The Creative Craft of Generative Design: New tools, same rules

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Research Question
How do creative episodes arise in the designer-maker’s use of analogue tools? How can creative episodes arise in the designer-makers use of digital generative software tools? What are the differences and similarities between these types of tools?

Method
This paper uses a mixed methodological approach. Literature from the fields of design and creativity research, particularly of Margaret Boden (2003), has provided a framework of mechanistic creative typologies. Reflection and analysis of the author’s own designer-maker practice provides examples of how such mechanisms can be facilitated by generative tools. Further evidence was gathered by interviewing designer-makers about their practices, particularly focussing on the creative episodes that stimulated particular pieces or collections of work and how tools were involved in these.

Tools
Characterising generative design systems as ‘digital tools’ has been discussed in academic literature by McCullough (1998) and Oxman (2006), who have both explored the idea of the analogous nature of the use of generative systems with physical tools and materials. A designer-maker is a particular kind of designer that designs through the activity of making: working closely with tools and materials to design objects that they either produce themselves or with the help of others. Digital tools have been adopted into the designer-makers practice in the last ten to fifteen years with the advent of easier access to digital software and digital fabrication tools, such as laser cutters and 3D printers. How does the designer-maker actually use tools, in particular digital tools? Design theory has a tradition of close examination of sketching in design processes (Oxman, 2002; Schön & Wiggins, 1992) to try and gain insight into the physical and cognitive operations of the designer, but little similar research exists for designer-makers working directly with materials.

A formal descriptive model that may be useful to adopt is a particular theory of design called shape grammar, originally developed by Stiny (2006). In shape grammar two or three dimensional shapes are transformed by rules, performing operations such as addition, subtraction, affine transformations and translations on points, lines, planes and solids, rules are visually represented as shown in Image 1.

Abstract
The co-evolution of new forms with specified tools characterises craft-led design. Algorithmic design systems are the latest ‘tools’ available to designers and makers. Why are these systems of relevance? Can such software be used by designer-makers to produce creative, that is, ‘new, surprising and valuable’ (Boden, 2003) artefacts? How do these creative opportunities arise through the use of these tools?

This paper seeks to answer these questions by drawing together, for the first time, literature from the fields of creativity, craft and generative design. Alongside this, examples have been drawn from the author’s own designer maker practice, which employs both physical and digital tools, and interviews with other designer-makers.

Keywords: Craft, generative design, tools, rules.
Shape grammar was first used as a way to design by computing with shapes a set of shape rules that can be used to define a design and generate new versions (Stiny, 1977), or simply used as explorations of shape and form. They have been the basis of digital generative design tools (Koning & Eizenberg, 1981). Later research on shape grammar recognised its strengths as a theoretical and philosophical way of thinking about designing (Stiny, 2006), where the actions of designers can be described and analysed.

If we take making to be a process of transforming materials step-by-step with tools, we can align this with the idea of transforming shapes by applying successive rules. We can characterise tools as a kind of rule used to transform material. Digital tools and computational rules are one in the same, and perform transformations on digital media. Viewing tools in this manner gives us the key to using ideas from creativity literature to formalise creative activities in designer-maker practices.

**Creativity**

What is creativity? Margaret Boden, a widely known researcher of creativity and artificial intelligence, describes a creative idea as one that is ‘new, surprising and valuable’ (Boden, 2003). We assume that such objects enhance the human experience and is something we strive towards as designer-makers.

How can we be creative? According to Boden and other creativity research (Csikszentmihalyi, 1996), creativity may be characterised by the original manipulation of formal rules of a particular conceptual space or domain to create a new artefact. Examples of conceptual spaces often cited in creativity research are things like Haiku poetry, or musical styles, where rules determine the form of an object of the domain. Boden defined creative actions into formal computational categories as she was interested in whether artificial intelligence systems were capable of creativity. The idea of rules being the key to creative activity fits neatly with the discussion of rules, tools and generative design in the previous section.

Designer-makers interviewed for this research were very concerned about their domains and their very specific position within them, how they wanted their work to be perceived by adhering to or even breaking certain rules. Indeed echoing the language of Boden, maker and writer Dormer (1994) also states that craft activity ‘follows rules, conventions and patterns.’ In craft disciplines, the main definition of the domain are the tools and materials used. So what kind of manipulations of tools, rules and materials yield creative episodes? And how do these occur in designer-maker practice with analogue tools, but also with digital generative design tools? The following sections address these questions.

**Searching the Space: Explorative making with tools**

Boden’s first classification of creative behaviour is that of selecting and exploring an established conceptual space. The designer-maker’s discipline is a conceptual space, predominantly defined by tools and materials as well as other rules and conventions. A generative design tool is a defined conceptual space, comprised of computational rules. The process of using a generative software tool to produce forms is a creative activity; it can in fact automate the exploration of the rules it is comprised of. It is much like a maker producing a range of test pieces in a material using the same tools and materials each time, but with chosen variations in the actions. How and when tools or conceptual rules are used in a making process yield different outcomes, some of which may be creative.

The user of a generative design tool can allow it to search the whole conceptual space it has been programmed with, returning an array of forms, potentially every possible form if the tool has a small number of variables. Image 2 is an example of some outputs from a very simple shape grammar generative design tool, in part using the shape grammar rules from Image 1. The rules have been applied to random shapes, a random number of times, producing a selection of different designs.

The number of potential outputs of a generative design tool may run to very large numbers if there are many variables. So like material experimentation the process can be more or less guided by the user. A less controlled approach can be taken, letting the generative tool search the space with random input variables in the

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**Image 1**
Shape grammar rules

**Image 2**
Outputs from a simple shape grammar generative design tool

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hope it returns something useful as in Image 2. Makers often employ this tactic in their practices, deliberately letting tools find the form in their work. One example is Ian McIntyre, a tableware designer who made pewter bowls by swirling molten pewter round a mould. Each bowl was completely individual due to the complex dynamic physical forces at play.

Using both physical and generative tools, this approach does have downsides. Many useless versions are likely to be produced, whether the rejection of these is down to aesthetics, functionalities or close repetition. This may waste time in these cases, the beauty of pewter is it is easy to melt down and start again; digital entities are even easier to rework. It may be worth experimenting to find something worthwhile.

In engineering the outputs of generative design tools are often then fed into an optimisation algorithm to siphon off the useful solutions within the generated design possibilities. For designer-makers it is likely that they perform this task as it is likely to be a question of aesthetics, something that computers have still not yet mastered. Again, a maker would review their works made with analogue tools, and select ones that they found to be useful.

More likely, is that the generative tool, like an analogue hand tool, can be guided by the designer maker. By changing the variables values a level of interaction is usually available in a generative design tool. The user can see onscreen and in real time the effects of the changes they make. Designer theorist Schön has developed well-known protocols about how designers perform a routine of ‘see-move-see’ making observations (Schön & Wiggins, 1992), followed by a transformation, followed by more observations of the results. The maker can make judgements about the results of their actions and continue with the next move accordingly. The same protocol can occur in generative tool use. The input variables can be adjusted as the user works cyclically between their input and the output.

Like physical making, searching a conceptual space in a generative tool can have a tacit element. Some generative design tools have an underlying computational physics engine, which allow the user to manipulate forms by hand, not just numerical values. One example of this is seen here in the generative programme Jenn3D, a freeware programme that allows complex geometries to be stretch and inflated with the cursor. The author manipulated the forms and used these to make jewellery via 3D printing and casting.

Transforming Conceptual Spaces: Making with transformed tools & new tools

According to Boden a higher level creative activity is to go beyond searching a known conceptual space and actually transform it in some way. These transformations can range from small changes (bending or tweaking rules), to dramatic, surprising conceptual shifts that produce whole new domains. The result being that these can then be used to produce novel artefacts. How can such creative shifts occur in tool use by the designer-maker?

One way this is possible is by bringing generative tools into new domains and subverting the intended use of the tool. The author did this by using the freeware program Jenn3D. Intended as an visualisation tool for mathematicians, it allows the user to visualise, manipulate and export complex three dimensional geometries. For those that have some digital knowledge, but no programming experience, this transference of a software tool from another domain is a good way to be creative. Like an analogue tool, you do not have to understand the inner workings of a generative tool to use it successfully. You don’t have to understand the mechanics of a lathe to subvert its use for creative ends.

Transforming a domain is also possible by transforming the digital tool by hacking or rewriting the underlying system or code. This way of transforming the underlying computational rules is similar to how a silversmith would file and shape their hammers to create different shapes or texture on metal.

In digital terms, this has been undertaken by makers such as Drummond Masterton who hacked the machine code for a CNC milling machine to fundamentally change the way it cut metal (Masterton, 2007), resulting in a body of work with distinct and rich characteristics, departing from the homogenised look of material cut by milling machines.

Perhaps the most creative transformation of conceptual space in terms of tools, is to make your own entirely new tool. This would constitute a new domain and is very creative behaviour. Anton Alvarez (www.antonalvarez.com) did this by inventing a thread wrapping machine, a tool that can be used to bind pieces of wood with glue soaked threads. He describes this as a ‘new craft’. The results are creative objects,
very different from any other kind of furniture joining process. The tool becomes a new conceptual space for exploration. Again, it is possible to build a completely bespoke generative design tool. For instance, Nervous-System (http://n-e-r-v-o-u-s.com), a company that pioneered generative, customisable jewellery, has done this many times, using algorithms based on natural morphology.

**Skill**

Hacking and building generative design tools does require the attainment of some coding knowledge. The most dramatic difference between analogue and digital tools is that coding is a different kind of skill from much craft work, but shares some common ground. It involves the learning of conventions and building up of expertise through practice. Most programming environments, like Processing and Grasshopper come with libraries, tutorials and online forums. Starting from a complete blank sheet is not usual or necessary as modules of code and ready-made rules/tools are available in most coding environments. Dormer’s investigation of attaining skill (1994) revealed that attaining craft skill involved the learning of rules, preferably from a master, something that corresponds with learning to program, either on-line or directly from a teacher. A greater level of knowledge or skill within a domain also means a maker is likely to be able to be more creative. Being able to understand and manipulate tools and rules is more likely to lead to creative outputs.

**Creative Episodes: Tools and analogy**

These are the ways that transformations can be made on generative design tools, and are similar to those we can do with traditional analogue tools. But choosing what tool or rule to use, subvert, transform or build is another challenge. There tends to be a moment in a creative process where some kind of leap (Boden, 2003; Koning & Eizenberg, 1981) occurs that brings a new idea to the fore. There are also mechanisms through which these leaps can occur. How these happen for the designer-maker are now discussed.

Much creativity literature purports the use of analogy (Boden, 2003) to trigger new combinations of concepts, which in turn produce new conceptual spaces and creative ideas. A point of correspondence is discovered between two conceptual spaces, or in the case of the designer-maker, two tools.

A neat example of this, which straddles physical and digital tools, is the work of Kathryn Hinton. As part of a research project she has developed her own haptic digital tool; a hammer with internal motion sensors that plugs into a computer via a USB port and works in conjunction with computer modelling software, replacing the usual input of the software use for a new personalised use.

The idea for this came about through analogy: when describing the new tool in an interview with the author she used several ‘like’ comparisons with other tools, ‘like a hammer….like a (Nintendo) Wii….like a Wacom pad’ (Hinton 2011). The link coming through the idea of digitally catching the movement of her making actions. These analogies had led towards the creative idea of a digital, silversmithing hammer, mapping the haptic use of a hammer with that of tools used for haptic inputs for computers. The resulting pieces of silverware are produced with digital fabrication techniques and have a novel and distinct aesthetic that is new to the world of silversmithing.

A more complex version of this is concept blending (Nagai, et al., 2009). Bringing together two concepts through a shared point of reference and then blending aspects of them into a third completely new entity is a source of creativity. In the author’s interviews an example of this was seen in jewellery designer Eleanor Bolton’s work for her MA at the Royal College of Art. Bolton blended the concepts of the jewellery archetype of chain making with tools and techniques from textile crafts, using the shared reference point of the idea of joining loops in a continuous length (see Image 6). She began hand stitching cotton rope together in coils to create wearable, soft tactile tubes.

Generative design tools can be used for blended concepts. If a concept can be defined as a computational rule then it can be combined with others. This occurred in a project undertaken by the author, titled the Butterfly Tool, a digital generative design tool was designed to demonstrate some ideas surrounding generative design to the public. The point of reference used was the wireframe shape of a butterfly wing. The digital medium allowed the Voronoi algorithm, a purely geometric algorithm, to be blended with shapes and intuitive ideas about natural diversity to give a new concept communicating ideas about generative and customisable design.
Emergence

Even simple sets of rules and tools can produce unexpected results and sometimes these emergent possibilities can be serendipitous for the creative process. This happened in Eleanor Bolton’s use of physical tools and processes when she happened upon the possibility of adding and dropping stitches in her tube-making process, giving her a new creative idea for use in her designs. This gave the varying widths in the stitched tubes creating interesting forms, seen in Image 6. This is also something that happened to the author whilst using a self-made generative tool made on CAD program Grasshopper and Rhino, to explore possible wire work jewellery designs. While using the tool, the author spotted an emergent visual phenomenon as the number of wires was increased. Moiré effects appeared and moved around as the forms were viewed from different angles. Realising this was an interesting phenomenon that would be attractive in jewellery, it became the fundamental creative idea for an award winning collection of 3D printed jewellery.

As in making, spotting useful emergent features when using generative tools requires a trained eye. Design theorist Oxman points out that a crucial aspect of making use of serendipitous emergent properties is a requirement of the user to anticipate and, critically, to recognise their presence (Oxman, 2002). Similarly McCullough (1998) points out the importance of the user being able to spot ‘algorithmic beauty’ in the digital on-screen milieu. In craft terms, this is complies with the idea of connoisseurship (Dormer, 1994), the skill of spotting qualities in objects through learning a craft.

Conclusions

This paper has examined how tools feature in the creative process for designer-makers and the many similarities between the use of analogue tools and digital generative tools for creative outcomes. It has been seen that both analogue and digital tools operate as rules for transforming materials throughout a making process, via the lens of shape grammar theory, and that the use, transformation and invention of rules is crucial to creative activity.

Like analogue tools, it has been shown that digital generative tools are open to many creative practices; these include explorations of exponential possibilities, subverting originally intended uses, transforming and hacking intrinsic rules embedded in tools. They are also fertile ground for the occurrence and embodiment of creative episodes, such use of analogies, concept blending and useful emergence. Designer-makers should find ways of working successfully with digital generative design tools to be familiar to them from their work with analogue tools and may find them useful in their work.

The author found that throughout a design and craft education formal, explicit strategies for being creative were never taught, yet levels of creativity and originality were what the students were ultimately judged on. The outcomes of this research, defined strategies for creative activity with tools, may have pedagogical applications, and it is intended that this will be explored in further research; introducing the idea of transformational rules from shape grammar and creativity literature and the forms they take – predominantly as tools in the making process, could be a useful concept for teaching students and designer-makers how to be creative in their practices, whether using analogue or newer digital tools and processes. If a practitioner has a clear idea of what creativity is and how it can be achieved they are more likely to succeed in designing and making new, valuable and useful objects.

References


Lynne Maclachlan is a graduate of the Royal College of Art, is currently undertaking a PhD with the Design Transformations group of the Open University, researching the role of tools in the creative process, and is a visiting lecturer at University for the Creative Arts. Lynne also works as a designer, making innovative, contemporary jewellery and objects using bespoke software and 3D printing alongside more traditional craft techniques. She has exhibited widely in the UK and Europe, notably with the Crafts Council and the V&A museum and participated in live projects with Tiffany & Co and Swarovski.