Parametric Urban Design as a Medium for the Artistic Exploration of Urban Space and Form

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Parametric design has only recently been applied to the urban scale in the form of parametric urban design. While parametric design has found its way into design engineering in the form of structural analysis and environmental simulation testing, and into architectural design in the form of 'parametricist architecture', so far, in urban design, it has mainly been used for modeling existing urban environments. Nonetheless, parametric urban design holds great potential for artistic design exploration at the urban scale. Based on a brief description of parametric design in architecture and in urban design, this paper takes its reader through two case stories of the use of parametric urban design for the artistic exploration of urban space and form. Applied to the scale of the urban, parametric design opens new ways of thinking about form and space, and enables the exploration of complex morphologies in more efficient ways than conventional design media.

Introduction

Parametric design software has found widespread application in the design disciplines in recent decades. In design engineering, it is used in structural analysis, as well as in environmental simulation testing. In architectural design, most notably, it is used to develop architecturally distinct buildings with a dynamic formal language in what has become known as the parametricist style.

Fig. 1. Kartal-Pendik Masterplan. Source: zaha-hadid.com

At the urban scale, in urban design, parametric approaches are more rare. Attempts have been made to apply a parametricist formal language at the scale of urban design as in the unrealized 2006 Kartal-Pendik Masterplan in Istanbul, Turkey by Zaha Hadid Architects (fig. 1). However, the typically non-artifact quality of urban design as the agglomeration of multiple individual designs responding to individual needs, interests, and land ownership patterns, and subject to planning, rules and legislation, has proven largely incompatible with this design approach.

Nonetheless, adopting a parametric design approach is still relevant in urban design. In fact, parametric urban design lends itself particularly well to the characteristics of urban development and the prescriptive nature of urban planning. By inference, as urban design is guided by rules, it can also be simulated with rules. And parametric design is essentially the application of rules to design.

Furthermore, parametric design may be used, not just for the simulation of existing patterns of development, but also for the artistic exploration of new forms and spaces at the urban scale. Rather than aiming for the design of unified artifacts, parametric *urban* design must take its point of departure in the formal and spatial properties of urban typologies such as buildings, urban blocks, streets, parks and plazas, and explore their potential for parametric variation and configuration.

One of the advantages of applying a parametric design approach to urban design is the ability to build design scenarios. While this is helpful in order to predict future development under different conditions, it is also a potential method for artistic design exploration. With little effort, parametric design tools enable designers to test and explore multitudes of different designs and to vary them by altering both code and parameter values.

This paper introduces parametric design as a method for artistic design exploration on the urban scale. By example of two exploratory design cases, the potentials and limitations of 'parametric sketching' is discussed and summarized. While it may not replace traditional sketching by hand, it may serve as an additional tool for artistic design exploration, which opens up for new design domains that are not immediately accessible through pen and paper.

Parametric Design

In its early days, parametric design in architecture was mostly associated with complex, plastic building designs by architecture studios such as Zaha Hadid Architects and UNStudio. With the predilection of architects for style, this dynamic and expressive architecture was baptized 'parametricism' by Patrik Schumacher [1], partner of Zaha Hadid Architects and one of the protagonists of design by means of parametric equations.

Thanks to the advent of inexpensive and easy-to-use parametric design software, parametric design has since proliferated among architects, and architecture students in particular. And while parametricist building designs are typically expensive due to their lack of repetitive building elements and thus reserved for signature buildings, many epigonic designs emerge from the efforts of young architects, trying to make their mark through the bending of algorithms.

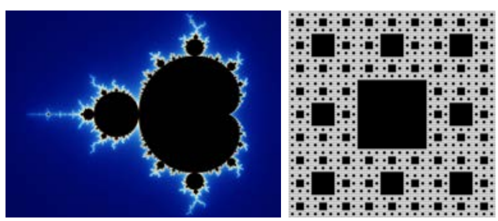


Fig. 2-3. The Mandebrot set and the Sierpinski carpet. Source: Wikipedia

Yet in essence, the application of algorithms to form-making in itself does not imply a smooth and wavy formal language, as ultimately it comes down to the math which is used in the code. Just as fractal patterns need not be curvy such as with the famous Mandelbrot set (fig. 1) but can develop in rectilinear fashions as with the Sierpinski carpet (fig. 2), the same is true for parametric design.

While computational design in general [2] as well as parametric design in particular [3] need not be performed by means of computers, they obviously facilitate the task enormously. In the past couple of decades, a series of different softwares have seen the day of light, which enable their users to design parametrically. First introduced in 2003, GenerativeComponents is a high-end parametric modeler which is used by architects and building engineers. Due to its visual programming interface, Grasshopper 3D, which is a plug-in to the Rhino 3D CAD software, has also gained widespread popularity in the architectural community. And several other parametric design softwares, such as Catia, which was originally developed for the aerospace industry, also see a growing user base.

Parametric Urban Design

Parametric architecture is notable for its expressive forms and easily stirs interest, both among architects and beyond. Nonetheless, urban design may lend itself even more to a parametric approach, due to its conceptual nature. Urban design rarely reaches the level of physical form. Rather, it negotiates the principles, rules and parameters which define the scope for architectural design of physical artifacts. In this sense, urban design is one step away from its object [4]. The relation between the rules and guiding principles which are the outcome of urban design, and the rule-based and procedural logic of parametric design, in other words, is obvious.

Several scholars have entertained the potential of a rule-based approach to urban design. Particularly within the theoretical strand of shape grammars, which was first developed at MIT in the early 1970s [5], studies have been made to describe urban space by means of shape rules [6] [7] [8]. But also other computational approaches which seek to encompass the logic of urban planning and building regulations have seen the light of day [9].

In 2008, the PhD research of Pascal Mueller carried out at ETH led to the release of CityEngine, which is procedural 3D modeling software specialized in the generation of 3D urban environments [10]. For many years, the software was mainly used in the game and animation industries where it is used to create imaginary urban environments. In recent years however, it is used increasingly in urban planning and design. As it integrates with geographic information systems (GIS), it facilitates the integration of physical 2D and 3D data, from terrain to streets and building footprints, into the model space. While existing urban environments can be generated parametrically from this data, proposed urban environments may obviously also be generated and placed in the spatial context of the existing city at any level of detail [10] [11].

To a large extent, urban design is structural and repetitive, as it builds from space and form typologies, such as streets and plazas, as well as urban blocks, housing blocks and towers, terraces, detached and semi-detached housing, etc., as described, for instance, by Curdes [12] and many others. These urban forms and spaces, and the way they connect, may be described mathematically as systems of graphs and nodes as in space syntax [13] and other less formalized descriptions [14]. Finally, urban space may also be analyzed for its fractal qualities, as in Bacon's notion of involvement [15] or, more extensively, as in Batty and Longley's comprehensive work on fractal cities [16].

Artistic Design Exploration

For a long time, the creative process of artistic design exploration – of conceiving novel designs – was little and poorly understood. Due to its non-verbal nature, it is difficult to communicate, let alone to explicate. While some have described the opaque nature of design reasoning as a deliberate mystification of a process which cannot be argued objectively [17], others argue that even if its tacit nature makes it incommunicable, it is methodological and rational all the same [18]. What is clear however, is that design thinking is a form of reflection-in-action [19] which takes place while the designer interacts with physical materials, such as pens and paper or physical modeling material such as styrofoam and cardboard, or with intuitive sketching software such as SketchUp.

In recent decades, our understanding of the mechanism of artistic design exploration has grown significantly, not least through the important research contributions by design thinking researchers, such as Bryan Lawson and Nigel Cross. Design problems are ''wicked problems' [20] in the sense that they cannot be defined exhaustively prior to their being solved but only through the process of solving them. This process may be described as a 'conversation with representations' [21] in which the designers make repeated attempts at coming up with design solutions by making sketches. Each new sketch – or reflection drawing [22], when done in pen and paper – 'talks back' to the designer, informing her of how to revise the sketch in the form of a new sketch.

It is through this process of interacting with visual media that the designer develops her design skills and particular 'designerly way of knowing' [23]. In the process, the designer may apply different strategies, such as the use of guiding principles, design precedents [21] or generative metaphors [24]. Therefore, as design educators will typically concur, experience plays a very important role, when it comes to design skills. It seems obvious then, that the way each individual designer designs, is as much a product of her personal journey through life, as of general design knowledge, skills, and competencies.

Apart from the strategies mentioned above, which may be described as internal to the realm of design, designers may also look to other fields in their artistic design exploration. Nature and geometry are often used as sources of inspiration, as are music and mathematics. In addition, chance and the unconscious may function as design drivers. The same is true for stringent and rational thought, as when design aims to fulfill specific performance criteria or takes its point of departure in research. Finally, design may be driven by generative processes, whether with the aid of computers or not [25].

Case 1: The Vertical Kasbah

The vertical kasbah project was an entry to a competition for the reinterpretation of urban space in the city of Abu Dhabi, UAE. The project was developed from the generative metaphor [24] of the termite mound. In nature, a termite mound is a hollow structure, created by termites, which allows air to pass through by means of thermal convection fig. 4). This way, the interior of the termite mound is cooled to be considerably cooler than its environment.

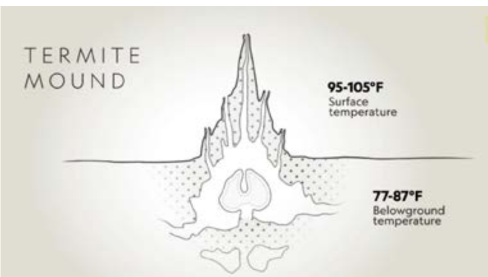


Fig. 4 Termite mound as a generative metaphor.

Working from this generative metaphor, focus was on the development of a three-dimensional structure of solids and voids which would offer useful interior as well as exterior spaces. This involves spatial reasoning on a very complex level. This may obviously be done by conventional drawing and modeling techniques; in fact, a classic basic design exercise in many Turkish architecture programs which involves carving out a set of traditional rectangular Hamam soap bars which are subsequently stacked in a tightly fitting box and used as casting mold for a gypsum cast to explore exactly this kind of solid/void relationship. Nonetheless, as highly complex three-dimensional structures of solids and voids are difficult for the human brain to hold, let alone to systematically modify, a parametric design approach may be a powerful medium for the exploration of such structures.

Hence, for the vertical kasbah project, parametric design was used to analyze and develop a three-dimensional structure which would meet a complex set of requirements such as 1) allowing for thermal convection as a principle of passive cooling, 2) providing useful interior spaces with adequate access to natural lighting and ventilation, 3) provide a hierarchy of open public spaces at different levels in the interior of the structure, 4) enabling the design of architecturally articulated facades which contribute to the passive cooling principle through the provision of shade under the merciless sun of the Arab peninsula, as well as 5) allowing the structure to scale in order to adapt to different plot sizes and building heights.

Fig. 5 The vertical kasbah in the context of downtown Abu Dhabi. The structure forms part of a continuous spatial system which includes acacia tree plantings at the foot of the structure. As the trees cast shade onto the tarmacked ground surface, air is cooled before entering the structure at the ground floor level.

Coding in combination with manual sketching and modeling allowed for the development of a series of principles for the spatial development in the structure, which could be tested and analyzed in the parametric model. As the power of parametric design enables the generation of both complex and detailed models in practically no time, several design iterations could be performed. For each iteration, both overall morphological qualities as well as architectural detail could be examined, as – once coded – the system will generate endless variations, as parametric values are adjusted.

Fig. 6. Front elevation. Parts of the facade protrude, while others are set back, in order to provide a high ratio of shaded facade parts. In setbacks at the bottom of the structure, windows are large in order to provide daylight in interior spaces. Higher up, windows in setbacks are smaller to minimize direct sunlight in interior spaces. Not to scale.

As parametric design is essentially the application of math to form-making, different mathematical models were tested which would encompass the many different design situations which would occur throughout the structure without causing design conflicts. Ultimately, a three-dimensional matrix was developed which allowed the control of all occurrences of design situations. Exterior facades on the outer perimeter of the structure as well inside it, whether adjoining exterior surfaces such as balconies and floors in voids in the interior of the structure, or not, is an example of such design situations. Another example is the gradual variation of the size of windows both on the outer perimeter and facing the interior voids, to negotiate interior natural lighting against the risk of overheating through direct sunlight onto windows.

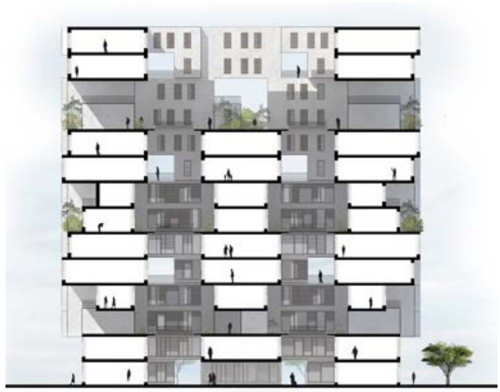


Fig. 7. Longitudinal section. Vertical shafts are connected to holes to the outer perimeter of the structure. In combination with setbacks, shaded exterior spaces are provided inside the structure at different levels. Functionally, lower levels hold shops and services, middle floors hold office spaces, while upper floors hold housing. Not to scale.

Fig. 8. Public open space in the interior of the vertical kasbah structure. The space is partially open to the sky, as well as horizontally to the exterior pe-

rimeter of the structure. A scaled-down sense of a low-rise structure is achieved through the morphological variation of building parts, even though the space shown sits at the 11th floor of the 14-floor structure.

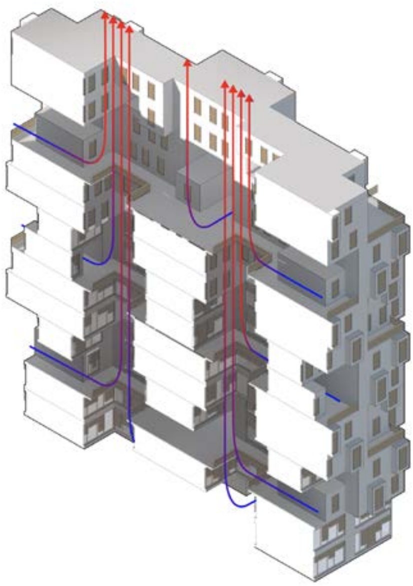


Fig. 9. Axonometric section view. Through convection (stack effect), air rises through the internal vertical shafts providing natural ventilation. air is sucked in through the holes connecting the shafts to the outer facade. Air flows over a system of water pools and vegetation for additional cooling.

Case Study 2: Fractal Kasbah

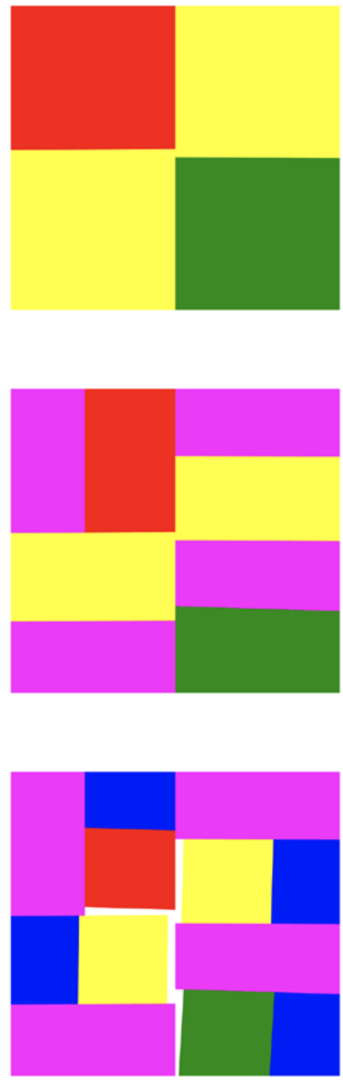
While the Vertical Kasbah project was developed as a response to external criteria in the form of a competition brief, the Fractal Kasbah project was developed free of any such contingencies as a mere exploration of the potentials of parametric urban design. Stemming from a fascination with the intricate structure and hierarchy of Middle Eastern and North African medinas, the aim of the project was to develop rules to simulate and generate this particular type of urban space, even if in a rather formalized way. As such, it served no outer purpose other than the exploration of the parametric urban design approach per se.

Medinas (as 'kasbah', strictly speaking, denotes only a part of the medina in the immediate proximity of the palace, surrounded by its own set of city walls) are complex socio-spatial structures in which streets and alleys at different levels of the hierarchy have different functions and meanings [26]. While main streets are designed as thoroughfares leading from the perimeter of the medina at the city gates to the souk (market) at the center of the medina, most other passages are organized in an intricate system of increasingly fine-grain alleys which end up in cul-de-sacs. While houses at the far end of this system are historically clustered according to family patterns, clusters of houses, in turn, are organized according to clans. Hence, the web of streets and alleys represent a gradual shift from the highly public spaces of markets and thoroughfares, over the neighborhoods of different clans, to the private space of the individual house.

In this web of wiggling streets and alleys, built structures from souks, mosques, and other public structures, to the mass of residential houses, forms one compact mass of buildings of predominantly two floors, and, with few exceptions, in the form of courtyard houses. This particular morphology constitutes a very compact structure which minimizes circulation space (in fact dimensions of streets were historically defined by the dimensions of packed camels [26]), and reduces solar radiation on facades and ground surfaces, in order to minimize passive heating.

In the course of the artistic design exploration process, different rules (algorithms) were tested with regard to their ability to simulate the space and morphology of the medina. As the web of streets and alleys has fractal qualities, a fractal approach was ultimately chosen, in the form of a recursive rule. Rather than building a web of streets and alleys along which buildings would generate, the approach was based on a recursive subdivision of shapes, some of which would generate street shapes along one side, which, in combination, would form a continuous street space. This particular strategy allowed for the generation of an irregular, yet continuous street space, as is typical for historial medinas.

Slight asymmetries by the division of shapes enabled necessary overlaps between street shapes, while the application of a subtle jitter added a slight measure of irregularity. Hence, while the resulting structure is rather formal – and in this regard quite different from organically grown medinas – it still assumes many of the spatial and morphological qualities of medinas. A stopping rule examining the size of shapes terminates the recursive rule, once shapes are too small for further subdivision. Through the application of a randomizing rule, final shapes are turned into either buildings or garden spaces, with an increasing share of garden spaces towards the edges of the system.



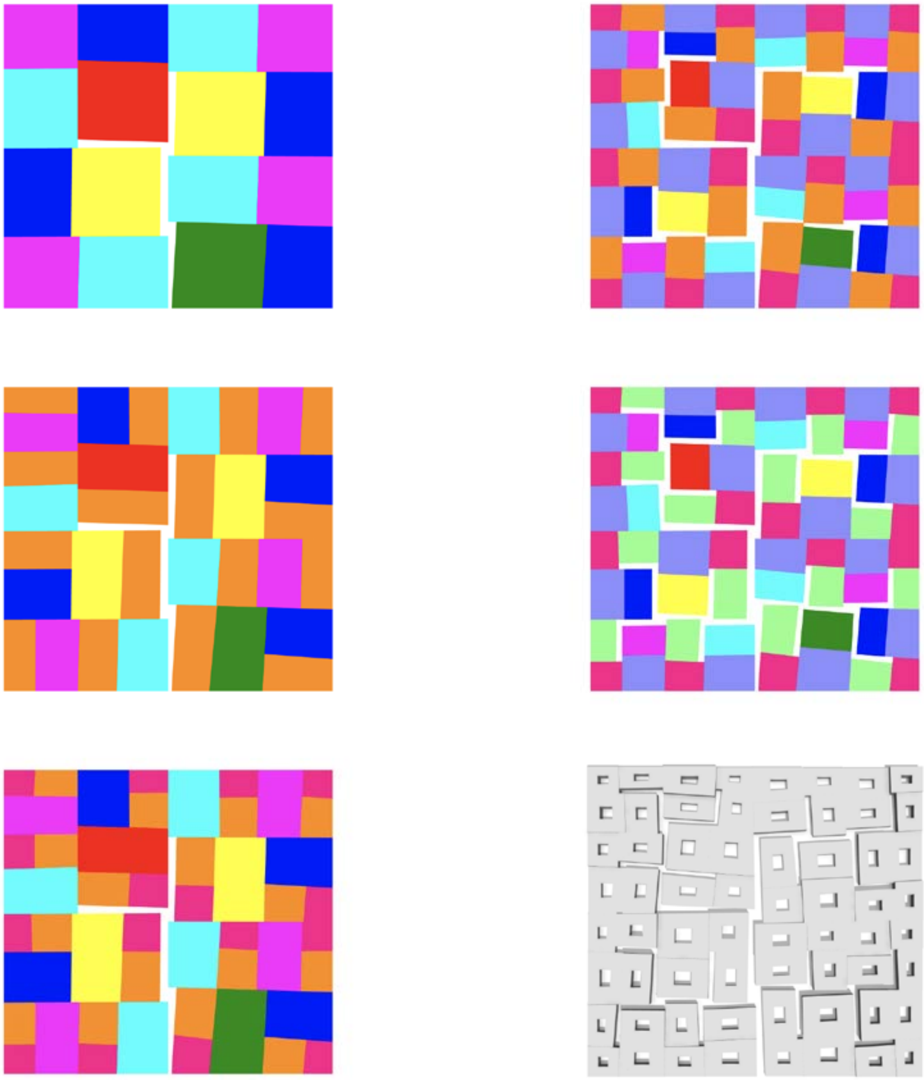


Fig. 10-18. Graphic representation of successive steps of the recursive rule for the fractal kasbah. The incremental generation of street spaces (shown in white) is visible from fig. 12 onward. Through slightly asymmetrical subdivisions, shape corners overlap to allow for locally generated street shapes to connect spatially. In fig. 18, volumes in the shape of courtyard houses are substituted for colored shapes.

Fig. 19. Final plan view rendering of the fractal kasbah showing final shapes in the form of buildings and garden spaces. The amount of garden spaces increases towards the edges of the system.

Discussion

The two case studies demonstrate examples of the application of parametric design to artistic design exploration. Conventional sketching techniques such as pen and paper were still used in the process. Designing by means of algorithms (which essentially are lines of text) needs an interpreting media to transpose spatial ideas into code. To this end, the author has developed a kind of serial graphic technique akin to comic books, where each step of the procedural rule is visualized graphically. Once the algorithms are (debugged and) executed, the resulting geometry may be examined in a viewport and adjusted by means of graphic sliders in the computer interface.

In a way, parametric design is just yet another tool in the designer's toolbox. Traditionally, designers have always shifted between different modes during the design process. They design at different scales, as they may interchangeably shift between the detailed scale, the intermediary scale or the structural scale, in order to get a full grasp of the emerging design at hand. They may shift between different projections, as they may examine their object in plan view, in section view or in perspective view. And they may shift between different media, as some aspects of the design are best (and fastest) explored by means of pen and paper, while other aspects may better be examined through scale or CAD models.

Nonetheless, parametric design is not accessible to any designer, as coding is not part of the core designer skill set. Furthermore, learning to code can be difficult for visually oriented designers, as the relationship between the algorithm and the resulting geometry is not immediately apparent. Nonetheless, it represents an additional skill set, which expands the designer's design vocabulary. In tandem with drawing and other conventional design media, it may enable the designer to explore her design in ways which would otherwise be impossible, or, at best, both complex and time-consuming to carry out by conventional means.

As demonstrated in the saying that "if the only tool you've got is a hammer, everything looks like a nail", our thinking is shaped by our tools. This is also true for parametric design tools. Both the structural logic of procedural modeling, as well as the ability to incorporate both gradual and random variation, as illustrated in the two case studies, shapes the designer's thinking about what and how to design. This way, the tool speaks back to the designer. This is not unimportant, as it represents ways of designing which would not be available otherwise. It is also not benign, as it may impact the design in unintended or even negative ways, if not applied consciously.

What is clear however, is that parametric design should not be seen only as a visualization tool for readily conceived ideas of form and space. By the advent of CAD software, it was originally seen by most architects simply as a medium for generating neat presentation drawings. Only slowly did it (to some extent) grow to become a natural medium for design exploration (for some). Similarly, parametric software, at the urban scale, has primarily been valued for its capacity to simulate existing urban environments. But in fact it holds a great potential for creative and artistic design exploration, also at the urban scale.

Conclusion

In recent decades, the advent of parametric design software has expanded the application of parametric design in design engineering, in architecture, as well as in urban design. In design engineering, it has mainly been applied to structural analysis and environmental simulation. In architecture it has most prominently paved the way for the so-called parametricist style of expressive, organically shaped signature buildings. More recently, and to a lesser extent, it has also been applied to urban design, although mainly for the simulation of existing urban environments.

Parametric urban design, nonetheless, holds a great potential for artistic design exploration by the design of new urban spaces. While parametric design skills are not part of the conventional skill set of urban designers, it potentially enables the design of more complex form and space, and significantly increases the scope for design testing and variation. It also facilitates ways of thinking about design, such as gradual and random variations to the design, recursive, or fractal, designs, and more. However, as with any device for design, it must be applied consciously, to avoid unintended or negative results.

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