Introduction to Parametric Form Principles

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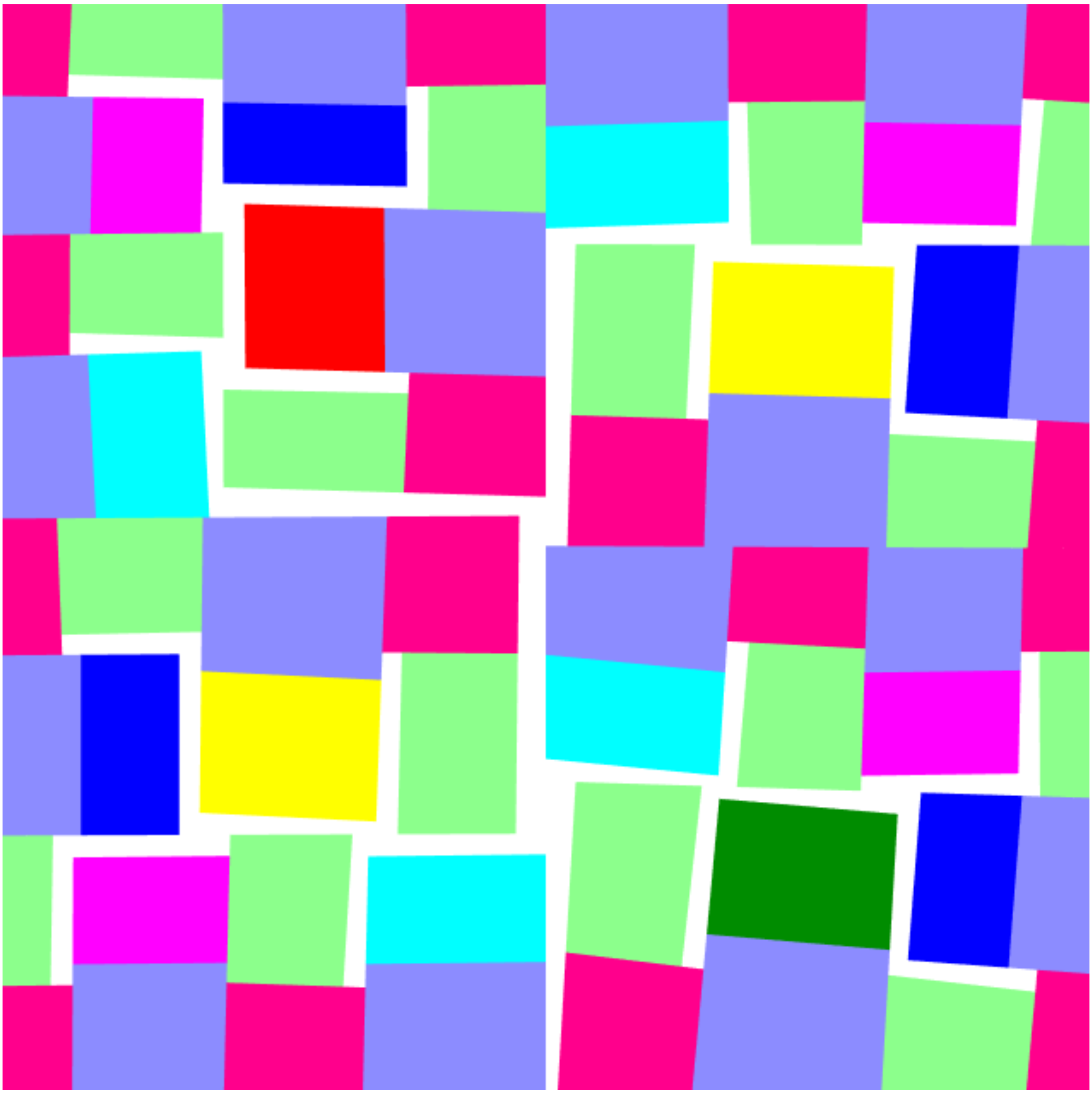
May 2014



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Teaching paper
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May 2014

by

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Introduction

This text attempts, in a very condensed form, to introduce some basic principles for parametric form making. Parametric design is about defining rules for making form. First, some basic parametric form principles are explained and how designs may vary as a result of changing the variables of different parameters. Second, examples are given on the level of site layout, building envelope and facade design, of how different designs may be analyzed and composed.

Contrary to traditional architectural thinking, site layouts must be analyzed with respect to their geometric and compositional qualities, rather than their architectural typology. Building envelopes may be more than simple box-shaped volumes. They may alter in height or have vertical and horizontal setbacks, all of which may be parametrically defined. And Facades may be described as differently composed structures which may be filled with different combinations of walls and openings.

Finally, it is explained how designs may be broken down into schemata which form a bridge between the graphic realm of design and the letters and numbers based realm of computer code. Through visualizing the steps which constitute the design rules of the parametric design script, even complex designs may be broken down into simple design rules.

Basic Form Principles

Probably the most difficult mental leap to do when dealing with parametric design, is to consider how the design may transform, when the values of different parameters change. Consider a simple configuration of squares in a rectangular array. It could be a site layout of four by four buildings in a grid plan:

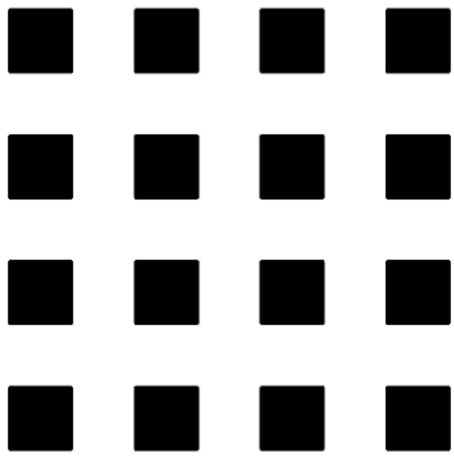

Figure 1: Simple site plan with building widths and buildings spaces of equal size in the x and z directions

This simple plan may be described parametrically by four parameters:

1. The width of the buildings in the x direction: bldgWidthX
2. The width of the buildings in the z direction: bldgWidthZ[1]
3. The space between the buildings in the x direction: bldgSpaceX
4. The space between the buildings in the z direction: bldgSpaceZ

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[1] While most often we work in a x/y coordinate system, in this text, I use a x/z coordinate system for horizontal planes, in consistency with the CityEngine software program.

Now consider what happens, if these parameters are changed. For instance, the value of bldgWidthX may be set to the value of 3 x bldgWidthZ. This would produce the following result:

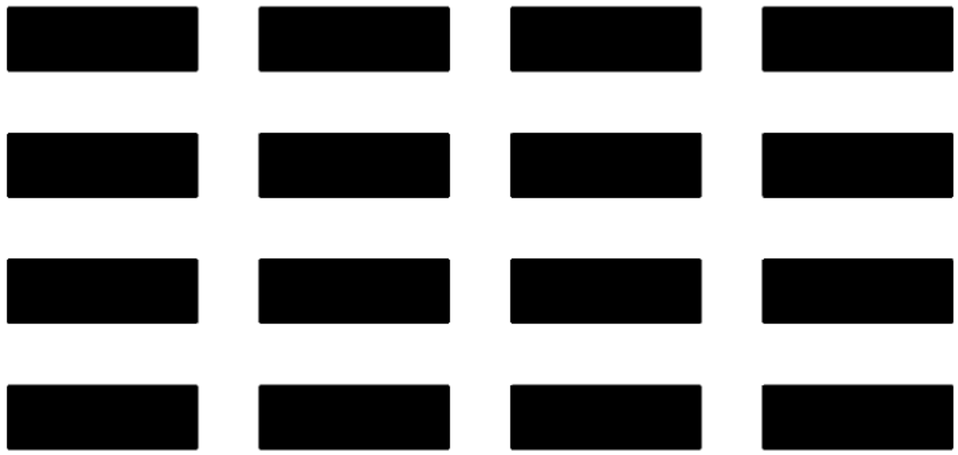


Figure 2: Site plan with bldgWidthX = 3 x bldgWidthZ

We may also change the value of bldgSpaceZ to the value of 2 x bldgSpaceX:

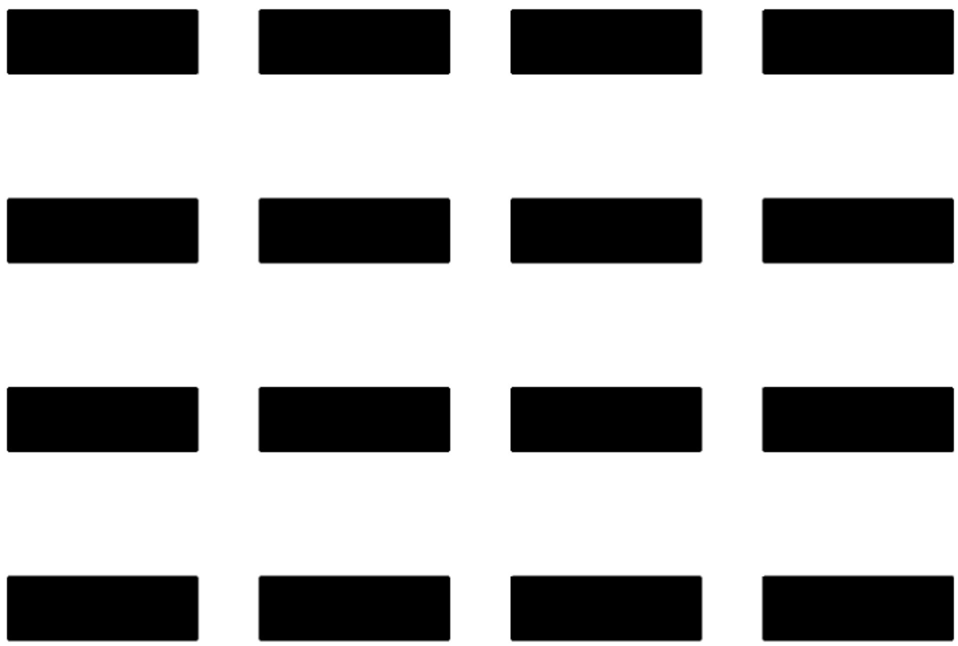


Figure 3: Site plan with bldgSpaceZ = 2 x bldgWidthX

We may now introduce two new parameters:

1. The shift of buildings in the x direction: bldgShiftX
1. The shift of buildings in the z direction: bldgShiftZ

Say we want every second building in the x direction to be shifted 0.5 x bldgWidthZ in the z direction, while we set every second-1 space in the x direction, bldgSpaceX, to 0. This would produce the following result:

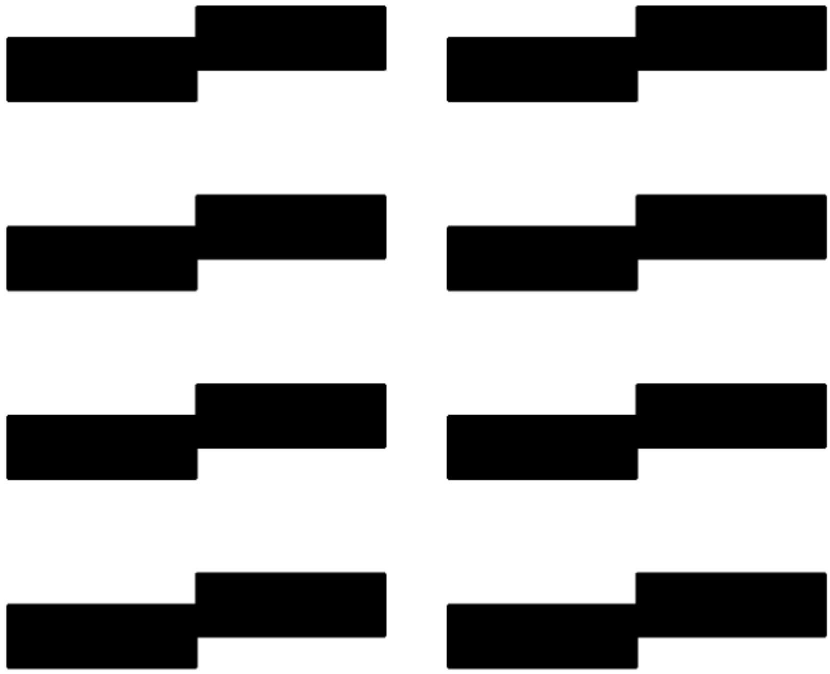


Figure 4: Site plan with every second building in the x direction shifted in the z direction and every second-1 space between buildings in the x direction set to 0

Finally, if we introduce a bldgRowShiftX parameter for shifting entire rows of buildings horizontally, we may shift every second row of buildings in the z direction by setting bldgRowShiftX = 2 x bldgWZ:

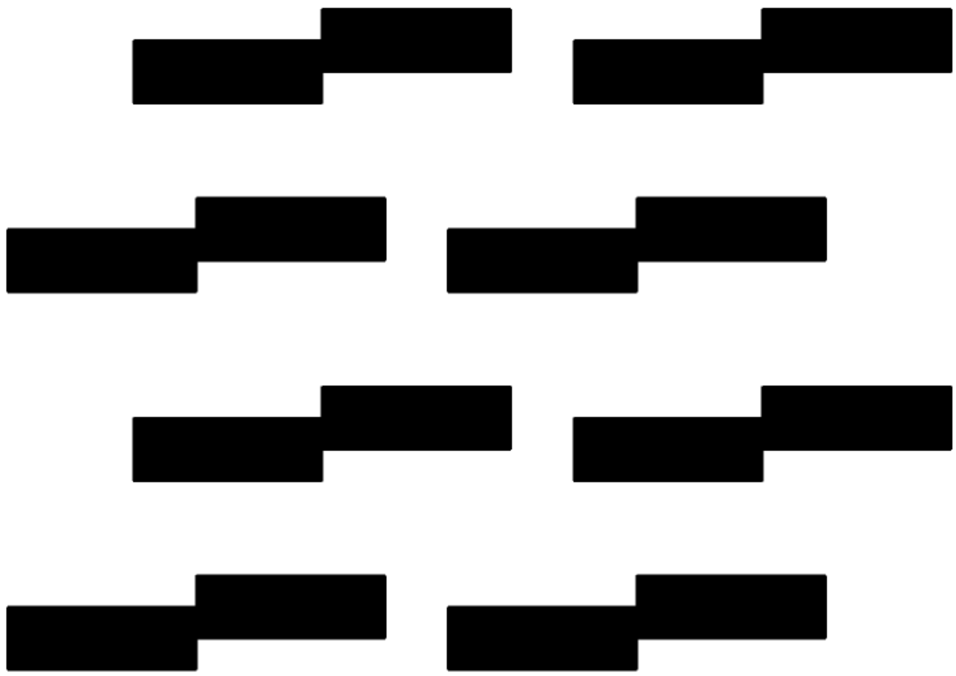


Figure 5: Site plan with every second row of buildings in the z direction shifted in the x direction

Now if we compare figure 1 and 5, they may be thought of as parametrically identical, but with different values for the parameters bldgWidthX, bldgSpaceZ in all cases, and for bldgSpaceX, bldgShiftZ, and bldgRowShiftX in some cases. As this simple example shows, the same elements may be combined to produce very different configurations by changing the values of only a few different parameters.

The challenge of parametric design is to imagine what particular parameters will enable you to do. For instance, the parameters in the above example will not be able to rotate any of the elements. Also, the only rhythm (repeated local variations) which may be achieved is based on the index (number from 0 to n) of the elements. Hence, in the example, buildings are shifted according to their index in the horizontal rows of buildings, and building rows are shifted according to their index in the vertical rows of buildings.

On the most basic level, elements (buildings in the above example) may be scaled, shifted, reflected (mirrored) or rotated. In turn, these basic geometric operations may be embedded into each other, for instance according to the wallpaper groups or other less repetitive criteria. On a more complex level, elements may be substituted for other elements. For instance, L-shapes, U-shapes or more complex or irregular shapes may be substituted for rectangular shapes according to different criteria.

Site Layouts

Architects would typically group different site layouts according to their typology, such as detached houses, patio houses, terraced houses, perimeter blocks, urban villas or tower blocks. These are useful categories for discussing different morphological compositions. Yet they do not consider possible parametric similarities and differences. As we have just seen, changing the bldgSpaceX value from anything to zero would be the only difference between detached houses and terraces.

Figure 6: Detached houses (left) versus terraced houses (right)

Although a particular typology may be the starting point for making a particular parametric site design, it may result in a host of different layouts which may be applied to different typologies. Therefore, a more useful starting point may be to consider the geometric qualities of any particular design on a more general level. This may lead to different groups of parametrically different designs. Here, an understanding of symmetry, hierarchy and fractals is helpful. While the example in the previous section was based on a simple grid, site designs may have many other spatial configurations.

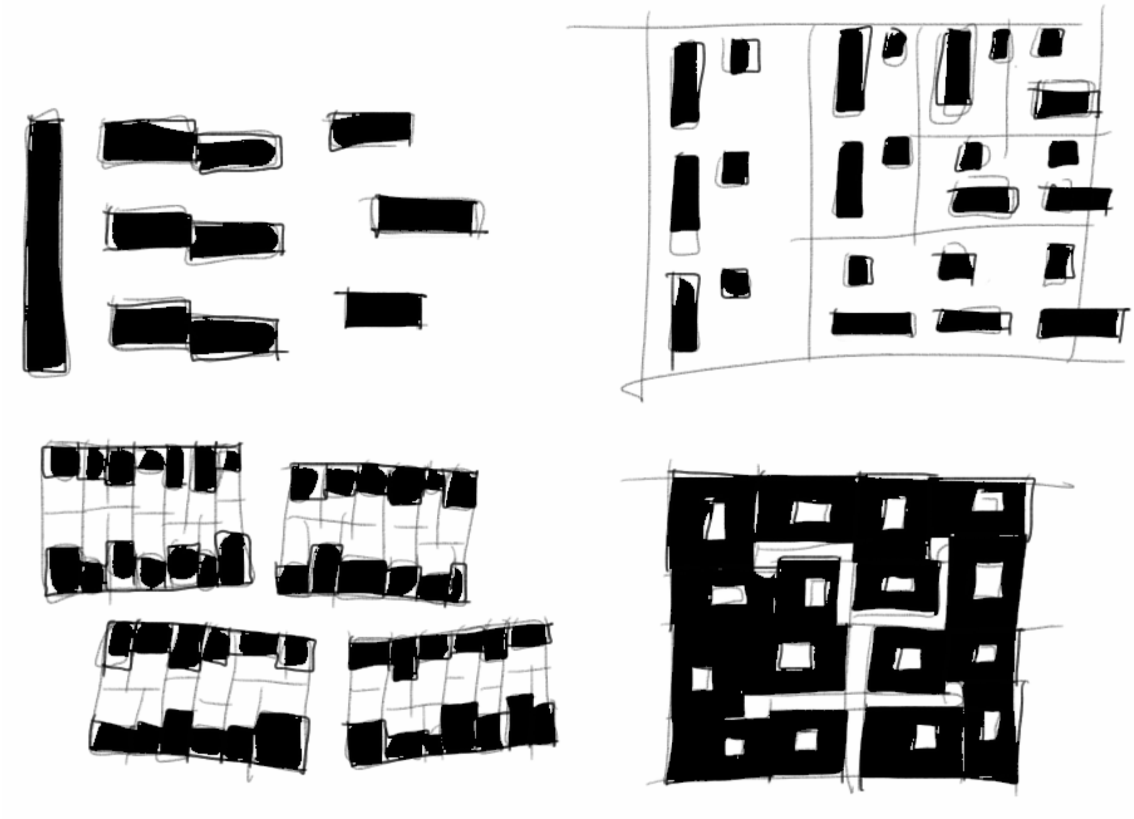


Figure 7: Examples of parametrically different site layouts

Consider the different site layouts in figure 7. In the top-left example, the layout has different configurations in the x direction with a vertical slab, semi-detached buildings and detached buildings respectively, while there is repetition in the z direction with minor local variations in the right-most part (horizontal shifting of buildings). In the bottom-left example, clusters of buildings arranged symmetrically along a horizontal axis (although with random building widths in both the x and z directions) are organized in rows which are shifted horizontally while slightly rotated.

The two examples on the right both have fractal qualities. The top right example may be interpreted as a repeated cutting and rotating of the site from bottom left to top right into rectangular slices which are subsequently filled with a configuration of an elongated and a square building, as many times as space allows for. In the bottom right example, a medina-like configuration emerges from the consecutive subdivision of a square into smaller squares, leaving open spaces for alleyways in the first iteration and for patios in the second iteration.

Building Envelopes

Just as different parametrically identical site plans may be very different in their spatial configuration, we may consider the footprints of a site plan as mere “placeholders” for a host of different building envelopes. If we consider the simple site plan in figure 3, each rectangular footprint may be just a simplified outline of different, more complex building outlines.

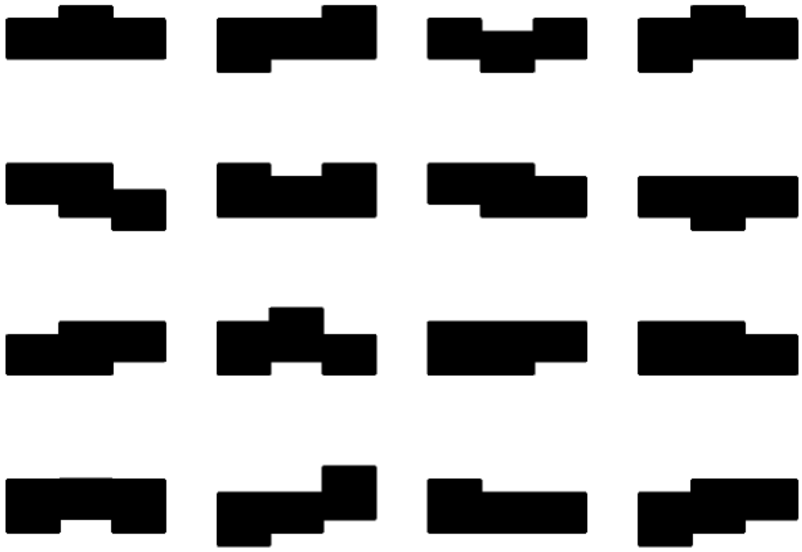


Figure 7: Different building outlines mapped to the site layout of figure 3

Taking the simple figure/ground (black and white) representation in the examples of the previous sections, it therefore makes sense to distinguish between *site plans* where black shapes represent actual building footprints, and *site layouts* where black shapes are simplified (rectangular) placeholders for more complex actual footprints of different building envelopes. This way, we may conceive of site layouts and building envelopes independently of one another, making it possible to combine each different site layout with any number of building envelopes.

Geometrically speaking, a building envelope is the overall form of a building, without detailing such as cornices, recesses, pilasters, and similar minor form elements. The building envelope does not speak of doors and windows, and sometimes (as in this text) not even of roof shapes. In its simplest form, a building envelope is a box-shaped object. But often, buildings may have parts of varying height, horizontal as well as vertical setbacks, recessed balconies, or any combination thereof, adding to the complexity of the building envelope geometry.

Similar to site layouts, parametrically identical building envelopes may feature very different geometric qualities. A building envelope consisting of three consecutive boxes may be parametrically changed, both with respect to the dimensions of the boxes, as well as the relative height and position of the boxes. In figure 8, variations of such a building envelope is shown with three possible height settings, three possible width settings and six possible shifted positions of the building parts from front to back (z direction). The figure shows 16 out of 243 possible combinations within these settings (some of which however, will be symmetrically identical).

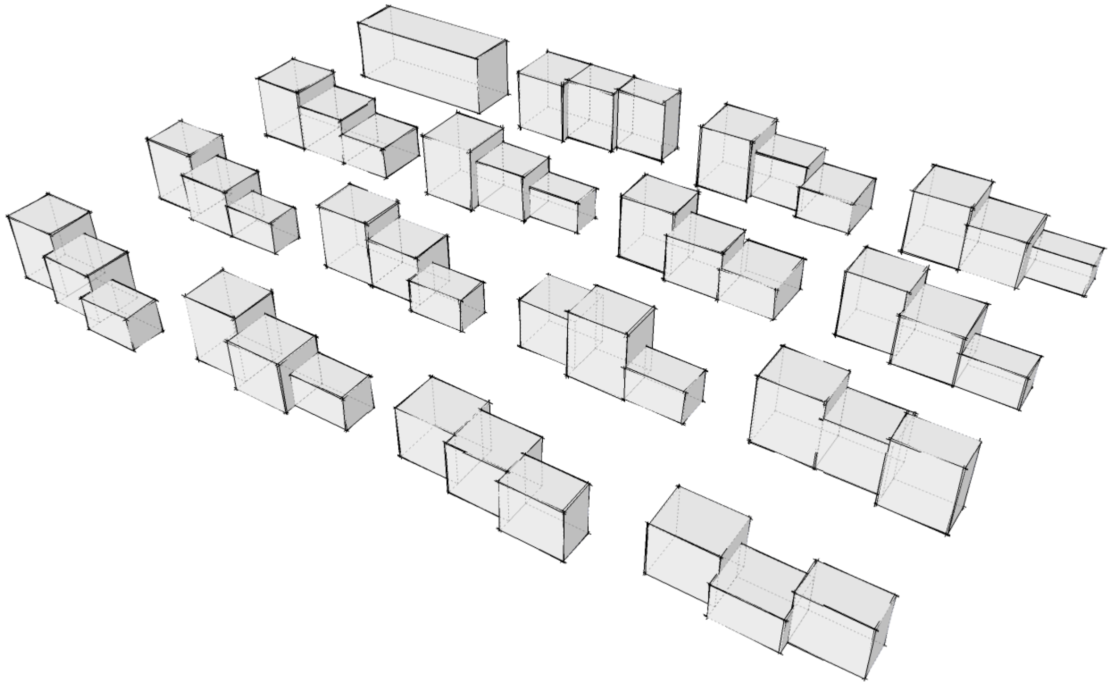


Figure 8: Building envelopes consisting of three volumes of constant x width and x position, and varying z width, height (y direction) and z position

In this example, only three parameters are necessary to achieve all possible combinations:

1. The width of the buildings in the z direction: bldgWidthZ
2. The height of the building (in the y direction): bldgHeight
3. The position of the building in the z direction: bldgPosZ

Needless to say, building envelopes can be geometrically different and much more complex than the above example. But even if they are geometrically complex, they may still be parametrically simple.

Facades

On each vertical face of a building envelope, there is a facade. We may consider facade designs independently of the building envelope. By conventional architectural design, we typically consider the facade as a composition in relation to the size and proportions of the face of the building. We also often think of facades as consisting of a base, a middle and a top, typically corresponding to the ground floor, the middle floors and the top floor. What we may not always think of, is that facades can be considered as patterns of walls and openings. And openings, in turn, can be windows and doors. This however, is very useful in parametric design.

As opposed to building envelope design, facade design is similar to site layout design in that it is basically a two-dimensional design of a (more or less) planar surface. It deals with shapes, rather than volumes. And while there can be symmetry in three-dimensional space, symmetry is often a much more useful tool in two-dimensional design, and particularly in facade design.

Consider two different facades like the ones shown in figure 9. From an architectural point of view, they appear to be quite different. The one on the left is a classical facade with symmetry in the facade as a whole, as well as in each door and window. In the first and second floors, the windows form a simple translation pattern (a group p1 tesselation of the wallpaper groups). The other, on the contrary, is a modern (and rather dull) facade with no symmetry in the facade as a whole, and with only a few other symmetrical elements.

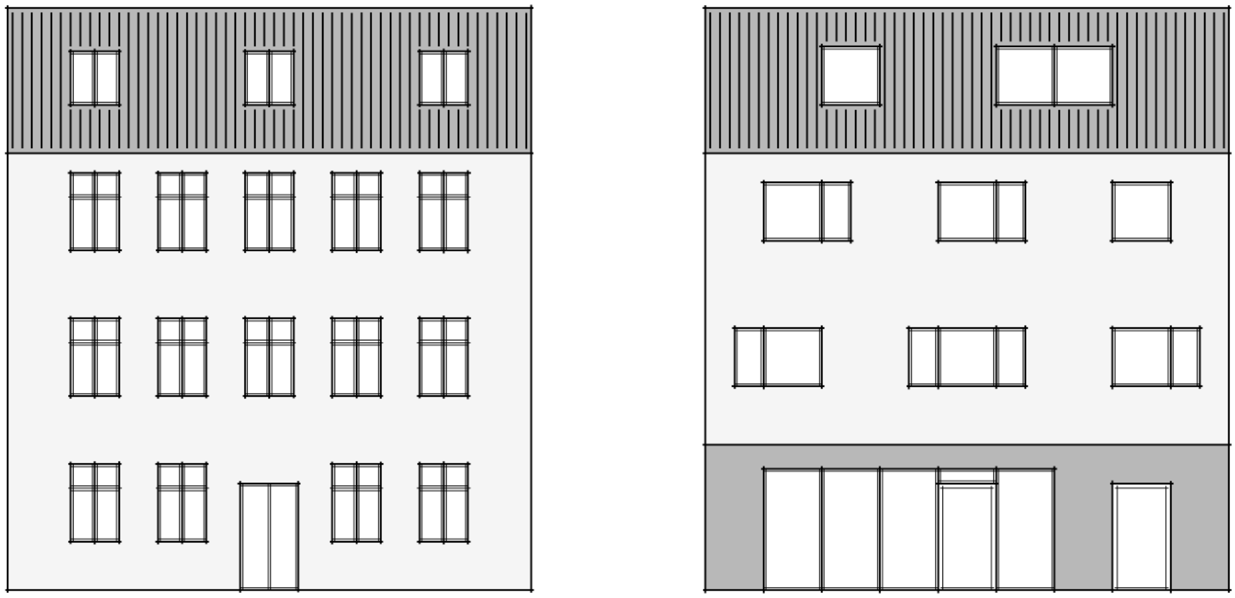


Figure 9: A classical facade (left) with many symmetries, and a modern facade (right) few symmetries

Figure 10: Same as figure 9 with grid overlay

From a parametric design perspective, however, the two facades have a lot in common. In figure 10, a grid has been overlaid the facades, which enables a reading of both facades as consisting of an (almost) identical set of facade elements: a) wall, b) window, c) half window, d) door, e) roof, f) roof window, g) shop window, h) shop door. All of these elements come in a classical and a modern version (figure 11). Note that elements g and h are not used and that color is not considered a difference (as the ground floor facade of the modern building is slightly darker).

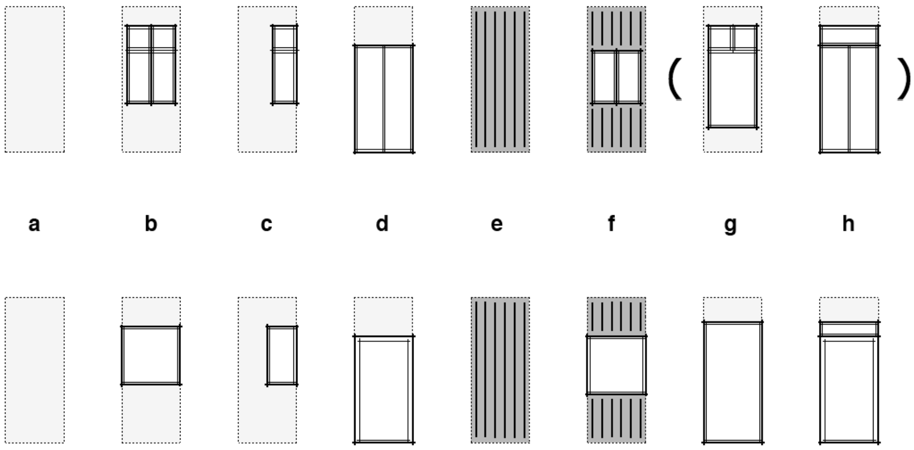


Figure 11: Facade elements of the classical facade (top) and the modern facade (bottom) shown in figure10. From left to right: a) wall, b) window, c) half window, d) door, e) roof, f) roof window, g) shop window, h) shop door. Elements in brackets are not in use.

Parametrically speaking, the two facades have different facade structures. The structure is the order of the constituting elements. If we consider the structures for the two facades without regard to the design elements, we can order the names of the different elements in a matrix as they appear on the facade:

e	f	e	e	f	e	e	f	e
a	b	c	c	b	c	c	b	a
a	b	c	c	b	c	c	b	a
a	b	c	c	d	c	c	b	a

e	e	f	e	e	f	f	e	e
a	b	c	a	b	c	a	b	a
c	b	a	c	b	c	a	b	c
a	g	g	g	h	g	a	d	a

Figure 12: Facade structures for the classical facade (left) and the modern facade (right) shown in figure 10. Letters refer to facade elements in figure 11. The subscript letter "m" indicates that the element has been mirrored.

As an experiment, we may now swop the facade elements of the two facades and fill the structure of the classical facade with the elements of the modern facade and vice versa. This will produce the result shown in figure 13. And with yet different facade structures, the modern facade elements may produce either a modernist design or a contemporary design, as shown in figure 14.

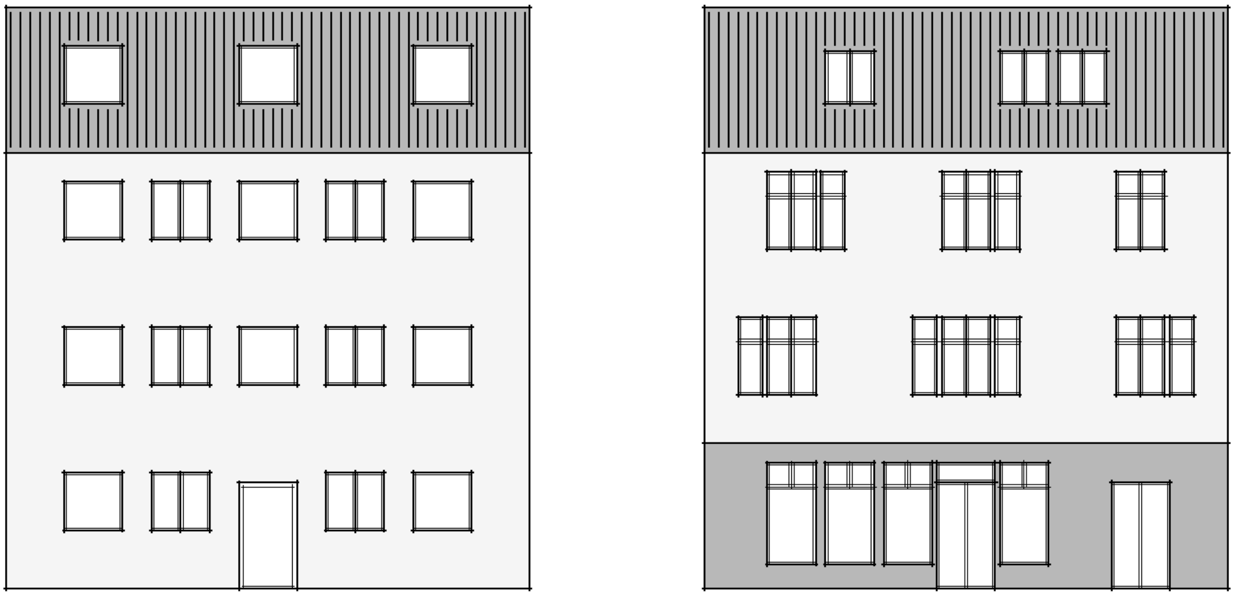


Figure 13: The structure of the classical facade filled with the elements of the modern facade (left) and the structure of the modern facade filled with the elements of the classical facade (right).

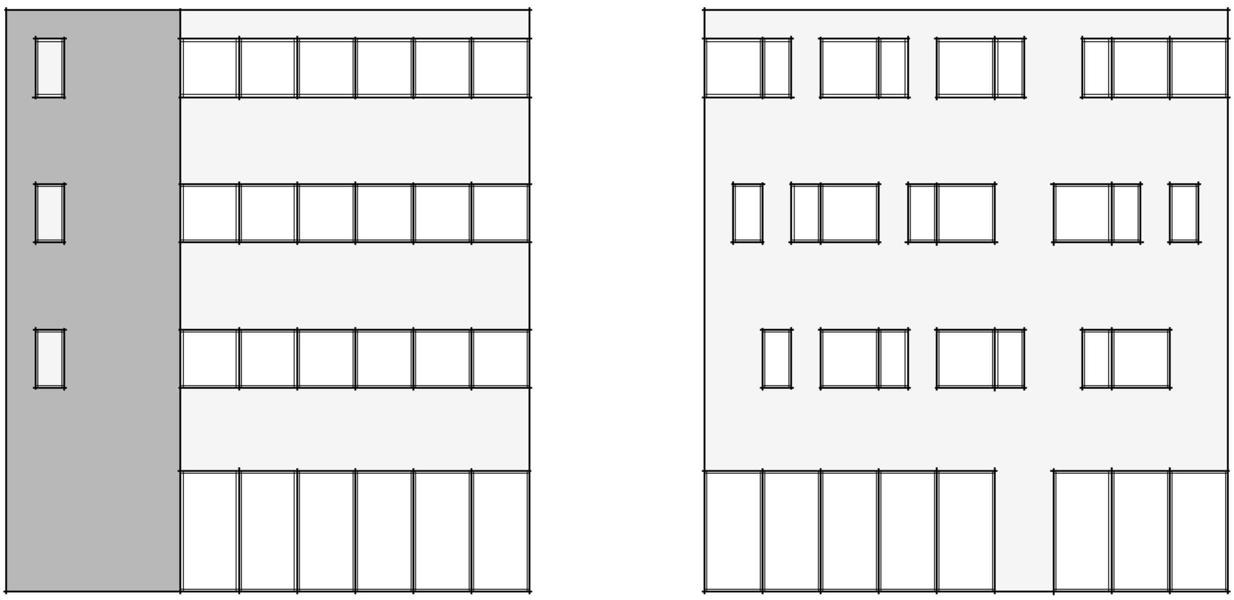


Figure 14: Examples of modernist (left) and contemporary (right) facade structures, filled with the modern facade elements of figure 11.

From Form to Script

Parametric design, essentially, is about defining the rules according to which the computer must generate the design. This is done through scripting (writing computer code). Therefore, we need a way to translate the design intentions into a script. Here the design structures mentioned above form an important intermediary step. Most parametric design is propagation-based[2] – or linear. This means that there is only one direction for the script to develop. This, in principle, is similar to conventional drawing. First, we draw the first line, then the second, and subsequently all the other lines it takes to finish the design. Only, by parametric design, the sequence of operations – the rules – is important, as previous lines form the basis for what happens next.

If for instance, we would visualize the step-wise creation of the top-right site layout of figure 7, we might get a series of drawings like this, which we may call a schema:

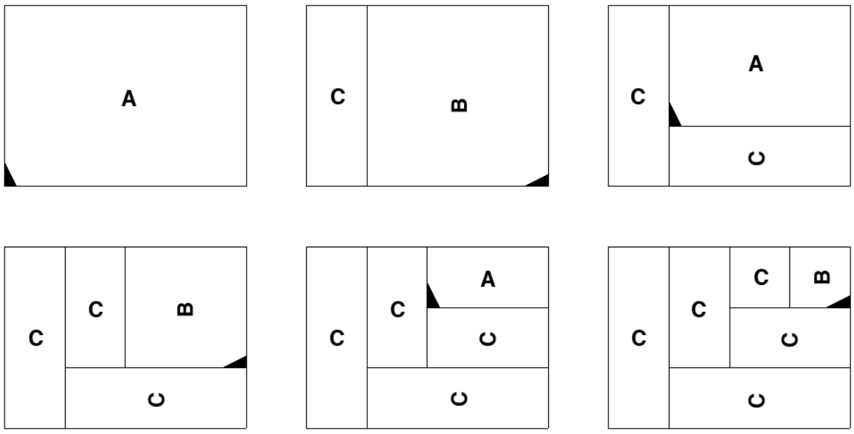
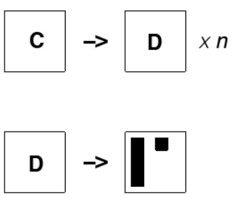


Figure 15: A schema for the creation of the the top-right site layout of figure 7. Each step indicates the division of the shape into two new shapes: A narrow strip shape (C) to the left and a large shape (A or B) to the left. While no further actions are performed with the C shapes, the large shapes are rotated 90° either left (B) or right (A) in turns, as indicated by the small triangle in the lower left corner of the shape.

A schema (schemata in plural) is a sequence which describes the rules for the creation of a design. It may be considered the “recipe” for the design, and forms an important step between conceptualizing a parametric design, and the script (computer code) which will ultimately create it. In the example in figure 15, we may describe the rules which are at play as follows:

A —> Split the shape in the X direction into a shape C with the width of *c* and another shape B with the width of whatever is left, and rotate the coordinate system 90° counter-clockwise
B —> Split the shape in the X direction into a shape C with the width of *c* and another shape A with the width of whatever is left, and rotate the coordinate system 90° clockwise

As the rule A will produces shapes called C and B, and the rule B will produce shapes which are called C and A, the two rules will be executed in alternation, until all shapes are called C. Observing the orientation of the coordinate system, we may then introduce another rule, C, which splits the shape C into as many square shapes D as possible. If rule D fills two buildings as shown, we will reach the top-left site layout of figure 7:



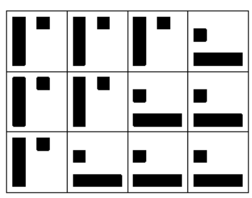


Figure 16 (left) and 17 (right): By splitting shapes C into as many square shapes D as possible and filling in an elongated and a square building into each shape D as shown, the result will be the top-right site layout of figure 7.

While the result of rule D is shown as a complex figure of two buildings, this composition may also be broken down into a number of rules. Similarly, the facade structure of figure 9 may be composed from splitting the rectangle of the entire facade according to the gridlines of figure 10 into shapes with names according to figure 12. In turn, each of the named shapes may be filled with the elements of figure 11.

As it is hinted in figures 13 and 14, the actual resulting design, relies as much on the elements which are filled into the structure as on the structure itself. The challenge, as well as the power, of parametric design is to realize what designs may result from the combination of different structures and elements which constitute a schema.

Summary

Probably the most difficult mental leap to do when dealing with parametric design, is to consider how the design may transform, when the values of different parameters change. The challenge of parametric design is to imagine what particular parameters will enable you to do. On the most basic level, elements may be scaled, shifted, reflected or rotated. These basic geometric operations may be embedded into each other. On a more complex level, elements may be substituted for other elements.

Architects would typically group different site layouts according to their typology, which is useful for discussing different morphological compositions. Yet typologies do not consider possible parametric similarities and differences. A more useful starting point may be to consider geometric qualities on a more general level. In order to distinguish parametrically different designs, an understanding of symmetry, hierarchy and fractals is helpful.

Geometrically speaking, a building envelope is the overall form of a building without detailing. In their simplest form, building envelopes are box-shaped objects, but often they are more complex. Yet, even if they feature very different geometric qualities they may be parametrically identical.

Facades can be considered as patterns of walls and openings. Facade design is similar to site layout design in that it is basically a two-dimensional design of a planar surface. The structure of the facade is the order of the constituting elements. The structure may be described as a matrix of names. Different elements may be substituted for these names. Both structures and elements of facades may be swopped to produce similar but different designs.

Parametric design is about defining the rules according to which the computer must generate the design. Therefore, we need a way to translate the design intentions into a script. A schema is a sequence which describes the rules for the creation of a design. The challenge, as well as the power, of parametric design is to realize what designs may result from the combination of different structures and elements which constitute a schema.

Further Readings

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