygonal section with an arbitrary number of vertices (where the vertices $v_r v_n$, which are also labeled points, must lie on parallel lines to vertices Vi'-v_n') or rule 29 which designs an elliptical section. These rules give the grammar a generality not usually seen in current products; more restrictive (or general) rules can be substituted if desired. Note that in these rules the x-coordinate of the extreme points of the base are pre-specified by rule numbers 1,2, and 4. Again the center point is specified along with points labeled C_3 and C_4 (for the polygonal

base shape, at the location of labeled points C_3 and C_4, there also exists additional labeled shapes v, and v'_b respectively) to indicate the extreme left-most points of the top and bottom of the base (and to create two more transition planes to be used later). A designer-specified burner is also placed on the part of the top of the base unit on which the pot rests. The base heater is now added and, depending upon whether the unit has one or two heating elements, the water-carrying tubes are included between points labeled w' and y' (rules 30 and 31); the label w' is also changed to w" to allow the water storage unit to later be designed.

Next, to complete the base unit, the top of the base is joined with the bottom. Note that rule 28, which chose a polygonal as opposed to an elliptical shape for the base, added a label 8. If label 8 is present, rules 32-35, and then rules 36 and 37, are applied to connect the polygonal top to the polygonal bottom, possibly through an intermediary line if such a break is specified. The points labeled v_k and v_k' refer to labeled vertices vi...v_n and Vi'...v_n' generated in rule 28. Elliptical shapes are assumed to have a smooth blend and thus require no additional rules.

Next, the grammar focuses on the water storage unit. The right part of the center side cross-section of the water storage unit was formed by the preceding rules by merging the initial shape with the boundary between the water storage unit and the filter and base units. The steps in generating the water storage unit are similar to those used in the filter and the base units; however unlike those units, the water storage unit is only partially designed first using rules 38-42. The unit is completed in the next stage where it is used to blend the various sub units into a single, finished coffee maker. The label WFi indicates a hinged top for the water storage unit, while WF_2 models a grating at the top for filling water. Rule 41 places the water tubing in the unit for a single heating unit; rule 42 places the heater and tubing for a double heater design.

The design is completed with rules 43-100, creating a water storage unit that conforms to the filter and base units. With the exception of rules 43-46, all of the rules in Figure 7 show only the top view. Labeled points C_u C_2, C_3, and C_4 lie on four different horizontal planes also containing r'\ s "\ y\ and v\ respectively. To allow for varying cross-sections within the water storage unit the grammar requires the top view cross-sections of that unit on these four planes to be generated separately. The bounds along the x-direction of the shape within the planes are specified by rule 43. On each plane two additional points labeled, from top plane to bottom plane in the side view, oti and a_2, Pi and P2, Yi ^d Y2> 81 and 82 (and in the top view the analogous primed labeled points), indicate critical points defining a range in which the left-most point of the section generated by rules 47 - 54 must lie. Note that since the labels are associated with 2-D shapes and not the corresponding solids, the same labels can not be used in different views; however, *analogous* labels can be used in the different views. The right-most point of the same section must lie within the range specified by points *C*\... C4 and the center line ^. These restrictions are imposed to ensure that the water tubing and water lid or grating lie within the specified volume of the water storage unit[3] and that the filter and base units merge with the water storage unit. Rules 55 through 70 then add additional connected shapes to each plane. These shapes are swept along the plane creating the shape of the water storage unit on each plane. The shapes between these four planes are then blended together to complete the coffee maker. This allows for a transition in shape along the vertical dimension of the water storage unit, permitting a variety of designs while ensuring integration of the filter, base, and water storage units. The grammar could be restricted to only the top and bottom planes, or could be made more general by allowing more transition planes.

[3] enough space must be allocated between a, and r", p, and t\ y, and y\ and 5, and v\ to allow for the placement of the water tubing

A significant aspect of the individuality of the design stems from parametric rules 45-90. Figure 8 shows that for each rectangular shape the side dimensions are specified while for each circular shape the diameter is specified on each plane; the distances from the center of the filter or base units are also specified. Again, these parameters must satisfy the restrictions mentioned above within each transition plane. The top view is specified through the addition of an arbitrary number of parametric rectangles and circles (rules 47-70) and a template shape for the grate on the top if one exists (rules 45 and 46). The resulting rectangles and circles on each plane are labeled x_1, x_2, x_3, or x_4, appropriately, except for the grate which is labeled G. Rule 44 is used in lieu of rules 45 or 46 if a lid is desired rather than a grate. Note that rules 44-46 are only applied to the top plane, providing an opening through which water is poured into the coffee maker. Note that separate labels are associated with shapes on separate planes to ensure that shapes from one plane do not merge with those from another.

The actual shape of the unit is specified by parametric sweep rules 71-90 and merge rules 91-100. On each plane, each rectangle and circle can be swept in an arc or as a straight tangent from center. As the section sweeps, the width and depth in case of rectangular sections and the diameter in case of circular sections as well as the distance from the center are allowed to vary through designer-specified functions (f). Two functions are specified for each plane of the unit, one for a positive sweep from center and one for a negative sweep. The straight sweeps are specified as:

$d, h, r_0 = f(z)$ where z is the position of the positive or negative sweep,

while the arc sweeps are defined as:

$d, h, r, r_0 = f(\phi)$ where ϕ is the clockwise or counterclockwise sweep.

As each sweep is performed, the labels arc changed to Xj\ x_2\ x_3\ or X4', appropriately; after sweeping the grate its label is removed and its shape is hashed. Each plane cross-section is then formed by considering the envelope of the sweep of the remaining shapes by iterative application of rules 91-100; rules 95-100 also merge the water storage unit into the filter and base. Note that the grate is not merged with any other section. The cross-sections on each of these planes must be blended vertically between the planes through designer-specified surfaces (the method for blending is beyond the scope of the grammar; smooth blends are assumed).

This rule set generates a wide variety of coffee makers. More details can be specified with additional rules. More restriction on permissible shapes can be asserted by restricting the freedom of choice of the parametric functions. As will be seen in the next sections, this language describes many coffee makers available in the market as well as many styles not yet available to consumers. Due to the parametric nature of the grammar, an infinite number of different designs can be generated.

4. Example: Generating Coffee Maker Designs

The coffee maker shape grammar is now used to generate a complete design through straightforward application of the rules (Figure 9). The design is chosen to be a single heating element unit indicated by the label • selected by rule 1 (Figure 9a). The initial shapes of the filter and base units are now generated via rules 3-5 (Figure 9b). We choose a simple side view cross-section by specifying many of the points to be coincident.

Next the filter unit is designed. Functional rules 6, 7, 9, 11, 12 and 15 are applied to the unit and the following labels are associated with it: FMi, FTi, FI, FFi and FS2. Thus the filter unit has a sliding conical filter, with a fixed flow rate and no mechanism to stop coffee flow. Function-to-form rules 16,17,18,20,22,23 and 26 generate the filter unit shown in Figure 9c.

The base unit is then generated using rules 27,29 and 31. The shape, both at the top of the base unit and the bottom, is chosen to be a circle; the burner is also specified to be a circle (Figure 9d). Since this is a single heater model, tubing is added to the base unit to bring and remove water to the heating element (rule 31). The top and bottom of the base are joined using a smooth surface generating a cylindrical base unit

Next, the functionality of the water storage unit is designed with rules 38,40 and 41. The label WF_2 is added to indicate that the unit has a grating at the top to pour in water. The resulting right-most side of the center cross-section of the water storage unit is shown in Figure 9e. Next, the final shape of the water storage unit around the filter and the base is designed. The section around the filter (the top) is generated first by adding a square for the water grate (rule 46) and swept in a straight tangent (with rule 87). The top two transition planes are kept identical with a square for the top view of the unit specified by rules 48 and SO and sweeping them in straight tangents (rules 71 and 75) as illustrated in Figure 9f (both planes are illustrated; the left-hand one also contains the grate). The shape around the base is also generated by sweeping two squares on identical planes (rules 52,54,65,69,79, and 83 - Figure 9g). The final shape of the water storage unit is obtained by joining the sections between the transition planes by straight planes. The complete coffee maker is illustrated in Figure 10.

5. Discussion and Concluding Remarks

The coffee maker of Figure 10 is similar to that of the Black & Decker model shown in Figure lb. As a matter of fact each of the coffee makers shown in Figure 1 are generated by our grammar as can be seen in Figures 10 and 11. Although each of these units may appear to be quite unique, small changes in the application of the rules of this grammar and the selection of the parametric values are the only real differences in their shape characteristics. As mentioned in Section 3, an infinite number of coffee makers can be generated with this grammar. Three designs generated by the grammar that are different from those in the market are shown in Figure 12. Of course, shape is not the only contributor to design quality and appearance. Choice of material, control unit, color, and finish all affect the final product. However, many of these features could be included within an extended grammar. For example, color can be associated with the design through color grammars (Knight, 1989).

Understanding the selection of rules and choice of parameters give insight into the characteristics that designers use in their designs, the resulting product image and the corporate identity associated with the products. As discussed above, among the four models illustrated in Figure 1, the Braun and Krups are considered the more costly and highest quality designs, while the Black & Decker and Proctor Silex are considered to be less expensive. Other model lines within these companies may elicit different feelings of quality from consumers; however, among these four designs certain characteristics differentiate them into two classes. The Braun and Krups have a flow-stop device (rules 14 and 25) while the Black & Decker and Proctor Silex do not (rules 15 and 26); the Braun and Krups have rotating filters (rules 8 and 19) while the Black & Decker and Proctor Silex both have sliding filters (rules 7 and 18); also, the Braun and Krups have lids on top of their water storage units (rules 39 and 44) while the Black & Decker and Proctor Silex have grates (rules 40,46 and 87). These last few features reflect the image of the products consistent with their cost. Focusing instead on corporate identity, both the Braun and Krups primarily use angular sweeps as the focus of the water storage unit cross-sections, while the Black & Decker and Proctor Silex use squares in a straight sweep, giving a very different, everyday feeling about the product.

Coffee makers are not unique in being amenable to shape grammars. Rather, they are indicative of the wide applicability of the field to a new area of focus. Note that while the coffee maker grammar uses only labels to represent functions, which is possible because the form partition is also the function partition and the functions are not coupled, more intricate functional representations may be required for other products and a detailed functional grammar may be needed. Mitchell (1991) describes a specialized shape grammar that operates at a level removed from the maximal line and point representation of conventional shape grammars (Stiny, 1980a; Krishnamurti, 1980 and 1981) but instead operates on atomic entities that combine to create functional shape. Schmidt and Cagan (1995, 1992) define an *abstraction grammar* as a production system for the representation and generation of function and form layouts. This paper presents a shape grammar for coffee makers; grammars for blenders, toasters, ovens, flashlights, telephones, washing machines and other consumer products could aid in the early design of many such common products.

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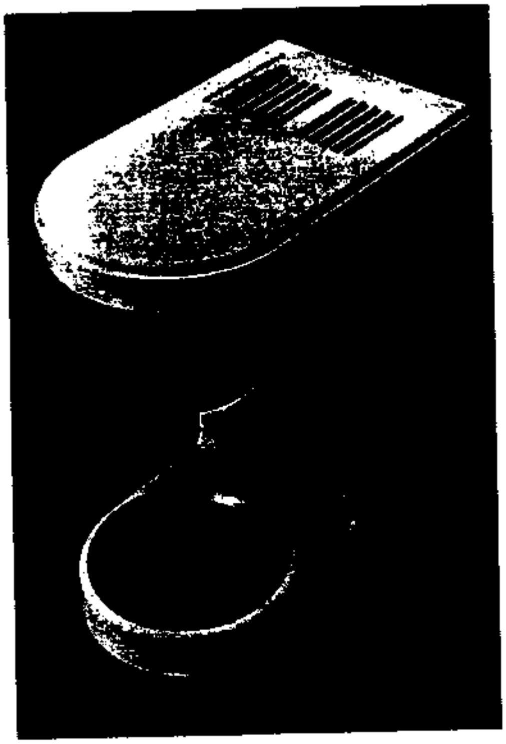
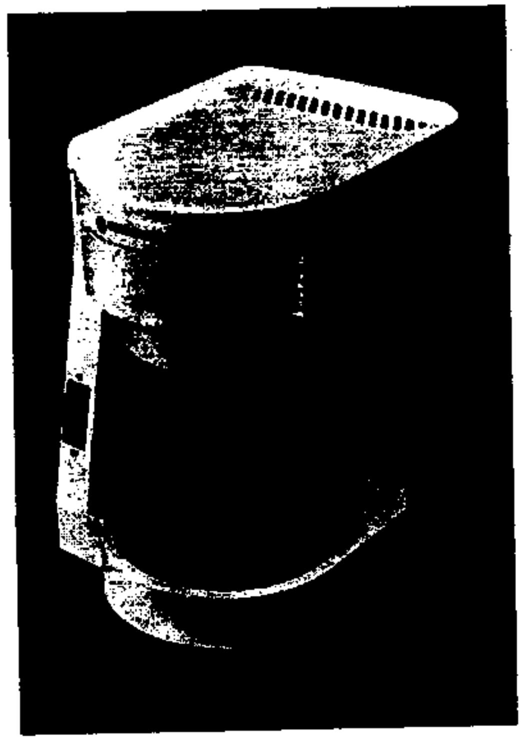
Stiny, G., and WJ. Mitchell (1980), "The Grammar of Paradise: on the Generation of Mughul Gardens", *Environment and Planning* B_y 7:209-226.



(a)



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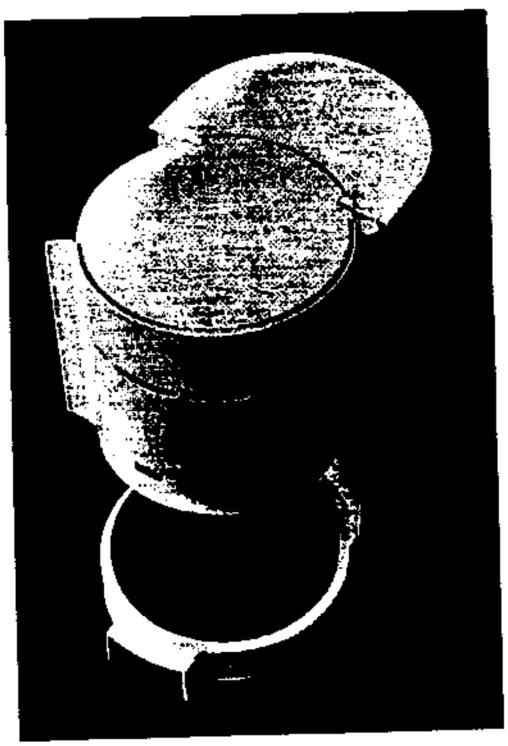
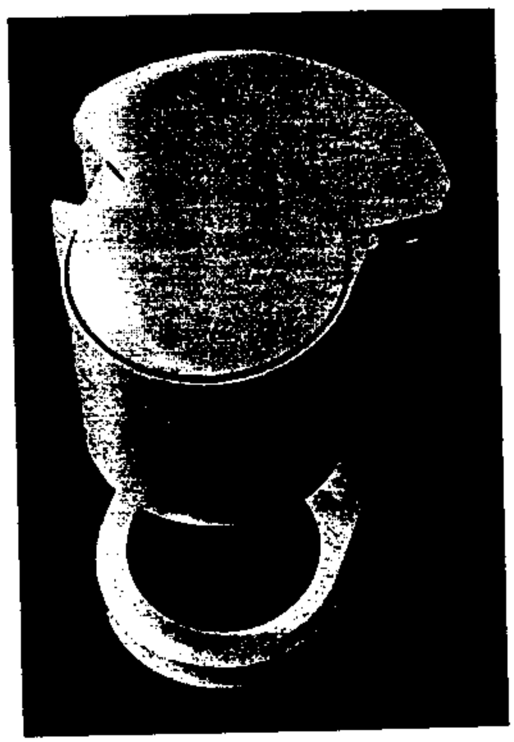


(c)



(d)

Figure 1. Coffee Makers: Proctor Silex (a), Black & Decker (b), Braun (c), Krups (d).

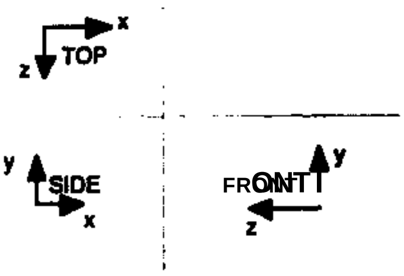


Figure 2: Notation for positioning of views in shape rules; single image is defaulted to be side view unless noted.

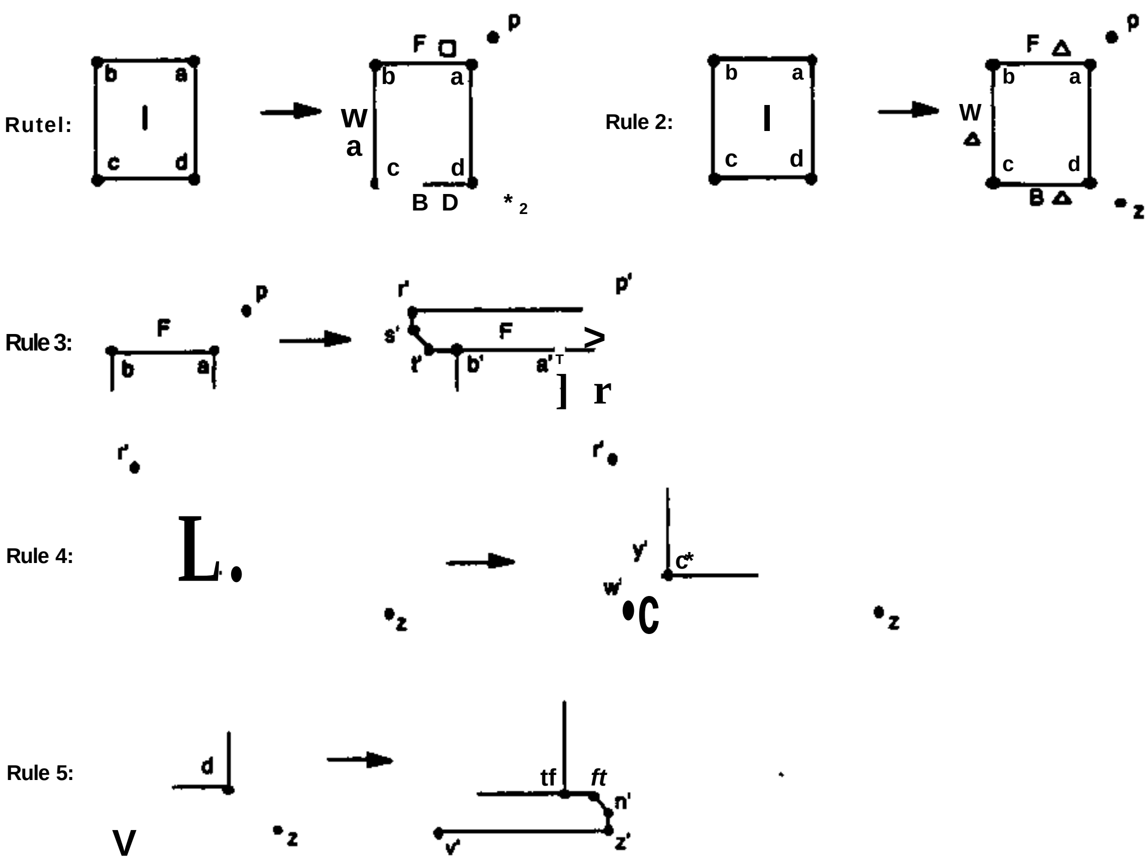


Figure 3. Initial shape rules

Rule 6: F —*» P (12345)

Rule 7: P (1) → p FM1

Rule 8: P (1) —^> F (r) FM2

Rule 9: P (2) → P (2') FT1

Rule 10: P (2) — ^ P (2f) FT2

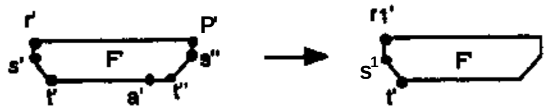
Rule 11: P (3) → P (3') FI

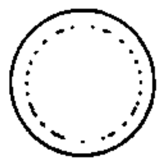
Rule 12: P (4) —^. P (4') FF1

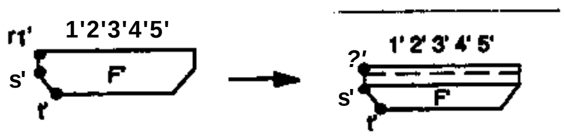
Rule 13: P (4) → P (4') FF2

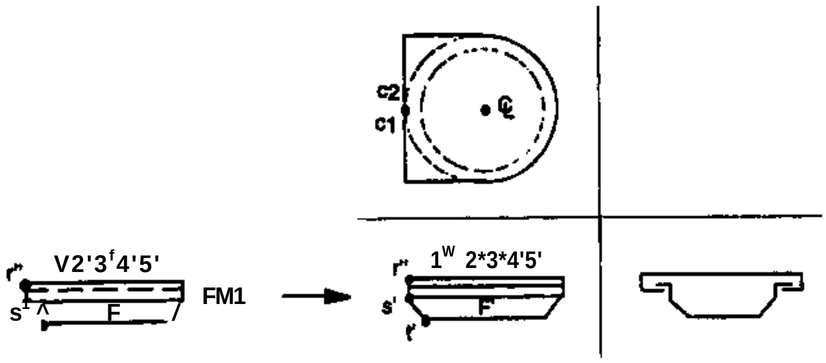
Rule 14: P (5) — ^ P (5*) FS1

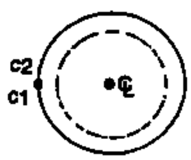
Rule 15: F (5) → P (5f) FS2

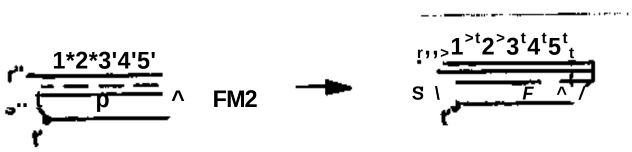
Rule 16: 



Rule 17: 

Rule 18: 



Rule 19: 

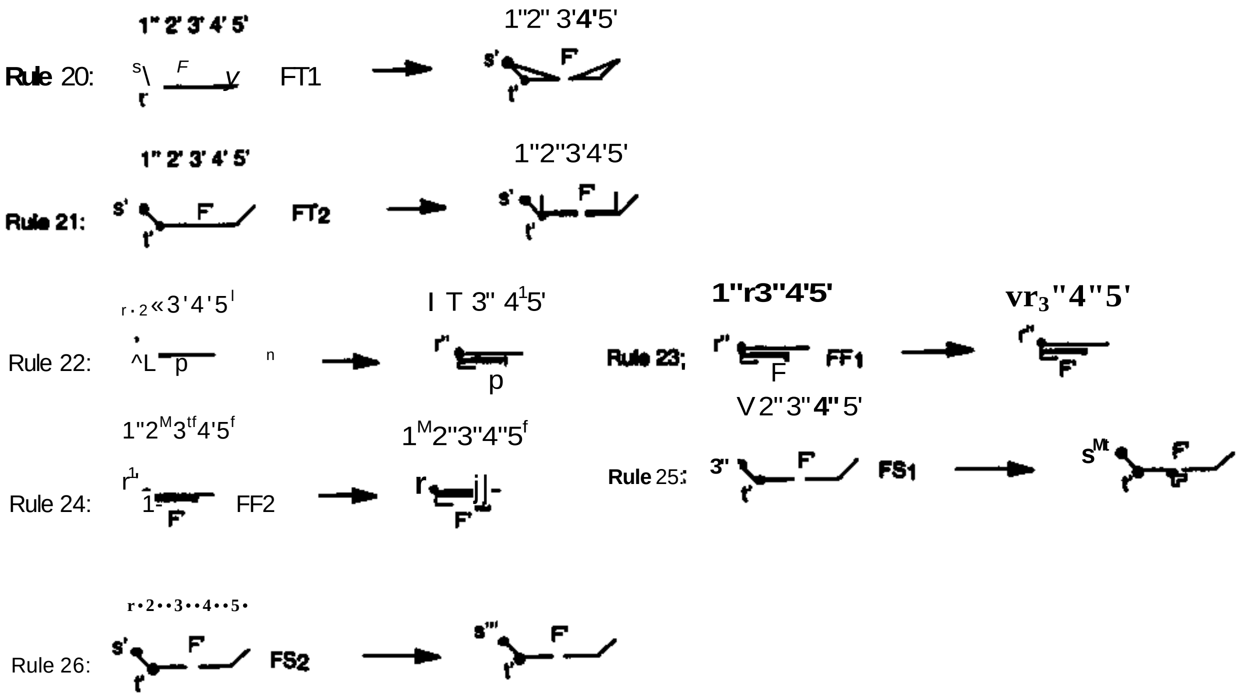


Figure 4. Filter rules

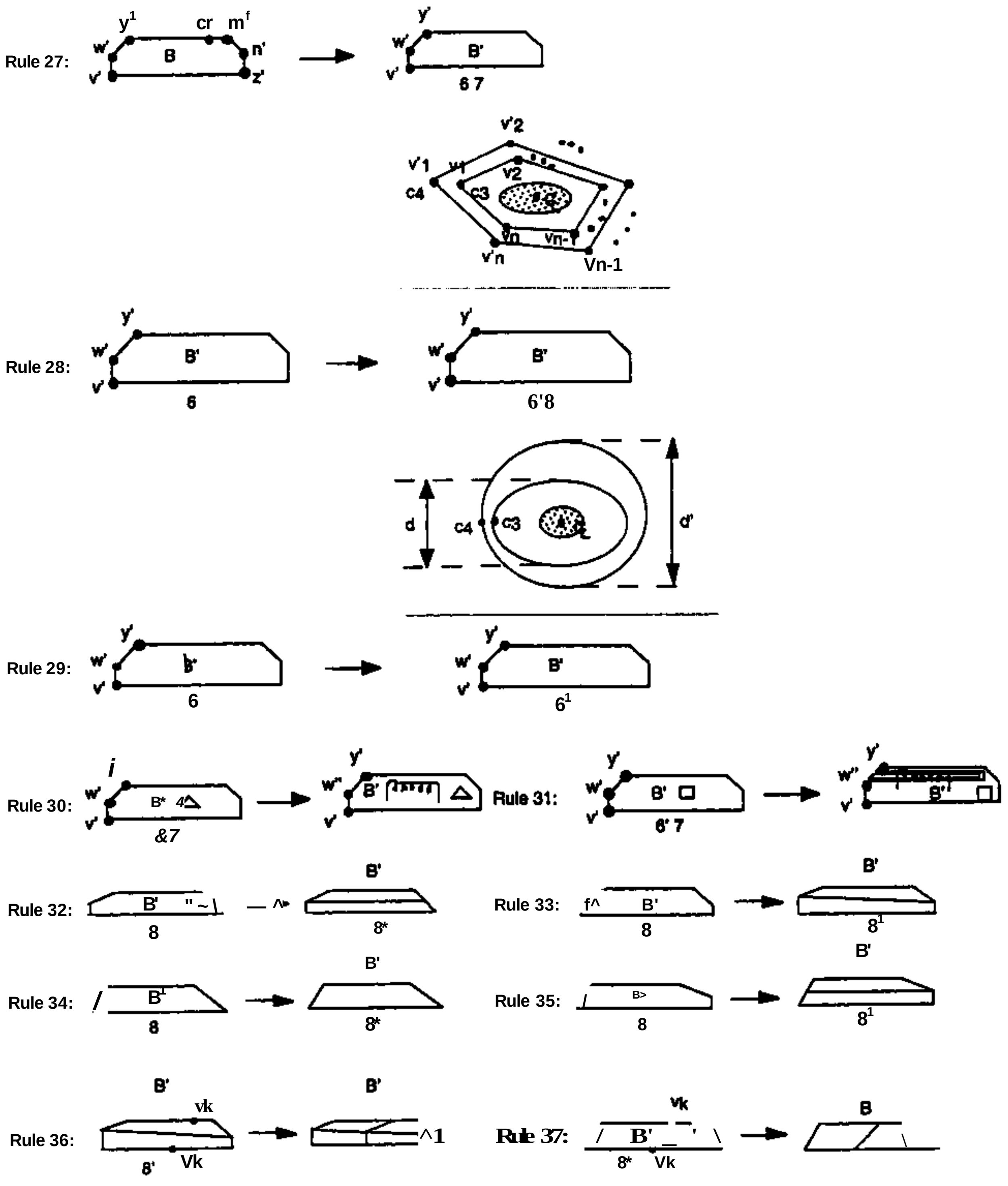


Figure 5. Base design rules

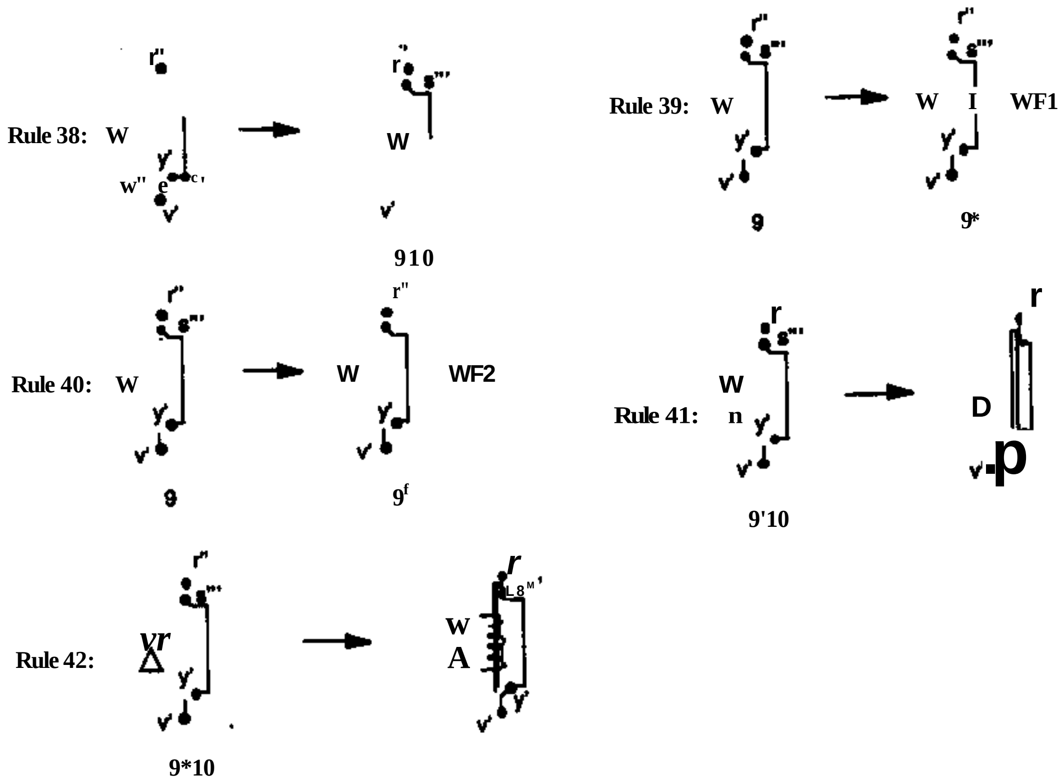
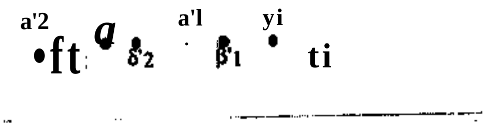
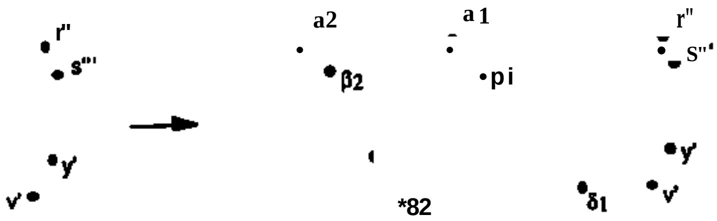


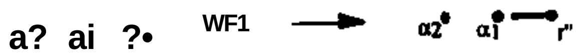
Figure 6. Water storage unit cross-section design rules



Rule 43:

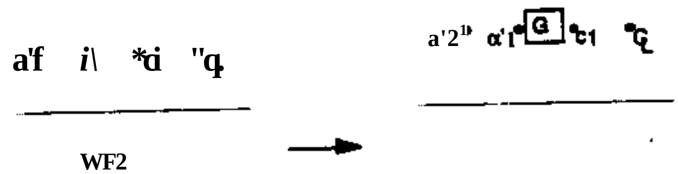


Rule 44:



Rule 45:

Rule 46:



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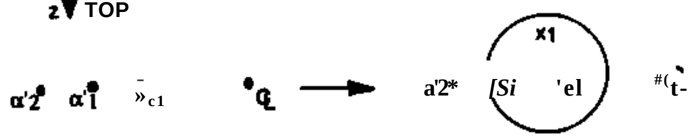
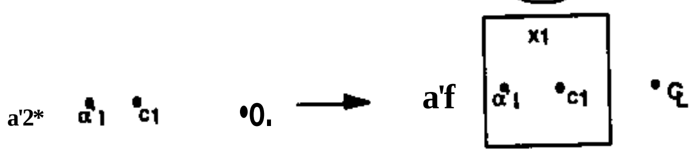


Rule 48:



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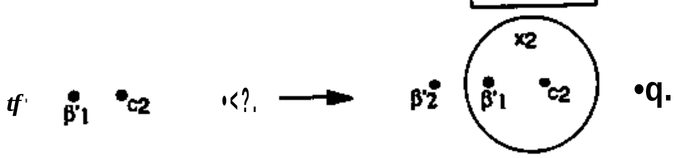
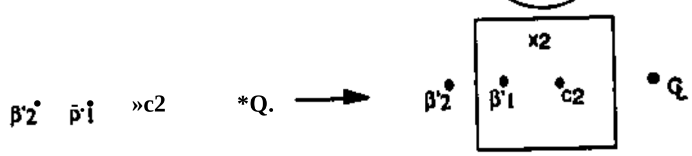
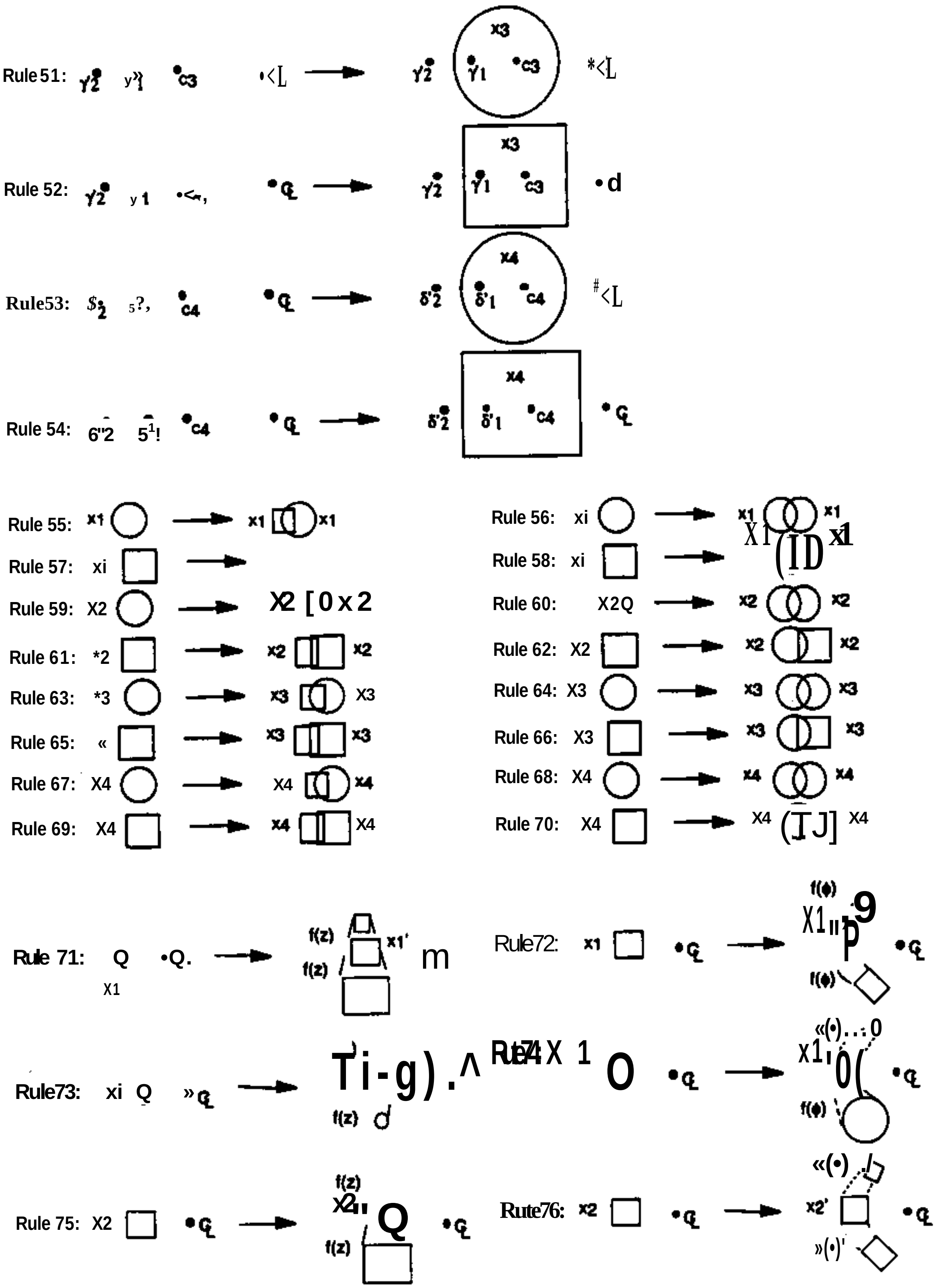


Rule 50:




Rule 51:
Rule 52:
Rule 53:
Rule 54:
Rule 55:
Rule 56:
Rule 57:
Rule 58:
Rule 59:
Rule 60:
Rule 61:
Rule 62:
Rule 63:
Rule 64:
Rule 65:
Rule 66:
Rule 67:
Rule 68:
Rule 69:
Rule 70:
Rule 71:
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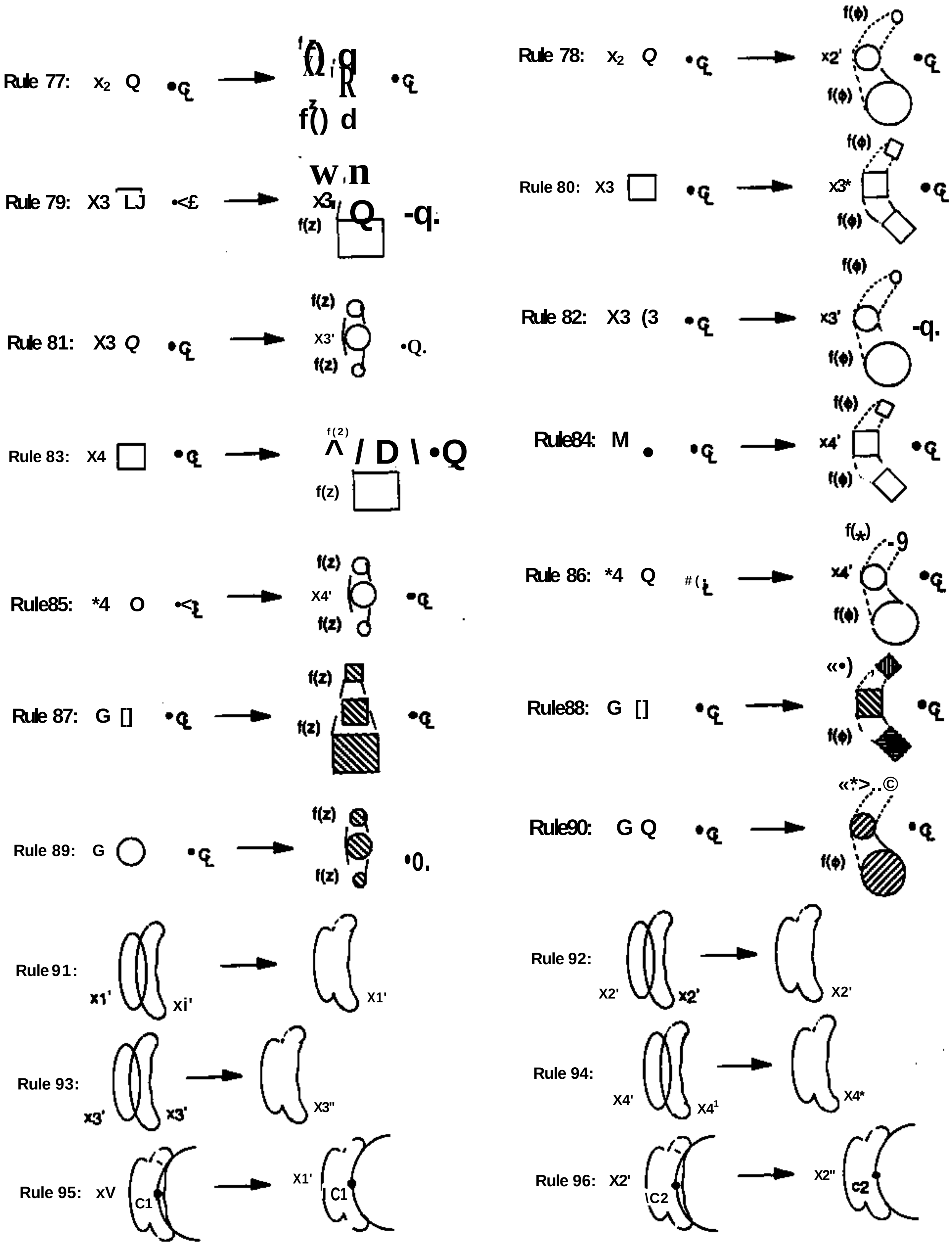
Rule 75:
Rule 76:


Rule 77:
Rule 78:
Rule 79:
Rule 80:
Rule 81:
Rule 82:
Rule 83:
Rule 84:
Rule 85:
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Rule 94:
Rule 95:
Rule 96:

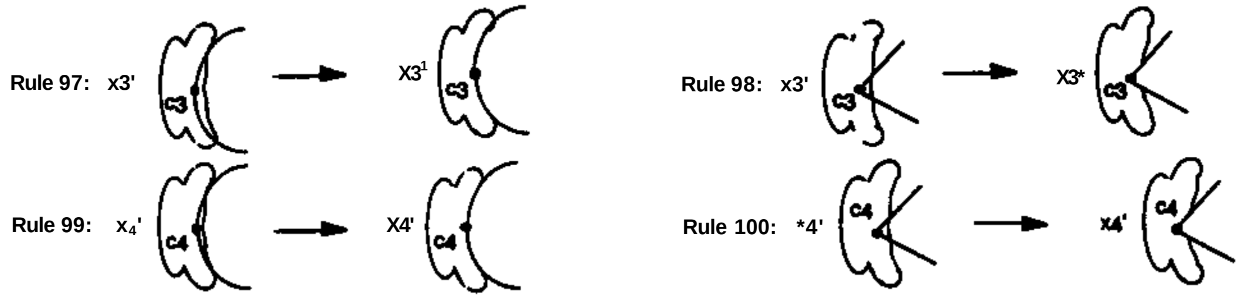


Figure 7. Completion rules

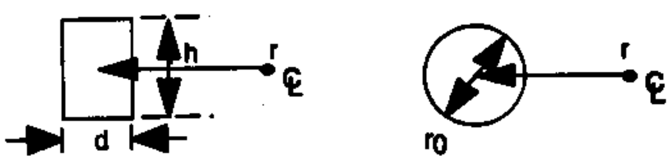
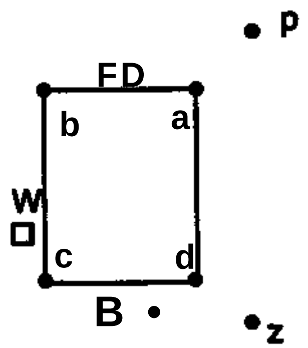
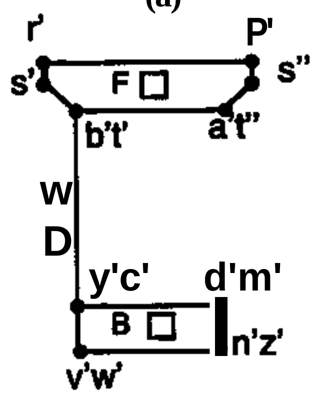


Figure 8. Parametric variables for rules 45-90



(a)



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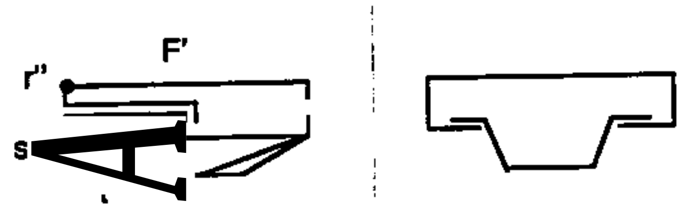

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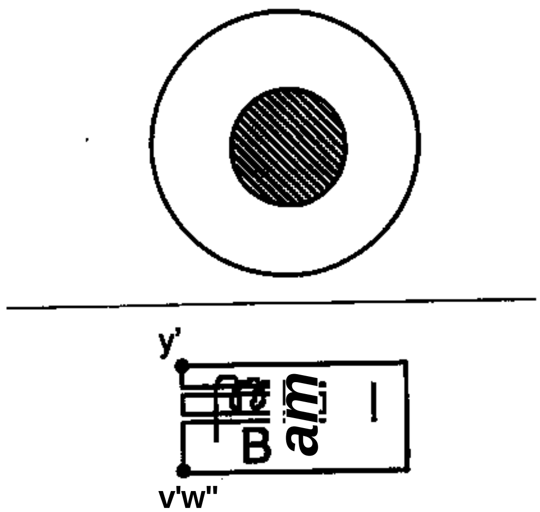
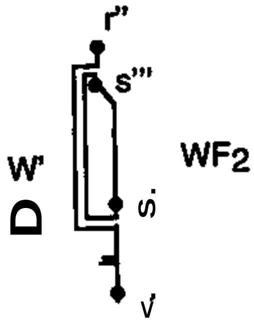
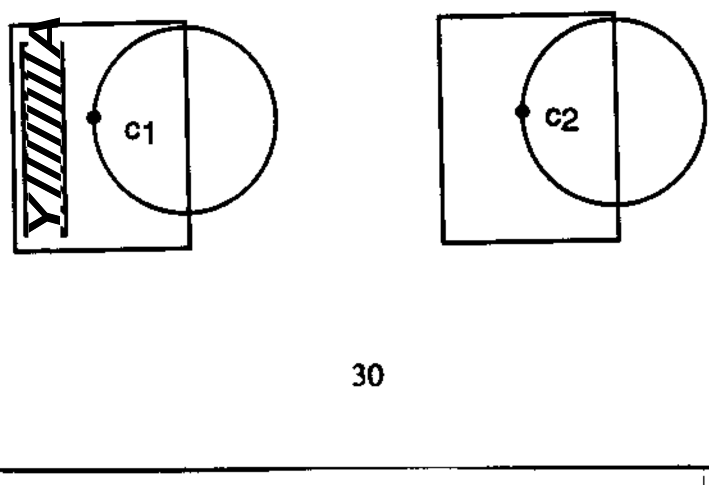


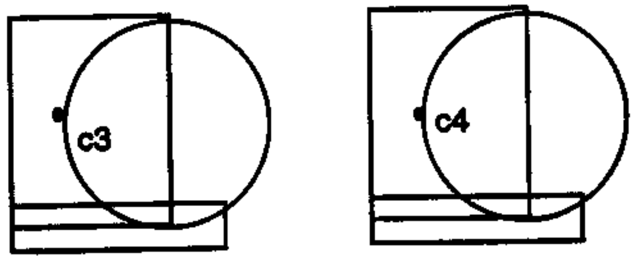
(d)



(e)



(f)



(g)

Figure 9. Example design sequence using shape grammar

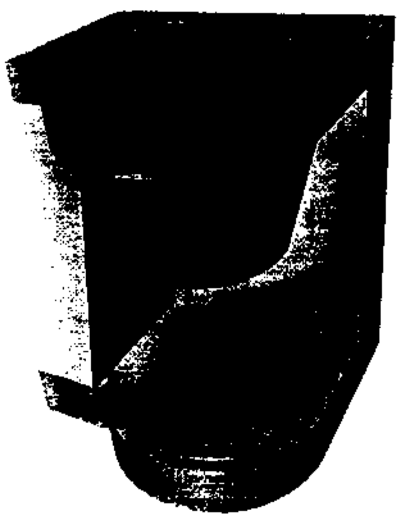
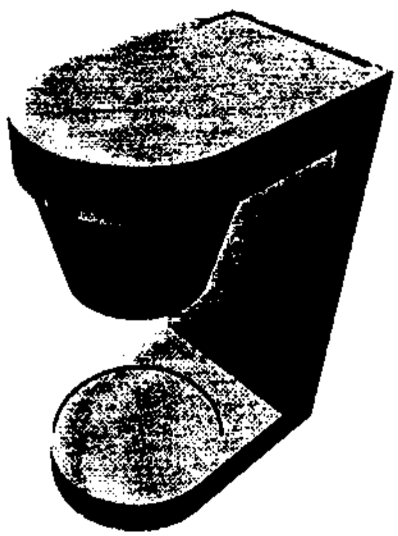
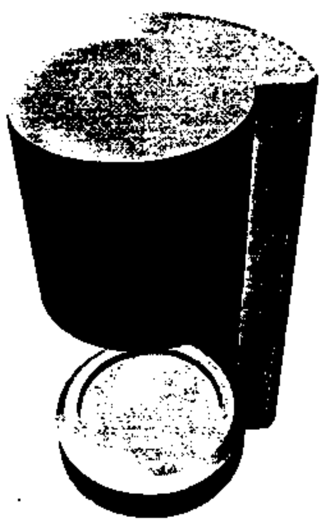


Figure 10. Completed Design of Figure 9 (Black & Decker)



(a)

(b)



(c)

Figure 11. Generated designs similar to Proctor Silex (a), Braun (b), Krups (c)

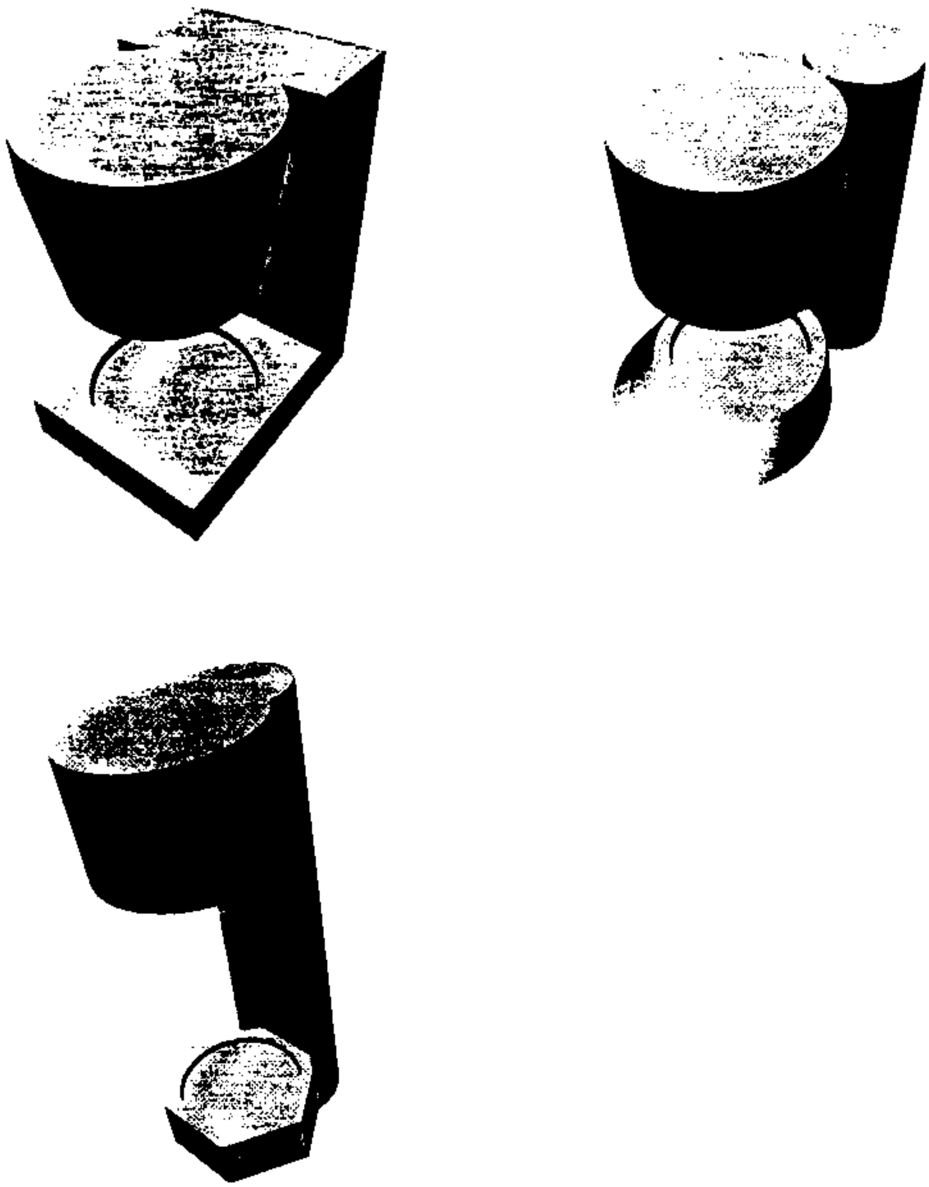


Figure 12. Novel designs generated from grammar.