ChairMaker - A Parametric Chair Modelling Program

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Abstract

In this report we describe a new parametric modelling program that can produce 3D models of chairs. The parameters used are easily understood physical traits such as back height and seat width. The finished ChairMaker program is capable of producing a vast range of semi-realistic 3D models from a set of 33 parameters. It is intended that these are used to explore automated chair design.

1   Introduction

With the rise in computers capable of handling 3D graphics, new techniques have been developed to produce these 3D models. Some of these can be used to produce 3D models with limited or no input from human designers. These models have the potential for use in digital environments such as games or 3D printed for use in the real world.

Early automatic 3D modelling was often done using basic primitives such as cuboids, pyramids and spheres. Bentley [1] used 'clipped stretched cuboids' in his work on evolutionary design. Using these forms he was able to create representations of objects such as coffee tables, heat sinks and even vehicles. However the forms remained very angular and should be considered as sketches of ideas rather than finished designs. Implicit surfaces have also been used as the primitives in work by Jacob et al [2] and Nishino et al [3]. These primitives can create a wide range of designs but often have blob or bubble like forms.

Primitives can also be taken from existing models and rearranged to create new variations (as in the work of Kalogerakis et al [4]). This allows for much more complex forms than could otherwise be possible in automated design. The challenge is to identify the equivalent component in all the existing models and how they are connected to the whole. This can be done manually but is very time consuming. Recently there has been considerable progress in automatically identifying equivalent parts, particularly in the work by Zheng et al [5]. However the work is limited by the existing models used. No new components are synthesised and used in the current models.

Parametric generation is an alternative method where the basic model is defined but many of the elements can be changed. For example in figure 1 we see how changing parameters such as 'roof height' and 'number of floors' can change the model. Using parameters in design is widespread in computer aided design. Parameters such as dimensions can easily be modified to change a design. Many CAD packages will automatically update other parts of a model to fit with the changed parameter. In architecture parametric design is becoming a discipline of its own (described in books such as *Parametric Design in Architecture* by Wassim Jabi [6]), with complex relationships between the parameters allowing for interesting new forms. These forms can been seen at their most extreme in the designs of Zaha Hadid Architects and the work of Patrik Schumacher, who has named the emerging style *Parametricism* [7] [8].

Outside of the style parametricism, we can use parametric design to fully describe a design space. By design space we mean the set of all possible designs and in the case of parametric design with N parameters this can be described as an N dimensional space. In automated design parameters have been used to create new form in the work of Hsiao and Tsai [9] to create new door handle designs as well as in our previous work in vase design [10].
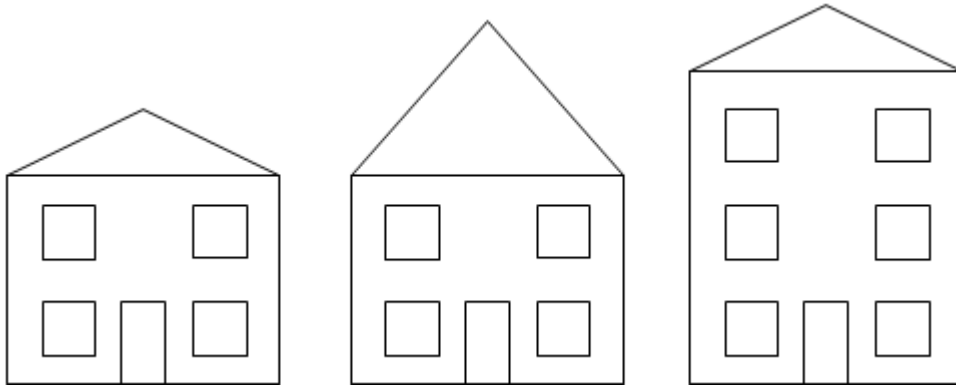
Figure 1: Example of changing a parameter in the design of a simple house. The first house is our basic design, the second house is the design with parameter 'roof height' increased. The third house has the parameter 'number of floors' increased. Many CAD packages will automatically add windows to the new floor.

The disadvantage of parametric design is the success of changing parameters depends on the robustness of the original model and the choice of parameters. A badly constructed model or unsuitable model will lead to potential conflicts and non-viable designs.

2 Aims of the ChairMaker

We choose to use a parametric model for our chairs, as it will allow us to create new forms, rather than using existing models. It also allows us to study the effect of parameters on different properties and therefore compare different styles of chairs. The challenge is creating a chair model that will allow for a wide range of different styles from the same set of parameters, that will be robust and will produce a chair from any combination. The set of parameters used in the model are described in the supplementary information.

2.1 Observations of Existing Chairs

We aim to produce a system that is capable of producing a wide range of chairs from a single set of parameters. To determine what these parameters should be and the range of chairs we wish to aim for we began by studying existing forms for similarities and differences that we can use. The existing chairs used were all designed by well known product designers and architects and are still manufactured and widely used today. In addition we include some classic chairs whose designers are consistently included in reviews of design history. Although the designer label of these chairs makes them high end items, most are ubiquitous in our lives and can be found in many everyday spaces such as shops, cafés, universities and offices.

We now discuss our observations and how these will be used in the ChairMaker program. In particular we look for patterns that can be controlled with a continuous parameter and those where parameters could be shared between different designs.

2.1.1 Leg Styles

There are many leg styles in the set of chairs including some of the chairs (particularly those by the Eames' and Jasper Morrison) having identical seats but varying legs. Repeated leg

Figure 2: Chairs in the Victoria and Albert Museum [11]. (a) Chair by Charles Rennie Mackintosh (1900), (b) Armchair by Mackintosh (1917), (c) Dining Chair by Frank Lloyd Wright (1902) and (d) Chair by Wright (1936)

Figure 3: Chairs Manufactured by Vitra [12]. (a)-(c) Plastic Chairs by Charles and Ray Eames (1950), (d) Lounge Chair by Eames (1956), (e) Aluminium Chair by Eames (1958), (f) Panton by Verner Panton (Designed 1968, manufactured 1999), (g) .03 by Maarten Van Severen (1998), (h) SIM by Jasper Morrison (1999), (i) Basel Chair by Morrison (2008), (j)-(l) HAL by Morrison (2010-2014)

Figure 4: (a) Side Chair No. 14 by Thonet (1859) and (b) B32 by Marcel Bruer (1928) both manufactured by Thonet [13]. (c) 3107 by Arne Jacobsen (1955) and (d) Swan Chair by Jacobsen (1958) both Manufactured by Fritz Hansen [14].

Figure 5: Chairs Manufactured by Knoll [15]. (a) Wassily Chair by Marcel Breuer (1925), (b) Barcelona Chair by Ludwig Mies van de Rohe (1929), (c) Womb Chair by Eero Saarinen (1948), (d) Executive Chair by Saarinen (1950), (e) Tulip Chair by Saarinen (1957), (f)-(g) Diamond and Side Chair by Harry Bertoia (1952)

styles include 4 separate legs, a cantilever, a central pedestal and a 'loop' on each side (seen in 3h and 3k). We also observe other styles such as the plastic cantilever of the Panton Chair (3f), the 3 legs of the Frank Lloyd Wright Chair (2d) and the crossed legs of the Barcelona Chair (5b). The pedestal bases have a range of 'spokes' from 1 (Tulip Chair) to 5. Finally we observe that the legs often carry up above the seat to help support the back, and in some cases they connect together at the top.

In addition to the overall leg forms, we also observe the use of both metal and wood and several cross–sections; chiefly square and circular. Many of the legs had cross bracing between the legs, this was either horizontal or crossed.

Three leg styles are used, to be chosen by a discrete parameter. These styles are 4 legs, cantilever and a side loop. The 4 legs and the cantilever have the option of continuing up into the back and all 3 styles have a parameter that will allow the legs to be be joined together, either along the floor at the side (side loop), at the top back (cantilever and 4 legs) and along the floor at the back (cantilever). Separate parameters are used for cross–section, leg material and leg width. Three cross–sections are used: square, circle and rectangle.

The three leg and crossed leg styles were not used as they are very unusual, however they would be compatible with the rest of the model and could be added at a later date. The plastic cantilever and pedestal base are not compatible with this model as they require unique cross–sections or more parameters (such as number of spokes). At this time cross-bracing is also excluded as it would require several new parameters and would be difficult to implement consistently between the different leg styles.

2.1.2 Arm Styles

There is a wide range of arm styles shown in figures 3 - 5. These include arms formed from the seat (Eames Lounge Chair - 3d and Swan Chair - 4d), separate arms (Eames Aluminium Chair - 3e) and arms formed from the legs (Mackintosh Armchair - 2b). Many of the chairs shown have alternative versions with arms, these include the Eames plastic chairs (3b) and the 3107 by Jacobsen (4c). The alternative versions are shown in figure 6.

(a)   (b)

Figure 6: Versions of case studies 3b and 4c

It was decided to exclude all arm styles in this version of the tool as the complexity and the number of required parameters was too high. Although arms can be a major feature, many chairs have versions without arms that still possess much of the same style and the function remains the same.

2.1.3 Seat and Back Styles

With the exception of the Wassily chair (5a), all the seats are structural. That is, they would keep their shape even if disconnected from the rest of the chair. The seats are also all formed of a single main component, with no slats or segments, although many have a separate upholstered piece on top of the main structure. Some of the seats are separate from the back, but we also observe many single seat–back forms.

The shape of the seats (as viewed from above) range from near circular to square. Their cross–sections (excluding arms) are either flat or have a slight concave curve. Those with upholstery can have a convex curve although this would be compressed when sat on. Materials include plastic, wood, leather and fabric.

Unlike the seats, the backs can have multiple segments. These can be a series of horizontal or vertical shapes. Most, however, feature a single panel, sometimes connected or
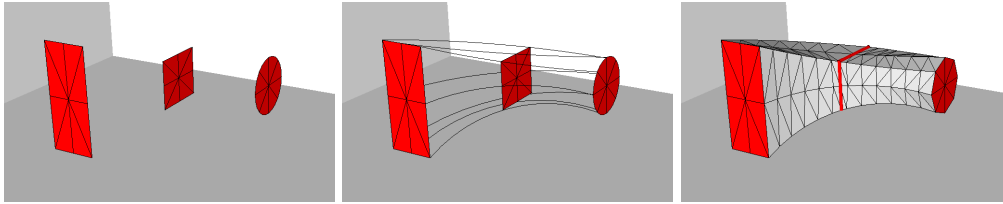
Figure 7: 3D shape lofted from 3 cross–sections

even part of the seat and sometimes suspended above the seat with a gap between the two. Similar shapes, cross–sections and materials to the seat are observed in the backs.

To construct the seat and back a series of segments is used, with a maximum of 1 segment for the seat and up to 10 segments for the back. This also allows the option of a single segment for both the back and seat. The segments are made of 2 or 4 cross–sections that are lofted together (see section 3.1 for definition), 2 cross–sections gives a blunt square shape, while 4 cross–sections gives a rounded shape. The number of segments and the degree of rounding is controlled by a single parameter, with 2 segments selected when the rounding degree is 0. There are 7 possible cross–sections (shown in figure 9), with the possibility of combining these to create further options.

In addition to the segments there are 2 further parameters controlling the back: These are the number of upright pieces and the gap between the seat and the first back segment. If the back upright number is 1 or 3 then the middle upright is wider. If the number of uprights is 2 or greater and the legs are of a type that can extend into the back then the outer 2 uprights are replaced by the legs. This model is not able to produce forms where the back descended below the level of the seat (as seen in the Mackintosh chairs).

3 Development of the ChairMaker

3.1 Tools and Techniques

Sketchup[1] was used as the Computer Aided Design (CAD) program to produce the chairs. Sketchup is a free CAD program that actively encourages expansion by users in the form of Ruby plugins. A CAD program such as this is designed for 3D modelling and therefore allows for a wide range of shapes and construction methods. Of the many CAD packages available Sketchup was chosen as plugins are an integral part of the program and there is a large community of professionals and hobbyists writing them. Other packages have much smaller communities (if they support plugins at all). In addition, the accompanying Google Warehouse[2] contains many of the chairs we are interested in. This indicates that it is possible to create these forms in Sketchup.

Lofting is a CAD technique to produce complex 3D forms from a series of 2D cross–sections, this method was used extensively in the chair maker. In particular it can create compound curves (forms where the curvature is different in different directions). The majority of our case study chairs have forms with compound curves.

To loft between two or more 2D cross–sections we first define the same number of points on each cross–section. A curve is then defined using a single point from each cross–section. This is repeated for each point, moving in the same direction around each cross–section. These curves are then joined together to make the outside surfaces of the 3D shape. This process is shown in figure 7.

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[1]www.sketchup.com
[2]http://sketchup.google.com/3dwarehouse/

Benefits of lofting include the ability to join shapes that are not aligned or facing the same direction. Further control of the resulting form can also be achieved by the type of curve used to join the points. In the example we use a 3 point arc but in the ChairMaker a cubic polynomial spline was used. The tension of the spline is used as one of the parameters (Curve - 32).

3.2 Parameters

From the methods discussed a full ChairMaker plugin for SketchUp was developed. This was capable of consistently producing chairs from a set of 33 input parameters. These parameters are divided into groups that determine form, proportion and texture and are listed in full in section 5.

In figure 8 we see how form and proportion parameters are used to create the chairs. You can see that most of the proportion parameters are maintained when the chair form changes (such as the increased rounding value and number of back pieces for the lower seat). However, the remaining proportion parameters and the form parameters are often affected by others. For example the use of gap and seat weight are dependent on the number of back pieces being greater than 0 and a seat rounding value less than 1 respectively.

Although only Back Rounding (10) and Seat Weight (16) are labelled here, the equivalent values (Seat Rounding (9) and Back Weight (17)) are applied in the same way. The Rounding values also control the depth and cross–section of the end pieces. If the rounding value is close to 1 the end pieces have the same cross–section as the seat or back but as the value is reduced the end pieces are combined with a rectangular cross–section to create a smoothly rounded edge.
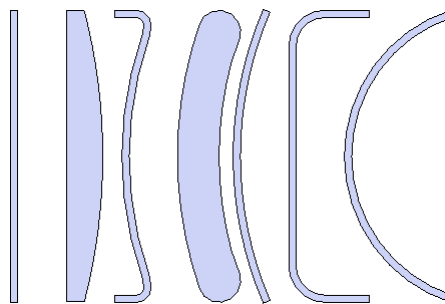
All of the examples shown use the arc for all of the main cross–sections. Other cross–sections used by the program are shown in figure 9. All the cross–sections have 38 vertices that are used during the lofting process. Equivalent vertices of two cross–sections can also be averaged to find a hybrid shape.

Figure 9: The 7 seat cross–sections

Further form parameters are used to create the wide range of back types we see. In figure 10 we can see how just a few parameters can be used to change the shape from a modern form to something more traditional.

One of the most important discrete parameters is the Leg Type. Here 3 leg types have been fully defined and there is no way to combine them. To reduce the impact of changing this parameter we ensure that other parameters that affect the legs (such as cross-section, colour etc.) have a similar effect on each type. Some of the main leg parameters are shown in figure 11. Changing the colour or cross–section of the legs is not shown but the effect on each type is consistent.

4 Chairs made by the ChairMaker

In figure 12 we show a set of chairs where the parameter values have been manually chosen to mimic some of our case study chairs, along with the other handmade examples in this chapter (such as in figure 11) we know that the ChairMaker design space contains a wide variety of viable designs.

However, in figure 13 we also present a selection of randomly generated chairs. Here the parameter values have been randomly selected from a set range. As we can see, all
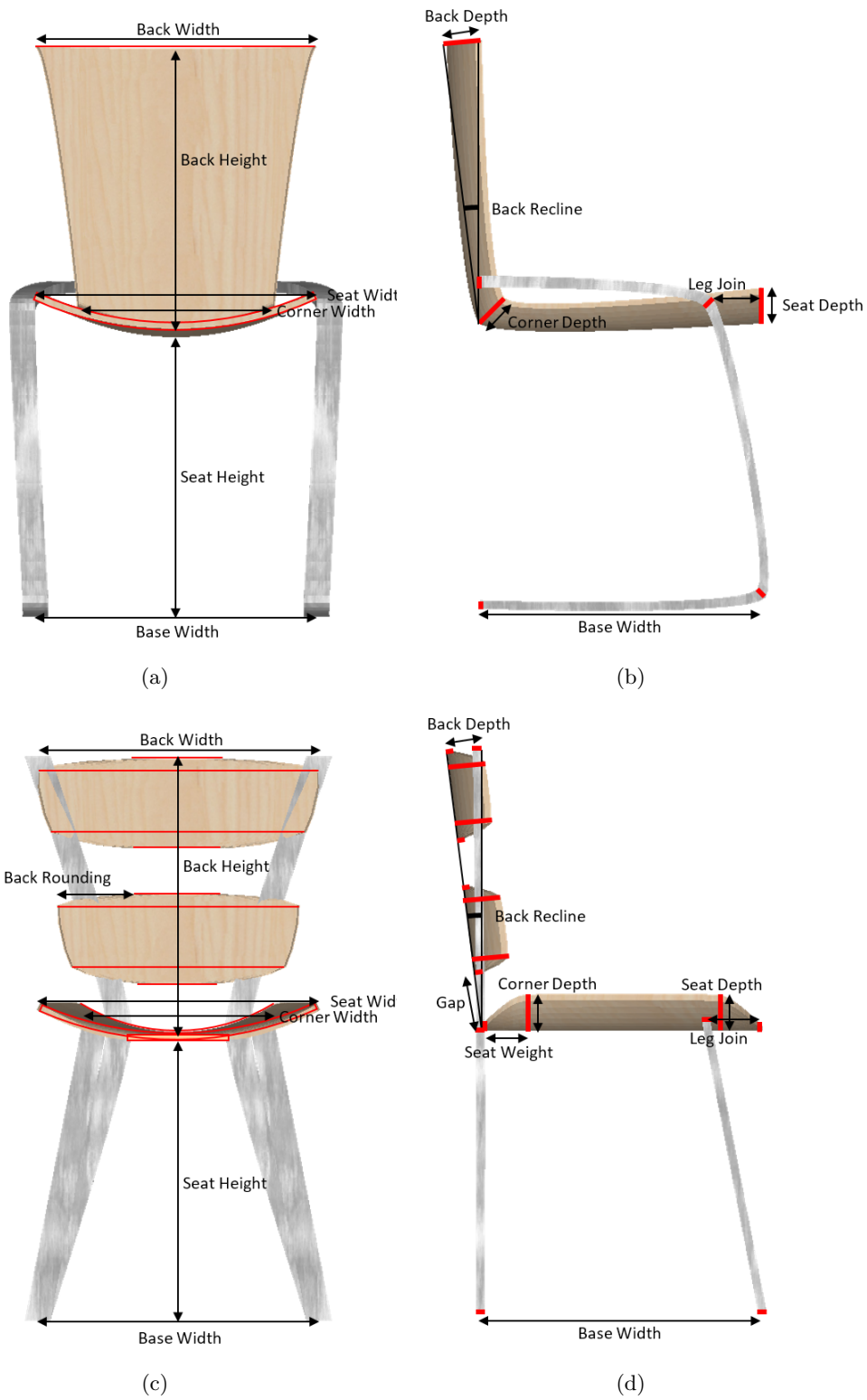
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Figure 8: Chair construction from parameters, cross–sections are shown in red
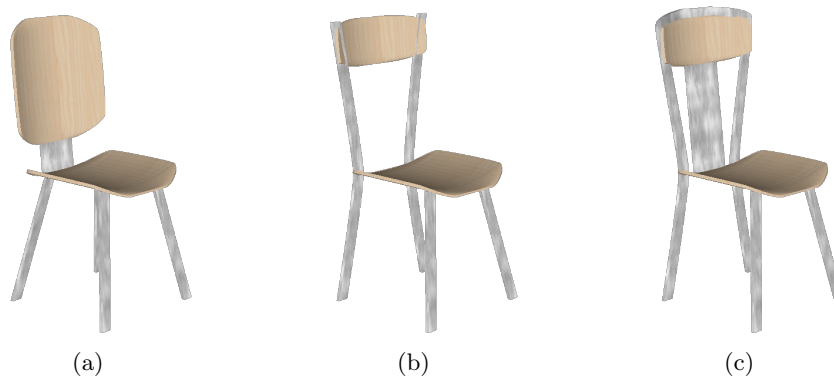
8

Figure 10: Effect of Back Parameters. From a to b, increase Gap (21) and Vertical Supports (11) (the number of back uprights). From b to c, set Connections (31) to true and increase Vertical Supports (11)

the chairs have a seat, back and legs and some would support a person. However most would be impractical or uncomfortable and appear rather strange to the viewer. Further observations of the random output of the ChairMaker suggest that the viable subspace of the ChairMaker design space is small and the probability of finding a viable chair through random generation is low.

5   Conclusion and Future Developments

The ChairMaker program is capable of producing a wide range of chairs from the parameters. The potential chairs include facsimiles of classic designs as well as new, novel forms. The finished chairs are realistic enough to judge their aesthetics, this means that the chairs produced are ideal for use in the exploration of automated design, although further work would be required if the chair is to be physically built.

It was observed that many of the chairs look uncomfortable, unstable or just 'weird'. Further work is required to remove these chairs without restricting the range of good chairs available.

There were several features that were observed in the case studies that we would like to include in further development of the ChairMaker. These include arms, leg cross–bracing and the pedestal type chair. These were not included due to the technical difficulties. However all of these commonly feature in chair designs and their absence leaves gaps in our range of chairs. Early versions of the ChairMaker also included further leg parameters, that could create tapered legs or legs that had multiple cross–sections. These were left out of the final version as they didn't translate well to some of the leg types and it was observed that certain combinations of parameter variables would create odd balloon like legs that early testers found very ugly, however further development could include these.
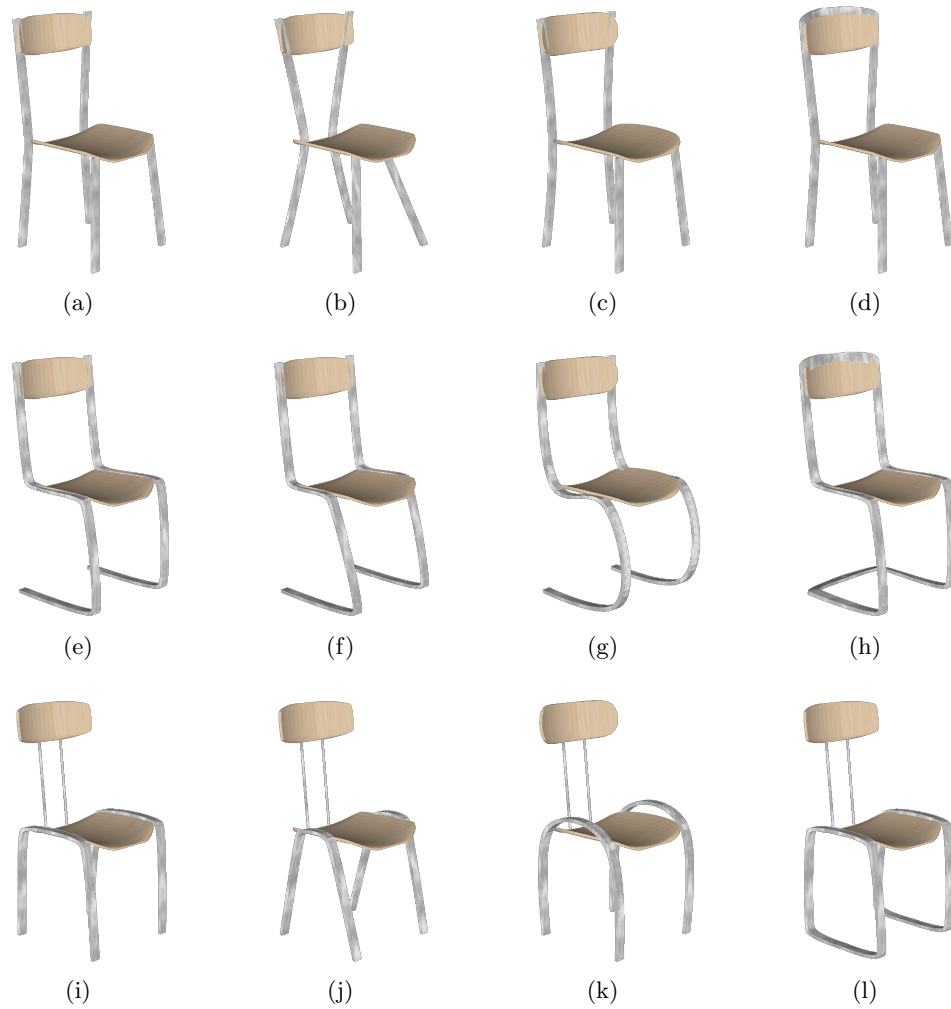
Figure 11: Effect of leg parameters on each Leg Type (26). From left to right the columns show the reference chair, increasing the Leg Join (27), increasing the Curve variable (32) and setting Connections (31) to true.

Figure 12: Chairs with parameters chosen produce facsimiles of case studies 2a, 3j, 3k, 3l and 4c

(a)   (b)   (c)   (d)

(e)   (f)   (g)   (h)

(i)   (j)   (k)   (l)

Figure 13: Chairs with randomly chosen parameter values

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[12] Vitra Design Museum: `http://www.design-museum.de/en`

[13] Thonet: `http://en.thonet.de`

[14] Fritz Hansen: `http://www.fritzhansen.com/en/fritz-hansen`

[15] Knoll: `http://www.knoll.com/`

Supplementary Information

Parameters used in the ChairMaker

The tables in this section list all of the parameters used in the final version of the ChairMaker along with a brief description of their physical effect. The numbering corresponds to the numbering used within the ChairMaker program.

Table 1: ChairMaker Proportion Parameters

No.	Name	Notes
1	Seat Height	Height is to the back of the seat, Seat Recline will change the height of the front when it is non–zero
2	Seat Length	Length of the seat in the direction of Seat Recline.
3	Back Recline	Angle of back away from vertical
4	Back Height	The length of the back in the direction of Back Recline
5	Seat Recline	Angle of Seat away from horizontal
6	Seat Width	Width of the seat cross–section
7	Back Width	Width of the top of the back, actual back cross–section widths may be altered by the Corner Width
8	Corner Width	Width of the corner cross–section if the seat and back are in 1 piece (number of back pieces is 0). Otherwise this is the width of the base of the back and the back of the seat.
18	Seat Depth	Depth of the seat cross–section
19	Corner Depth	Depth of the corner piece, only used if the seat and back are in 1 piece
20	Back Depth	Depth of the back cross–sections
21	Gap	Size of gap between seat and back, only used if the seat and back are separate
29	Leg Width	Scale of the leg cross–sections
30	Base Size	Ratio of the leg positions on the floor to the Seat Length and Width

Table 2: ChairMaker Texture Parameters

No.	Name	Notes
23	Seat Texture	Choice of texture for seat from predefined set shown in next section
24	Back Texture	Choice of predefined texture for back, not used if seat and back are combined
33	Leg Texture	Choice of predefined texture for legs

Table 3: ChairMaker Form Parameters

No.	Name	Notes
9	Seat Rounding	When set to 1 the seat is constructed with only 1 cross–section at each end. When set to less than 1 the seat has 2 pieces at each end and the outermost piece is reduced by the Seat Rounding value
10	Back Rounding	As Seat Rounding for all back pieces
11	Vertical Support	Number of uprights between the back and seat. If this value is greater than 1 and the leg type is suitable the legs extend upwards, becoming 2 of the verticals.
12	Seat Shape	Choice of predefined cross–section, combined with the unifying shape to make the seat cross–section
13	Corner Shape	Choice of predefined cross–section, combined with the unifying shape to make the corner or back of the seat cross–section
14	Unifying Shape	Choice of predefined cross–section used to 'even out' the change between cross–sections
15	Back Shape	Choice of predefined cross–section, combined with the unifying shape to make all the back cross–sections
16	Seat Weight	Distance away from the middle of the innermost cross–sections, used only when Seat Rounding is less than 1.
17	Back Weight	As Seat Weight, used in each back piece
22	Back Pieces	Number of horizontal pieces in the full back length. When this value is 0 the seat and back are combined
25	Seat Lip	Used to change the angle of the front piece of the seat.
26	Leg Type	Switches between the 3 predefined leg types
27	Leg Join	Distance between the seat sides and the top of the legs
28	Leg Shape	Leg cross–sections
31	Connections	Creates joined up legs. The location of the join changes with Leg Type
32	Curve	Makes the Lofting between the cross–sections more curvy. The cross–sections are also moved to ensure the overall form has the same proportions.

Colour Palettes

This section shows the full range of textures, not all of these are in the palettes and so not all would be used in a chair design. These could be used if further palettes were added. In figure 14 we have 36 fabric textures with a range of colours and shades along with 3 leather textures in neutral colours. In figure 15 we have 3 wooden textures in neutral colours, 1 metallic finish and 8 coloured textures that are assumed to be plastic or plastic covered metal.
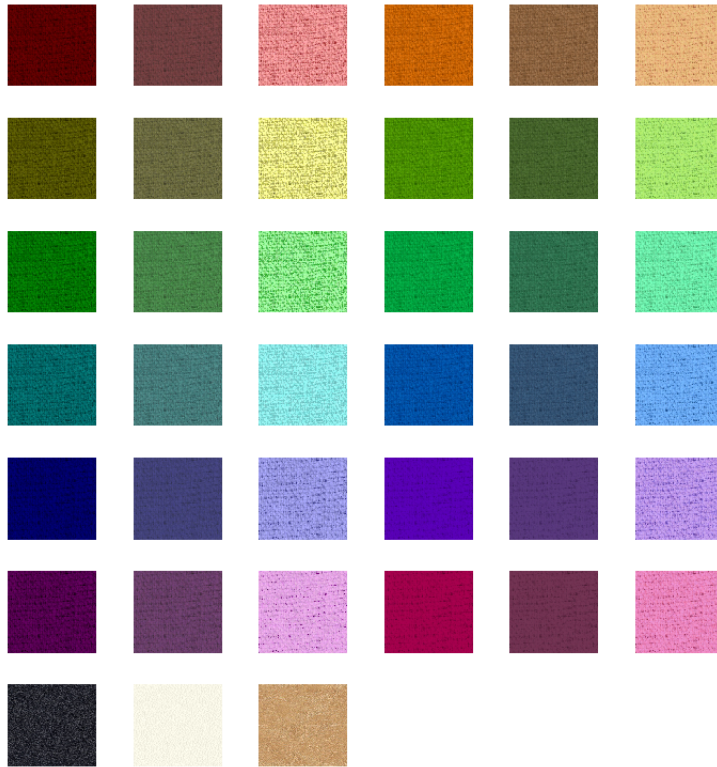
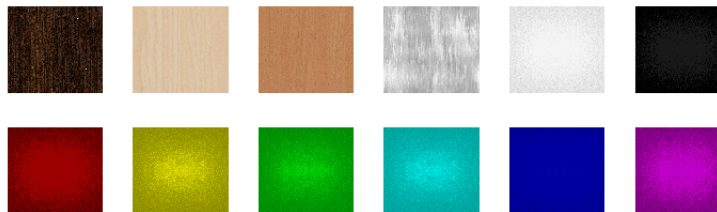Figure 14: Upholstery Textures. Bottom three are leather textures, all others are textiles.

Figure 15: Solid Structural Textures. Top (l-r): dark wood, pale wood, orange wood, metallic, white and black metal/plastic. Bottom: Coloured metals/plastics.