Interpretations of Complexity

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Abstract

Three dimensional fractal forms are most often generated as point clouds and then converted to mesh objects. The resultant meshes are subsequently quite large in file size and irregular when viewed alongside similar parametrically derived forms. Mesh conversion to NURB curves and surfaces is a conventional process of reverse engineering from scan data but is unique when used to interpret algorithmically derived fractal forms. This paper explores the process of translating the forms in a technical sense but is largely concerned with the conceptual issues of navigating software applications of shape grammar and of the issues regarding spatial reasoning within the Cartesian frame

Keywords

Fractal, Complexity, Holon, Mesh, NURBS, Creativity

Introduction

Generating new forms is difficult and time consuming. It is expected that an artist or designer produces works of novelty or for novel purpose. This pressure to innovate requires creative output that equates to, new combinatory outcomes. The requirement to innovate is both simultaneously exhilarating and exhausting, that is my experience and perhaps the experience of many.

Creating new forms requires a substantial inventory of pre-existing forms and a requisite capacity in human memory of shapes and forms and all of the subsets of those shapes and forms, inclusive of line and curve type, surface pattern, texture, colour, dimension and more. In stark contrast to memory however, Computer aided modelling uses predefined workflows and regulated operations in order to generate new forms, and at the core of this process is the initial generation of two dimensional curves or lines that can then be extrapolated to three dimensional forms through processes such as extrusion and lofting to name but a few.

The parametric workflow is common to many CAD software applications and functions well because it preserves a history of all mathematical operations used to describe an object or objects. What is however restrictive is that this process uses a limited parameter set and many examples of industrial design software in particular (to a novice) uses the language of industrial processes, subtractive fabrication for example.

The idea of mechanical and industrial design is that the outcomes can be manufactured, and importantly can be manufactured to great dimensional accuracy at large quantities and are repeatable using conventionally available manufacturing processes. CAD and Parametric workflows were designed around manufacturing processes and are still heavily influenced and somewhat constrained by those processes and the economical imperatives of large scale manufacture. The constraints are shifting of course and new processes such as additive manufacturing permit changes to how objects/forms are mathematically described.

As someone who is relatively experienced at using solid modelling applications that contain parametric kernels, I must admit that there is something quite comforting and obsessively pleasurable about repeating the same processes and being constrained by them in turn. There is a creative challenge in seeking answers to new problems posed by goals constrained by restrictive workflows. That creative challenge however can often reveal the burden of design software and the angst that ensues when the creative brain is conditioned by pre-defined algorithms, as to how something should be made.

As someone who began my career as a sculptor, I was initially attracted by a discipline containing a vast array of intrinsically deep and rich processes, stretching back millennia. Shape grammar alone owes a great deal to sculptural processes and enquiry, especially from periods when sculpture and architecture were intrinsically interconnected. Thousands of years of working with clay alone exhibit a complexity of forms that CAD modelling is only now beginning to describe. It is obvious that for a time design and art had differing purposes and the foundations of consumer culture beginning in the industrial revolution certainly helped shape manufacturing processes which in turn helped shape design paradigms. The functional artefact has left its mark on society and its echoes in computer aided design.

I believe in the view that, we, as a society have certainly been conditioned by our tools. CAD software for instance shapes how we think, it liberates the repetitive task but it constrains the set of opportunities. It is however just a tool and can be refashioned or adapted or co-opted at will, with experience and dedication of course. Some tools are easy to refashion, making changes to software requires particular and unique skillsets, this is imperative, but to most of us, adaptation co-option and even subversion is certainly applicable.

Philosophically, it becomes imperative to address the notion of the tool and as Alva Noe states, Tools and technologies are central to our lives and they become habitual and organize us[1].

The tool as in the modelling process is refashioned from application to application. There are some old favourites that have a trusted user base particularly in the engineering community, software from pro engineer and Autocad through to contemporaries such as Solidworks and inventor. The commonalities are the communities of users they serve, and the paradigm of the engineer and industrial designer. Shape creation using the toolsets of solid modellers as mentioned have had a history of tending toward subtractive manufacturing frameworks. It could be said; that the process fashions the tool which in turn fashions the process.

The disruption of additive fabrication affords a reshaping of process or the adoption of new processes which permit a change in tool. The software applications now have the ability to radically change, grow and adapt to changes in additive manufacturing processes. The users of the applications and processes also have the ability to change and adapt to new (and unusual) creative potentials. The paradigm of engineering and industrial design shifts and we in turn, are reorganized by our tools.

The points I wish to raise in the next section are in regard to how the lexicon of shape grammar, grows, changes, adapts as a result of the affordances of new and changing tools. Design and particularly industrial design has had a tendency toward the refinement and simplification of form. The simplification of form in industrial design however, can be seen as a circumstance of process and tool. The artefact is not the best artefact it can be simply because it is simplified it is simplified to suit the economics of the manufacturing process.

Sometimes the tool, the software, is very useful in modelling highly complex forms. This is becoming increasingly more apparent as new software applications emerge to service additive fabrication, or as software applications unintended for the manufacturing paradigm adapt, as it is realised that new potentials exist and can be attained.

Cartesian Reasoning

Education used to include and favour some very old and revered notions of geometry. A good foundation of the understanding and application of geometry, geometrical systems and application underscored a ‘classical’ education right through to the end of the twentieth century. It is my experience as an educator and practitioner that unfortunately, (from my perspective as an educator) geometry has less support in secondary and tertiary education than it should. The chief reason I make this argument is that spatial reasoning which underpins our navigation in the world and negotiation of the world, is not well developed unless a thorough body of knowledge regarding geometrical systems is experienced, applied and critiqued. The Cartesian co-ordinate system is crucial to the understanding of space and yet it is applied but rarely understood in terms of its historical origins, and its necessary conventions. Cartesian coordinates define objects precisely in computer displays, software applications for three dimensional design and modelling and has been the dominant method of definition for the history of computing.

The reason I speak of the Cartesian system now is so the premise can be entertained that Cartesian space is (mostly) required to define the geometries that we commonly understand. And it must be thought of as a premise, as Cartesian space is an elegant tool for enabling many, many processes, but it is just that, a tool, the tool could be changed and the result would be, that the processes of definition would change as well.

It is a simple premise, possessing a mindset shaped by the three dimensional domain of length, breadth and height lends itself well to applications of this tool in processes that exploit the simplicity of Cartesian space. If we are conditioned to think in boxes, we will continue to build boxes. The cliché is true, it often is applied in the most banal and metaphorical environments, but our spatial reasoning in regard to Cartesian space requires constant critique.

Rene Descartes shaped his view of coordinate space to house Euclidean geometry and support it with a algebraic framework. There is no denying the brilliance of Descartes coordinate system and why it has shaped our world till now. Many mathematicians have contributed to the geometries described within the parameters of this space and countless new contributions to shape and form have been made, but the space itself, just as the software applications that utilise it, is just a tool that requires us to understand it as such. By this I mean we need to understand its constraints as well as its benefits.

Using the language of computer aided design, terms such as curve and spline have real world significance in respect to the object being modelled for specific purpose. Cartesian space requires a curve or a spline to have a precise mathematical definition which most users are not overly conversant with. These definitions are precise and concrete but in a sense they are conceptually abstract to the designer or user of the software. What I mean is, these definitions are not usually directly relational to the intent of the designer, and they exist to achieve a goal. It seems as software applications for CAD and solid modelling in particular become more user friendly, a true understanding of their function or underlying rules slips away. Of particular note with CAD software is the inherent necessity of refinement and simplification, every curve, every spline if not refined by the user will be smoothed and fixed by the software, or at least the user will be prompted to refine. These toolsets are there to support the engineering and manufacturing paradigm. The model/ object require refinement and simplification to make the file structure and subsequent process of manufacturing it efficient.

Conceptually it is necessary to return to Cartesian space and geometry and critique it as an abstract tool. Descartes did not claim the coordinate system as his own and it may very well have a very long tradition dating earlier than Eratosthenes perhaps, but Descartes in his *Discourse on the Method*, writes of the philosophical standpoint regarding the position of ego. Ego may, in Descartes view, correspond to the origin in coordinate space. This ontological position is inferred in his writings but not explicitly stated [2]. The importance of this idea is that when we attempt to understand coordinate space we potentially assume the position of origin or ego. .We are at the centre of our own worlds, as it were. The essays published with *Discourse*, importantly, *Geometry* are disconnected in position but certainly not in intent. Descartes tools of analytical reason are clear and explicit in their instruction and this is how from Descartes through Leibniz we are entrained with a clearly useful set of tools in the form of Cartesian Space. Cartesian philosophy on the other hand asks us to critique these tools. Descartes in his four precepts [3] gives clear instruction regarding methodological scepticism. Descartes instructed all who followed to be critical of even his theories.

The reason it is essential to conceive of Cartesian space and philosophy together, is that the fields of mathematics and physics have evolved considerably from the time of Descartes but Cartesian space remains in place as a dominant paradigm. Geometries such as fractal forms are difficult to describe in Cartesian space, and higher dimensional forms such as quaternion algebra for instance, require translation to three dimensional Cartesian space. It is possible to define forms in a four dimensional or Quadray space but the dominant paradigm in computer graphics is still three dimensional Cartesian space.

Navigating, and modelling within Cartesian space does not require the designer to possess high levels of geometrical and mathematical ability, I certainly do not. The position I state though, is that users of CAD software must remain aware and be critical of the environment that we operate within especially with geometry which departs from simplicity.

Old Tools, New Tools

Now that I have set out a rough framework of Cartesian space it is essential to move on to geometries and topologies that are a challenge to our conventional uses of Cartesian space. I am speaking of geometries that possess characteristics of roughness instead of smooth and complex instead of simplified, edges and surfaces. By this I mean shapes and forms that exhibit fractal and complex characteristics.

Solid modelling which is the norm for industrial design and engineering software is reliant upon precise mathematical definition and consistent translation and communication. Geometrical form of certain characteristics can be described simply and repeatedly using solid modelling applications but not all geometry can be described this way and what can sometimes requires complicated procedure. Solid Modelling software is just one kind of tool, there are many others, particularly now that the barriers to fabrication are shifting away from a subtractive paradigm. Geometrical Modellers that once existed only in the domain of modelling for cinema, animation, computer games and visualisation have long possessed the ability to comfortably describe complex objects in Cartesian space. The paradigm for manufacture has shifted, so too has the awareness that many software applications including geometrical modellers and all of their requisite subsets can accurately model form that solid modellers cannot, and have it physically realised. The reason this is possible is that the mathematics has evolved to permit the description of extremely complex objects in Cartesian space, and yet it is common practice at a novice level at least to accept the constraints of the old paradigm.

In contrast to some of the earlier constraints of applications reliant upon the paradigm of constructive solid geometry, polygonal modelling for instance goes a long way to producing forms efficiently that solid modelling cannot. There is still a perceived distinction in industry (albeit changing) that CAD and computer graphics speak of and service differing realms, solid modellers representing applications for computer aided design and polygonal, implicit surface modellers and even voxel modellers reserved to service the Computer Graphics industry.

Much is changing thankfully as many realise that the existing tools can serve new purposes and the existing and changing processes of manufacture permit the co-option and adaptation of tools. Simply put, we can now make new things with old tools and use new tools to make things using old processes. The tools we speak of are the mathematics underpinning the modelling operations within software.

There is something crucial that I wish to discuss as distinctive to design, as design is the purview of the manufacturing paradigm. This contextualises the limitations of the protocols of design simplicity and function. Alva Noe proposes that we are designers by nature and that we are organised by the technologies that we make and consume, but his caveat is that we are organised only insofar as those technologies become embedded in our lives [4]. Conventional geometries conceived in Cartesian space represent for us the designed object. These objects, these artefacts are fashioned from familiar technologies and activities, processes of design and manufacture that we understand. The familiar technologies to the design process are those that replicate well the industrial design and engineering paradigm, the shapes, forms, and geometries that we are accustomed to. Alva Noe differentiates between design and art when he states; ‘Design, the work of technology, stops, and art begins, when we are unable to take the background of our familiar technologies and activities for granted [5]’.

As a designer at times and an artist at others it is an imperative for me that technologies, tools and processes speak of intent rather than simply used to fashion an outcome. As a practitioner with experience in physical media it is obvious that media such as clay can be shaped quickly and masterfully in ways that computer aided design software cannot for instance produce complex and organic form. The same media however can be co-opted for the design paradigm. Utilitarian objects can be designed and produced in clay. Replication and mass production in turn, may disguise the input of the creative process rendering the whole set of technologies as transparent. The crucial question here is what is creative and does than represent any distinction between art and design? The utilitarian object may have started as a novel work, something that exhibited unique characteristics never before seen. At some point however in the processes of replication the object gained familiarity and thus is perceived as designed. Where this occurred however is not easily able to be identified. One ceramic object may be art. A roomful of similar ceramic objects in the right context may be art. A shipment of identical ceramic objects distributed to department stores presumably renders the object as designed.

The question in this context is, when is the shape or form unique? Is it when it can be perceived as separate from the background of familiar technologies? If this is the case as Noe argues, the geometries described in software applications must break with the normal set of characteristics of geometries modelled in computer software as to be perceived as art or even just novel. The authors of *Organic Creativity and the Physics Within,* a creativity workshop held at Leiden University in 2013 offered a succinct definition of creativity, they stated

‘Creativity is the production or emergence of novel combinations out of pre-existing components and that it occurs at all levels of organisation of the physical and psychological world [6]’.

It is basic combinatorial theory that permits us to understand the potential combinations from a given set of shapes and parameters that change or modify those shapes. 3d modelling software possesses potentials for creation of initial geometric primitives and parameters to modify those primitives in many possible ways. Primitives in this context refer to two dimensional points, lines, splines, planes, circles, ellipses and polygons, and to 3 dimensional forms such as spheres, prisms, cylinders and so on.

The potential combinatory potential is significant when it is considered that lines, splines, planes, circles, ellipses and polygons and the development of them to three dimensional forms permits an extraordinary capacity for shape creation. But yet there are still significant limitations to the repertoire of three dimensional geometric primitives for instance in many applications.

The five platonic solids have been known to us since Plato described them in Timaeus but yet we won’t find a complete list of platonic solids as primitives in any commercial 3d modelling application, and yet we often will find the Utah teapot (for good reason). Many findings of geometers from thousands of years of discoveries have yet not made their way into 3d modelling software as geometric primitives. Imagine the explosion in combinatory potential if the history of geometry and mathematics is included in the libraries of modelling software from non-Euclidean geometry through to fractal form.

Novelty, an often used definition of creativity, Mihály Csíkszentmihályi, states can simply result from the juxtapositions of differing ideas [7]. Solid modelling software often contains a short list of primitives. It is true that with experience the tool is adapted or co-opted for us, but often objects of similar characteristics are created by many users. In contrast graphics software can contain a much higher number of geometric primitives and the potential for combination, recombination and juxtaposition of diverse elements is, by comparison far greater.

Solidworks and Inventor for example permit 10 different types of two dimensional geometric primitives where by contrast Rhino permits 18. Solidworks contains no 3D geometric primitives yet 3DS max contains 23. This is not to say that there is a preference for one or another, it simply is to illustrate the potential combinatory output from 2D and 3D primitives.

Holons, Fractals, and Combinatory Potential

One of my favourite software applications is not a cad package, nor was it produced for the film, animation or games industry. In essence it has no serious application. Xenodream [8] according to its maker Garth Thornton just evolved from an application that produced 3D objects for rendering. Xenodream is exploratory, playful, whimsical, and fits the criteria most adequately for what true creativity should feel like with software, especially in a divergent sense. The software showcases combinatory creativity by permitting divergent processes in shape creation. Geometric primitives form the basis of the software as shapes called constructors. Many shapes are available that don’t quite operate as standard geometry that we are used to however, in Xenodream each primitive can operate independently or inherit characteristics from other building blocks. The software introduces each shape as a Holon, in honour of Arthur Koestler who derived the term to describe something that is both a whole and an identifiable part of a larger whole [9]. Philosophically the idea of the Holon is important as it discussed in terms of self-organising systems. What is of note in the context of this dialogue is that here Xenodream represents concrete representation of the opportunities afforded by recursive and iterative processes and shows genuine opportunities for realising new contributions to shape grammar.

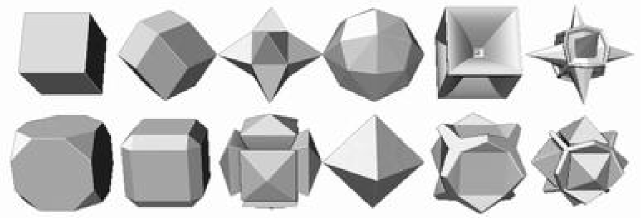

Figure 1 Xenodream; cube and box variations

Xenodream possesses 49 shape sets in its ‘constructor’ set alone; each constructor can be manipulated with three sets of variables with positive and negative values. Each initial Holon can in turn be transformed using ‘metamorphs’, preset formulas that modify the original form. There are 380 metamorphs (including constructors) with 3 independent sets of variables each. To permit an analogy in terms of shape grammar 6, six by four Lego bricks can be put together in 915,103,765 different ways

A shape or Holon within Xenodream can inherit the characteristics of other Holons, it makes a copy and transforms it with its own parameters of scale, orientation, position and skew, and its own metamorphs (formulas that modify its form). Because it inherits itself, it makes more copies and transforms them [10].

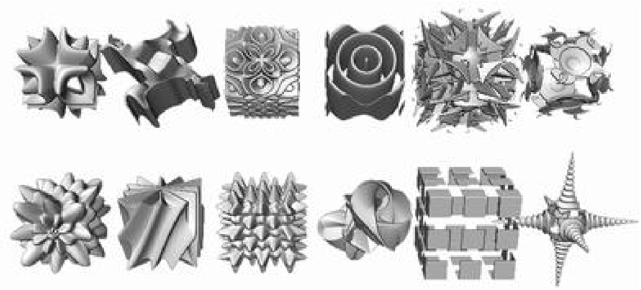

Figure 2 Xenodream; Examples of metamorphs applied to a cube

This process is referred to as iteration and mathematically this is significant as the classification of shape creation within the software is referred to as an iterated function system [11]. The process of creation is iterative and produces self-similar results; therefore it can be referred to as fractal. In mathematical terminology the Holons as described in Xenodream are referred to as transforms or functions hence, iterated function system.

What differentiates this software particularly from CAD is that it is play based, in many senses that removes it from the design framework. The intent of the software is pure exploration, and not production for purpose. That is not to say that it is not useful. As a divergent process it is incredibly beneficial to creative thinking. As a tool it lends itself to the curious definition of a strange tool as proposed by Alva Noe [12]. Xenodream in some respects is game-like. Noe's examples of art seem to exclude game and particularly software. His examples of art are mostly constrained to the pictorial, although I believe it is a mere extension to incorporate game, software and the permutations of both.

Xenodream may be a software tool for producing artworks but may also be seen as an exploration in self–similar combinatory potential and in itself a method of producing something more than mere novelty. Margaret Boden states, 'A merely novel idea is one which can be described or produced by the same set of rules as are other familiar ideas [13]'. The enormous potential offered by combinations and Holonic interactions in Xenodream stretch far beyond the familiar. Most of the algorithms for example underpinning Xenodream's functions far exceed the included parameters within conventional CAD and 3D Modelling software.

Xenodream and applications like it that break the conventions of CAD and 3D modelling software represent changes to conceptual space, and as Boden offers, a conceptual space is a style of thinking, 'it is the generative system which underlies that domain and which defines a certain set of possibilities [14]'. Xenodream is one example of a conceptual space that differs from familiar spaces developed for the industrial design and engineering paradigm, that is not to say that it is any better or worse, it simply differs. By presenting a rich and complex conceptual space it affords opportunities that break from convention and introduces the artist, designer or experimenter to the unfamiliar.

Translation and Interpretation

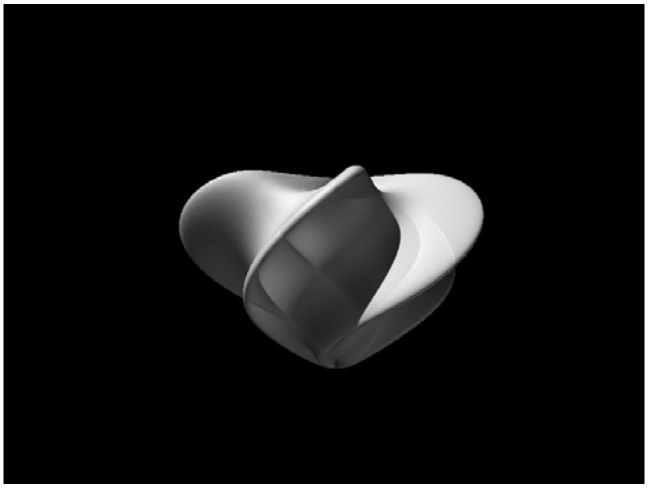

Figure 3 Xenodream: Example of constructor and metamorph

The object in figure 3 represents a simple form made with a constructor/ geometric primitive, in this instance, a sphere that is inflated in one axis and pinched in another. The sphere is again transformed by the parameters of one metamorph with three parameter variables. The variables apply radial ribs to the sphere of a certain number with a twist of a particular strength. The form is not complex and does not really represent self-similar features to a high degree. It is possible to generate this form in Cad software or in 3D modelling software. 3DS Max or Rhino could produce this form reasonably well. The point is though in Xenodream the 'idea' of the form is generated within seconds permitting an almost instantaneous capacity for revision and reselection.

I find the process of shape creation with these processes liberating. It feels like discovery, rather than the burden of complicated procedure with CAD software. I also find that the shapes, edges, and curves generated, present an elegance that is either difficult or very time consuming to achieve in other ways. The shortfalls however are in translation, attempting to translate from one language to another. Xenodream generates objects as point clouds; each point is calculated as an iteration of the formula until millions of points describe the object

Xenodream uses the chaos method for calculating points, starting with a point that is probably not in the shape and with each iteration, successive points converge towards the shape. The shape is sometimes called the attractor for the set of Holons. The software ignores the first thousand points in the random sequence to be fairly sure that the points are in the shape before it starts plotting them [15]. Xenodream plots points in space that are more akin to biological processes, those familiar with solid modelling find this strange and imprecise to begin with at least.

To translate a point cloud a polygonal mesh must be created of the object, either in Xenodream or the point cloud exported to other software for a mesh to be generated. This is where the surfaces generated differ greatly from the surfaces in solid modellers.

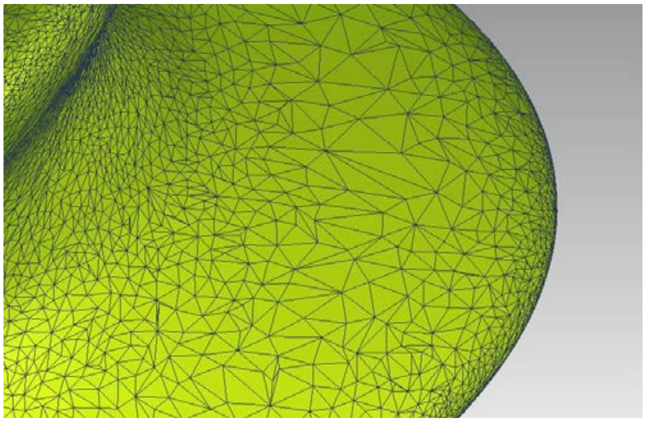

Figure 4 Mesh creation in Xenodream

Mesh creation in Xenodream can often produce results which are less refined and regular than mesh creation and manipulation in 3d modelling software. Geomagic is one software application that is useful in converting point cloud data to usable mesh objects and surfaces. Geomagic is usually used to interpret, and repair scan data from a variety of sources, either from laser scanning systems or medical scanners such as magnetic resonance images or CT scan. Interpreting data from fractal formula seems to be a fairly novel exercise, so efforts that I have made in interpreting and refining form using Geomagic have required that I adapt workflows from the medical and paleontological sciences, rather than design and engineering.

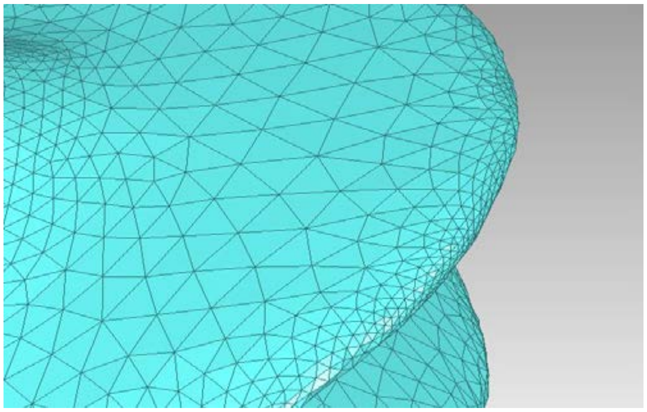

Figure 5 Mesh creation and refinement in Geomagic

Working between software applications is akin to communicating between languages. The chaos method of point cloud rendering of points to permit the expression of formula is quite a different method to the description of objects using precise informational completeness within solid modellers. The object so far illustrated is reasonably simple and lacks complexity and roughness evidenced in more natural forms, nevertheless there is a great deal of work to do in translating an object such as this into a form that is understood within a solid modeller. Geomagic offers numerous operations to interpret and extrapolate curves and subsequently redefine mesh surfaces as NURBS, (Non Uniform Rational Basis Splines/ or Surfaces). Without spending a great deal of time explaining NURB splines and surfaces I do wish to point out that this mathematical representation of form is growing in popularity and efficiency as a method of communicating and translating form between software applications. It is simply another method of representing form but one that bridges the divide between solid and 3D modellers. It is a descriptive method that is mathematically accurate and permits high degrees of manipulation. The reason I am fond of the potential of NURB splines and surfaces is that like the objects described using fractal formula and iterative process NURB surfaces have the opportunity to exhibit complex and elegant qualities. I personally am drawn to objects created using iterative formulae such as Xenodream. There is unexpected geometry in what algorithms and Holonic interactions of algorithms can produce.

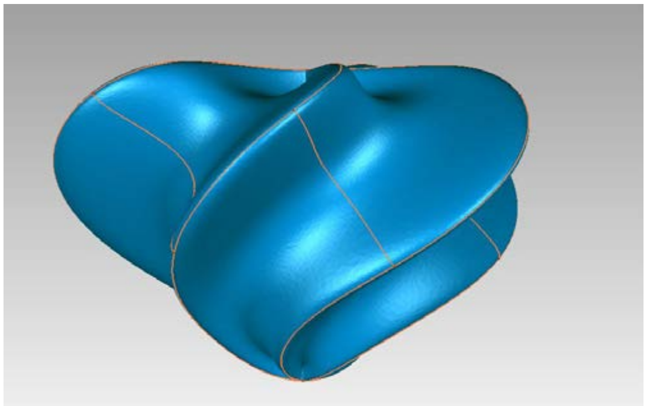

Figure 6 Geomagic; extrapolation of NURB curves

The aesthetics of discovering form in many ways is more pleasing than being the 'creator' of it. In contrast to the joy of discovery, there is considerable time and effort involved in the translation of point cloud to mesh to NURB surfaces but the process in itself reveals new potentials for curves and surfaces that would otherwise be overlooked.

It is a subjective opinion that I hold as an educator that artists, designers and craftspeople are subjective in their use of tools. Proficiency comes with use and familiarity but most creative practitioner's still possess a limited repertoire of preferred lines and shapes. I do not excuse myself from this summation. An elegant, sinusoidal line can be drawn by hand with practice but is much more time consuming with a computer mouse and still vaguely annoying with a stylus. Again I say as an educator, what I observe of myself and others is that it is easy and efficient to repeat the same practised set of lines curves and shapes. Tools that permit exploration rather than repeat constraints can certainly be liberating for the user. My experience has been that the constraints of modelling software offer an intellectual and technical opportunity to express form in new ways. I certainly would not have explored forms in such detail were it not for having to understand and solve the problems in translating and interpreting those forms.

Boden regards the constraint as crucial in the creative process [16], which I certainly agree with.

Moving and translating between many software applications exposes creative opportunity identified by the constraint of just one application or just one tool within the application.

The exploration of Holonic interactions allows for serendipitous outcomes, and it is these unintended consequences of play and exploration that have the potential to reveal forms that have applications elsewhere. If I were to intentionally design an object all of the time I would forsake the opportunities offered by chance. Some examples in my research involving the creation of forms for tactile interaction have led to the creation of objects for instance, that potentially can serve another purpose. As Xenodream offers an enormous range of variables to transform objects, the resultant outcomes can be evaluated as to their potential for the task at hand or for unintended application.

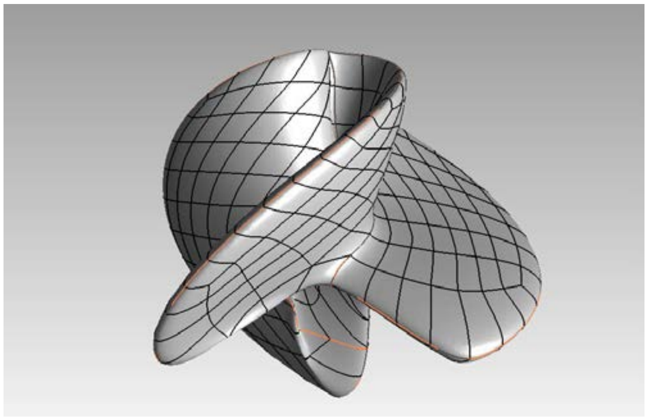

Figure 7 Hypothetical Design Outcome

The object in Figure 7 represents one object in a series of forms that point to an unintended, but probable design solution. A particular coalescence of parameters was explored as a departure from the task at hand because the resultant forms offered contributions to impeller design.

There is much work to do in terms of refining and testing these forms but Figure 7 shows one outcome of refining curves and extrapolating NURB surfaces for potential use. The potentially functional artefact arose, to borrow a term from evolutionary biology, from a process termed exaptation, (an evolutionary technique where an adaptation that occurred for one particular purpose becomes useful in another function or purpose).

Stephen Gould speaks of adaptation as the model driving evolutionary fitness and exaptation as co-option [17], serving a particular use for unintended purpose. Peter Stebbing's conceptual leap however is that even our ability for aesthetic organisation could have evolved from the ability to recognise form by pre-adaptation or exaptation [18].

Interpretation does invoke some aesthetic rationale. Generative software such as Autodesk's project dreamcatcher, Paragen or Galapagos for Grasshopper and Rhino may well offer design alternatives and options by interrogating and interpreting forms using evolutionary algorithms, but it is the aesthetic choice to stop, refine and ultimately decide on outcome that substantiates the act of creative convergence. There are many shapes that I may consider either beautiful or useful, but that is based upon my principles of aesthetic organisation, I make the choice as to where and how my thoughts and practices converge, software cannot and should not dictate that. But someone else may make a different set of choices

The Special case of Fractal Interpretation

Benoit Mandelbrot famously asked in his last ever lecture; what are fractals good for? To which he replied, Very little [19].

Mandelbrot spent a good portion of his career building the field of fractal geometry, not just for the sake of mathematics, but to help describe many mathematical opportunities for many disciplines. The language of fractal geometry is interwoven with descriptions of complexity but in terms of shape grammar helps describe certain classes of forms in terms of the tenets of self-similarity, iteration and recursion.

Mandelbrot summarised in his last lecture that his research had been about the pursuit of roughness [20]. This idea as a conceptual focus brings into light the difficulties and inherent problems with CAD environments, as the mathematical descriptors used do not cope very well with rough edges or surfaces of fractal forms.

Fractal forms (mathematically speaking) have the potential to possess an infinite surface or edge. Roughness is revealed at each magnification as a new series of points is iterated. Translating those infinite edges requires a decision about where to start and stop. In the software that renders fractal form stopping is referred to as bailout position. Translation of edges requires a decision based upon permissible time devoted to the task, as complex forms could take days or weeks to translate.

Figure 8 Julia Set, Rendered in Xenodream

The formulae mathematically described by Gaston Julia in 1918 [21] evidence roughness that is difficult to describe in Computer Aided Design space and any attempt to do so is somewhat inadequate. Gaston Julia only glimpsed the potential; of his formulae, having to plot each point by hand, but producing fractal objects such as the Julia Set requires little effort with contemporary computing. A variation of the

Julia set as shown in figure 8 can be rendered in fractions of a second but again this represents a point cloud in a two dimensional plane, the translation of these points is another matter entirely. For the shape to be useful in CAD or 3D modelling software it has to be interpreted. Most vector applications are time consuming to use for a shape of this complexity and lack the control of curves to effectively approximate this shape. Some CAD software such as solid modellers cannot deal with this kind of information at all and frequently fail. Rhinoceros is one application that can deal with thousands of control points on one curve and contains a large repertoire of curve descriptors and modifiers that can effectively interpret complex form.

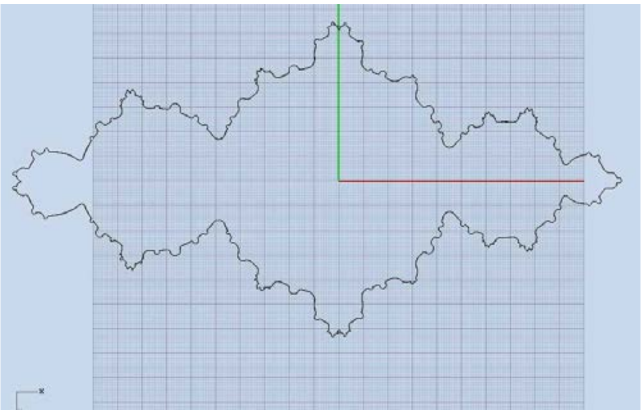

Figure 9 Julia Set interpreted in Rhinoceros

As I have intimated, Figure 9 shows an approximation of the shape, it represents nearly 80 hours' worth of careful work slowly interpreting the edge of the Julia set as well as could be done but it is also restrained by the capacity of the software to utilise the resultant curves in further processes. It is still an approximation and a fairly crude interpretation that under close scrutiny does not do justice to the elegance of the pure point cloud created by the formula. This is the issue with interpreting fractal shapes. But it is a worthwhile exercise in learning from the shape, exploring its asymmetries, finding the nuance of curvature and negotiating with how far the software can be coerced.

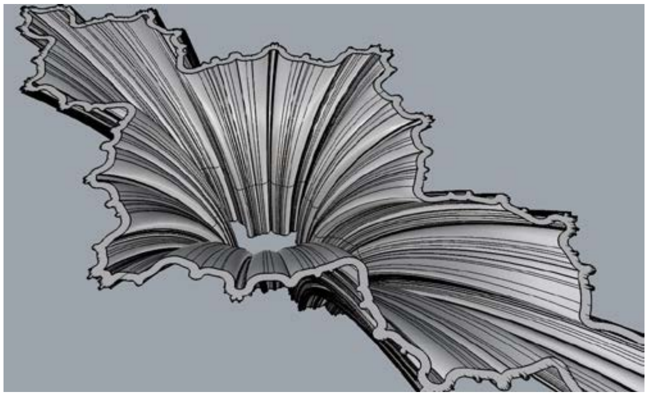

Figure 10 Julia Set Lofted

The object in Figure 10 shows a three dimensional form lofted from the two dimensional Julia sets created in Rhinoceros. The object evidences an extrapolation of a set of curves and subsequent offsets and scaling of those curves to then describe a lofted surface. This is a difficult and memory intensive shape to process and it seems only Rhinoceros is capable of achieving this outcome. Many experiments were done with Solid modelling software, but none were capable of producing this shape. The creation of NURB curves and surfaces within Rhinoceros presented the only viable set of outcomes. Just to achieve one lofted and watertight shape acceptable for export for additive fabrication took in excess of 200 hours' worth of trial and error.

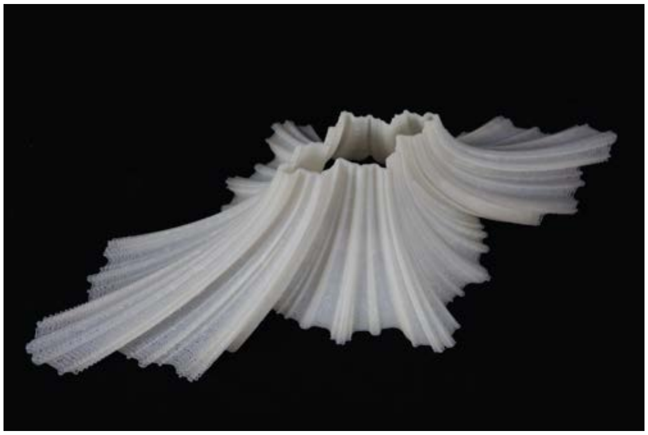

Figure 11 Lofted Julia Set, 3D Print, Polyamide

The lessons learnt in interpretation are many. The greatest must be though, the discovery of form through the processes of interpretation. Following the edge of something new and learning about its curvature and not enforcing a predefined notion of shape is revealing, rewarding and humbling. The goal of additive fabrication enforces constraints on shape creation and drives the creative process with its necessity to accurately describe surfaces and volumes in a fashion that can in turn be interpreted by build software in fabrication technologies. Point clouds can only really exist in virtual space; machines require a different set of descriptors.

Figure 12 Julia Set variant

The object in Figure 12 represents a form that evidences holonic interaction and inheritance. It is based on a variant of the Julia set and currently resides at the edge of the ability to fabricate. It is possible to be printed in a small range of additive processes, and has been produced at a small scale, but it remains a time consuming and difficult entity for translation into NURB surfaces

What do I now do with all of these fractal forms and NURB interpretations of fractal forms and all of their subsequent exports into the physical realm? To paraphrase Benoit Mandelbrot; ‘very little’.

If I was a product designer I should be concerned but I am not. These objects represent for me intersections between art, design and the ontological explorations of both. By stubbornly navigating the methods of translation between fractal creation and 3d modelling applications I believe I have helped bring to light some of the countless forms that fractal mathematics describes, and maybe there applications for some of them.

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