JAMES NOVAK

James Novak is a PhD Candidate, Lecturer, Industrial Designer and self-confessed 3D Printing Geek at Griffith University. Having designed and 3D printed an award-winning full-size bicycle frame in 2014 called 'FIX3D,' he has turned his attention to the advanced digital technologies required to make products like this truly customisable. With a number of years of industry experience, James brings a unique perspective and professional rigour to his research, focusing on genuinely functional, marketable product solutions.

DRAWING THE PEN: FROM PHYSICAL TO DIGITAL AND BACK AGAIN

The aim of this paper is to examine the ways in which drawing in the digital age presents new methods of hybrid product creation, blurring the boundaries between the physical and digital creation of a three-dimensional design. A project called 'MyPen' illustrates an *interactive fabrication* workflow, and investigates how complex products may be created by customers with no knowledge of CAD programs, using instead their innate ability to draw simple geometry or mould a shape with their hands.

Introduction

Within design discourse, particularly three-dimensional disciplines including Industrial Design and Architecture, numerous studies have investigated the tension between physical sketching in the traditional sense of 'pen and paper,' versus the development of a concept directly within the three-dimensional Computer-Aided Design (CAD) environment (Veisz et al. 2012, Ibrahim and Pour Rahimian 2010). With the rapid growth and adoption of digital technologies including 3D printing, 3D scanning, and a range of new CAD software tools incorporating coding and algorithms, the boundaries between the physical drawing of a design and its digital interpretation are becoming ever more blurred. This paper examines the opportunity to develop products that are customisable in both ergonomics and aesthetics, focusing on a project called 'MyPen' developed by the author to explore the translation of data between the physical and digital environments. Within this research it is important to note that terms like 'sketch' or 'drawing' can refer to both the "hand drawn representation of a concept or idea" (Veisz et al. 2012, 318) or the creation of geometry within a CAD program which typically uses the same terminology (Anderl and Mendgen 1995). For clarity, the qualifier 'physical' will be added to describe traditional hand drawing, while 'digital' will be used to describe the creation or translation of drawing information within the computer.

Context

Many believe 3D printing signifies the next industrial revolution (Vavra 2013, Petrick and Simpson 2013), radically shifting the traditional paradigm whereby products are manufactured *en masse*; rather, bespoke one-off products can be produced for the individual needs of each consumer. However the challenge faced by the typical consumer is the high level of skill required to engage with a CAD program and produce something that firstly reflects their imagination of a

3D object, and secondly is sufficiently defined and 'watertight' in order to be produced by a 3D printer without error. Imagine instead if CAD software was intelligent enough to translate a design from physical drawing to 3D digital model; drawing is an innate skill for all humans, despite their level of skill, and is therefore far easier to communicate an idea than investing the time required to learn a specific CAD package.

One of the world leaders in 3D printing services, Shapeways, has achieved this through an online tool simply called '2D to 3D' (Eleanor 2014). As shown in figure 1, the tool allows everyone to upload an image of a drawing to their websites, and then take some control over how this is translated into a 3D form suitable for 3D printing in a variety of materials. In similar fashion, Makerbot recently released an iPad application called 'Shape Maker' (Miller 2015) that performs a similar function, the difference being that the prints can be produced on a home desktop printer. While both demonstrate a relatively new workflow called *sketch-to-fabrication* (Gannon, Grossman, and Fitzmaurice 2015), whereby a physical drawing is translated into digital three-dimensional data, and then returned to the physical world via 3D printing, they are only appropriate for producing simple geometry like the pendant shown in figure 1. The limitation for a consumer is that the software is not yet sufficiently intelligent to produce a complex functional product incorporating multiple parts or organic forms. In order to progress these tools and explore how physical drawing can be used to generate truly functional one-off products, MyPen has been produced as an experimental system whereby a custom drawing pen is created by drawing with a 'test pen' and digitally recording two key pieces of information.

Figure 1. Shapeways. "Turn Your 2D Design into a 3D Print." Shapeways, https://www.shapeways.com/creator/2dto3d#landing.

Drawing with Code

While it may sound absurd that a custom pen can be created by simply drawing with another pen, it is the workflow of a *sketch-to-fabrication* system that is of most interest. In order to understand this process, the creation of digital drawing information must first be analysed in comparison to its physical counterpart. Within a software package called Rhinoceros 3D (Rhino), an add-on called Grasshopper allows for the creation of 3D geometry using algorithms and coding. The workspace to create these functions is called a 'canvas,' and will have sections of code added to describe something as simple as a circle (figure 2). Rhino translates this code, in this case into a 2D drawing of a circle centred on the origin, with a radius of fifteen millimeters (figure 3). The advantage of the algorithms within Grasshopper is that they are parametric, meaning that the drawings and geometry can be modified at any stage of the modelling process through changes to dimensions and constraints, rather than requiring geometry to be sliced away and re-modelled similar to a piece of clay.

This may seem an abstract method of drawing, however to designers the use of tools like algorithms is standard practice to rationalise what can be a complex design into a series of three main processes; sketching, constraining and solving

(Anderl and Mendgen 1995, 2). By developing layers of information, greater complexity can be achieved, and in the case of MyPen, results in a complex network of algorithms used to generate digital drawings, and then connect these drawings to form solid geometry. Figure 4 shows just one section of the code used to define some of the geometry for the lower grip section of the pen design, which continues on to link with other sections of information to define the complete 3D geometry of MyPen, in particular the customisable elements.

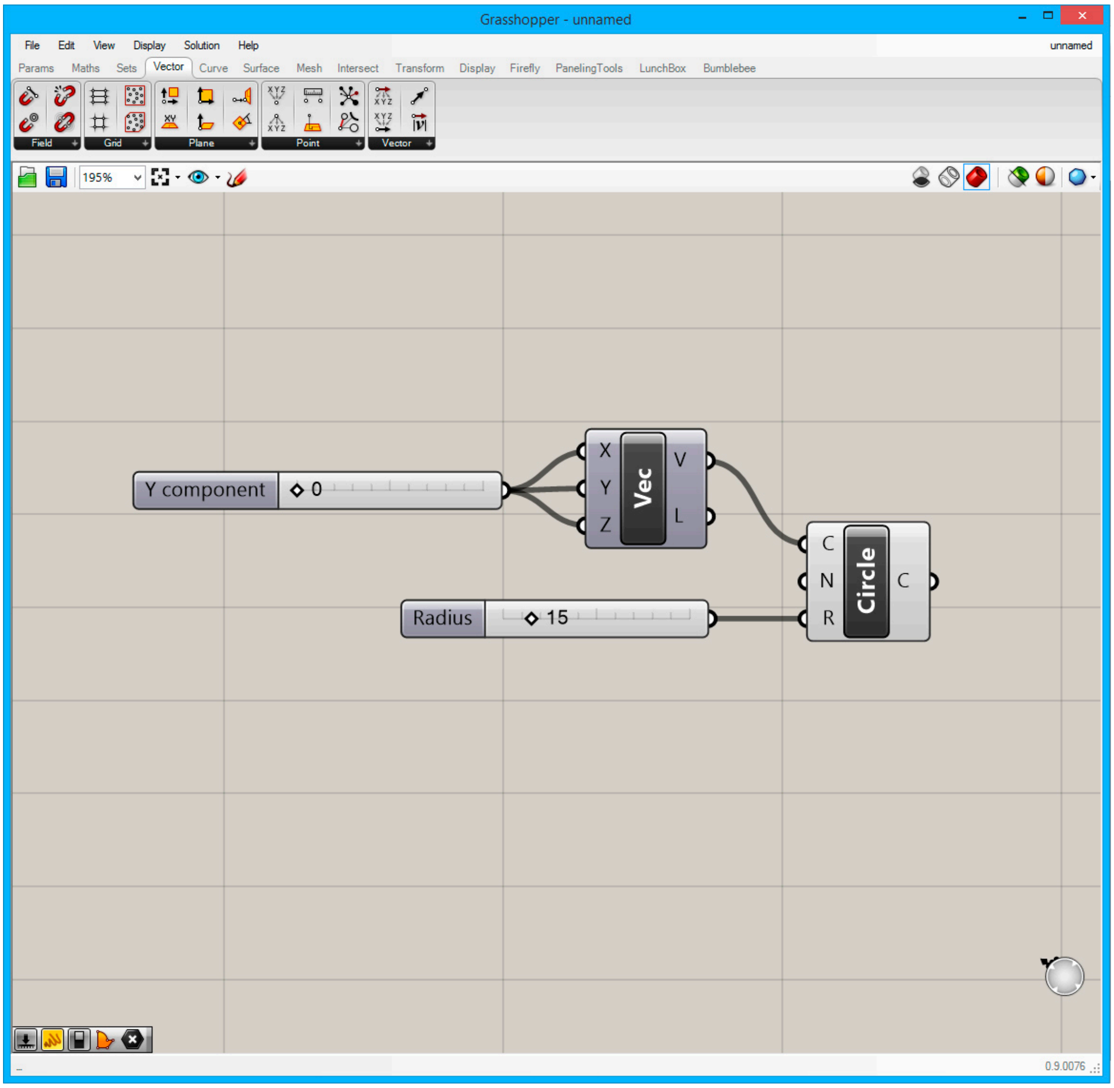

Figure 2. Novak, James. "Grasshopper Canvas – Circle." 2015.

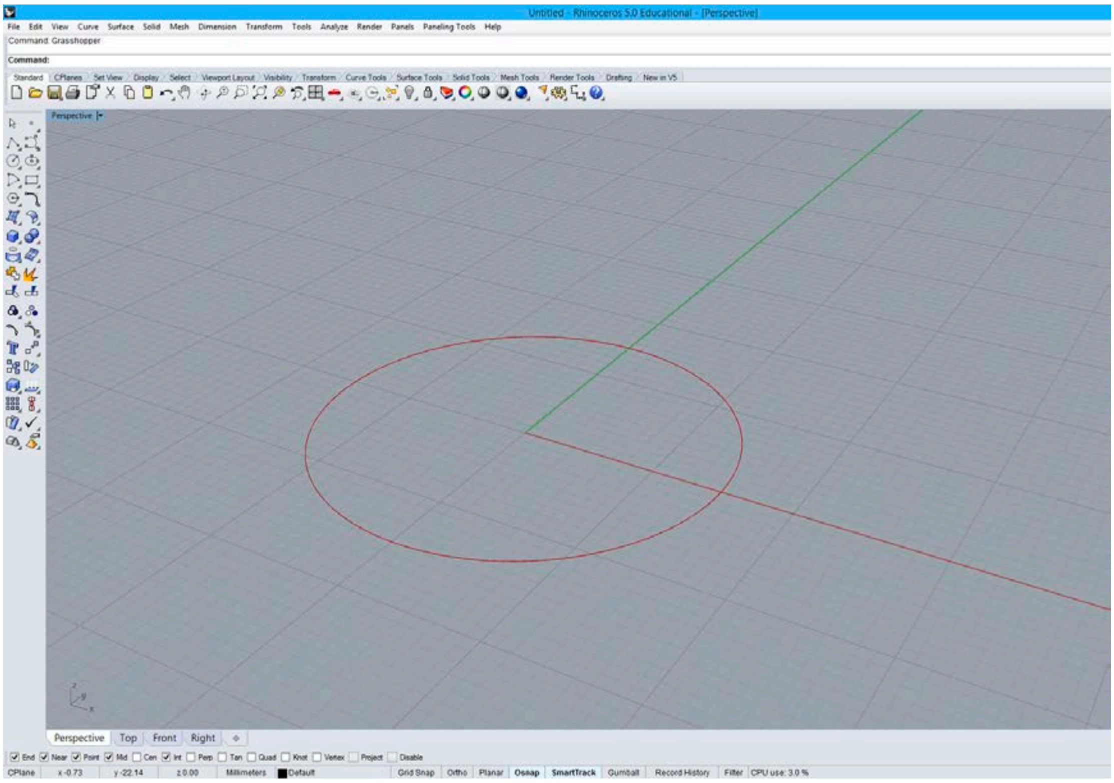

Figure 3. Novak, James. “Rhino Translation of Grasshopper Circle.” 2015.

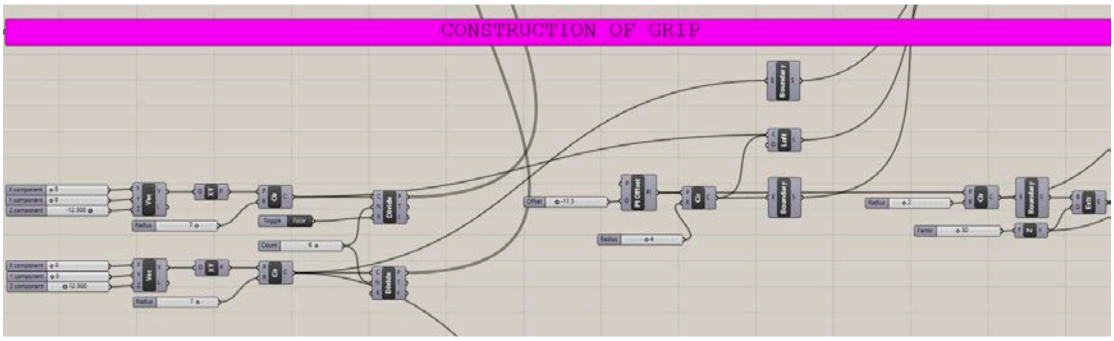

Figure 4. Novak, James. “Grasshopper Canvas – Construction of MyPen Grip.” 2015.

MyPen – Custom Ergonomics

As mentioned earlier, there are two vital pieces of information required from the customer in order to completely customise MyPen. The first of these relates to ergonomics, and the individual grip each person has while drawing or writing with a pen. Capturing these complex 3D shapes has been exhaustively pursued from individuals simply shaping pieces of clay by hand, to more recent advanced processes including the 3D scanning of moulded grips and reproduction using 3D printing (Iderstine et al. 2015, McLaughlin et al. 2011). However the goal of MyPen is to streamline the process of customisation for a consumer, and the potential to do this directly to a CAD model has been realised by incorporating force sensors into a testing pen that can be read by Grasshopper (figure 5) to manipulate a 2D digital drawing.

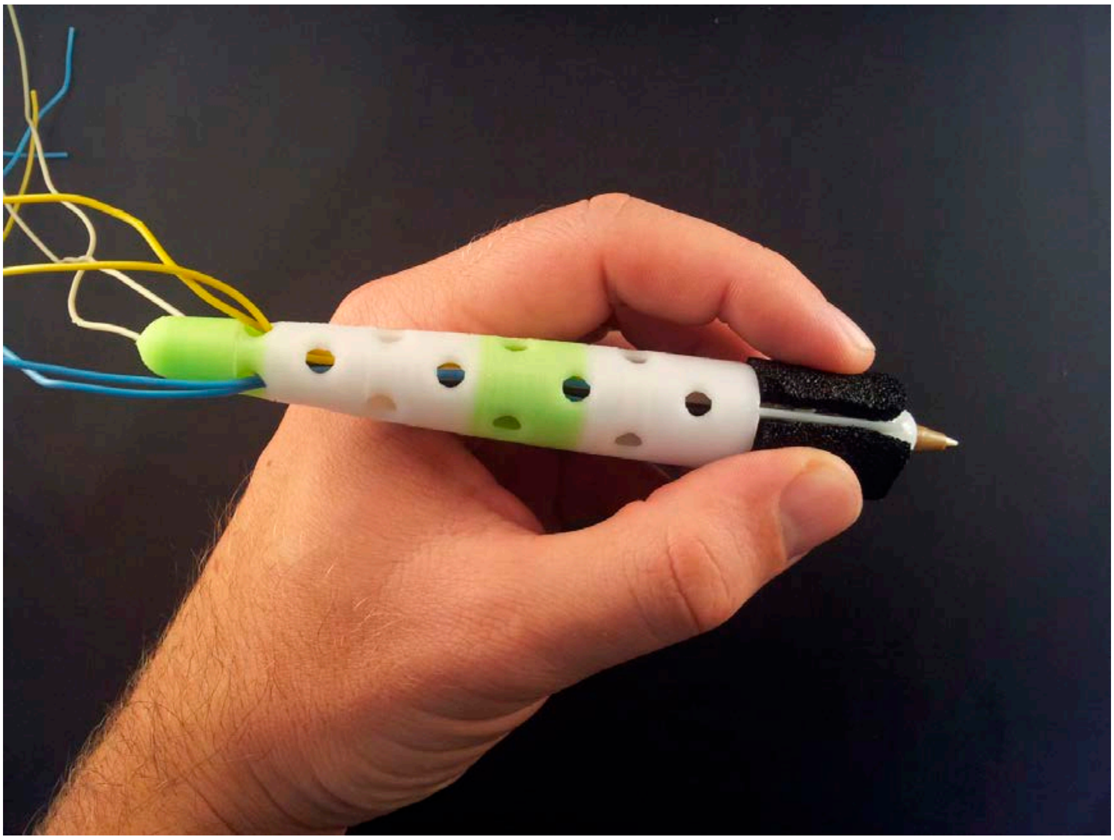

Figure 5. Novak, James. “MyPen ‘test pen’.” 2015.

The testing pen features conductive foam grips plugged into an Arduino micro-controller, which in turn is plugged directly into Grasshopper through an added package called Firefly. As the user grips the pen as they would while drawing or writing, the force is measured as a change in resistance, which has been programmed within Grasshopper to cause the central 2D digital drawing of the grip form to change. Simultaneously, the 3D model of the grip is manipulated as the algorithm stitches a number of 2D drawings together as a *lofted* feature. Figure 6 demonstrates the neutral readings from the sensors with no force applied, lofting through a total of four 2D sketches, while figure 7 has been captured when gripping the pen, causing the model to update in real time without any compromise to the model's integrity. Through the physical use of a product, in this case a pen, it is demonstrated that physical action can be seamlessly translated into digital data to manipulate the parametric sketches used to define part of a product; a process described as *interactive fabrication* (Gannon, Grossman, and Fitzmaurice 2015). At this stage customisation is limited to 3 axes, linked to the 3 main digits of the hand typically used to hold a pen; thumb, index finger and middle finger. With a greater number of smaller sensors, a higher resolution could be achieved for even greater complexity in form.

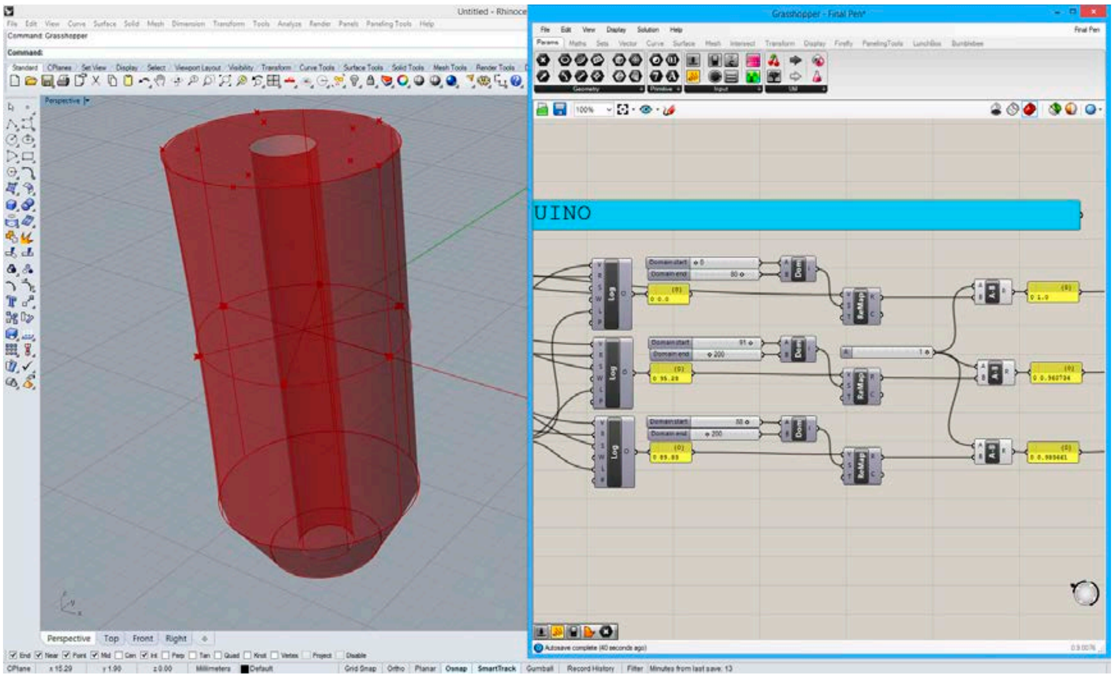

Figure 6. Novak, James. “MyPen grip detail in Rhino – neutral position.” 2015.

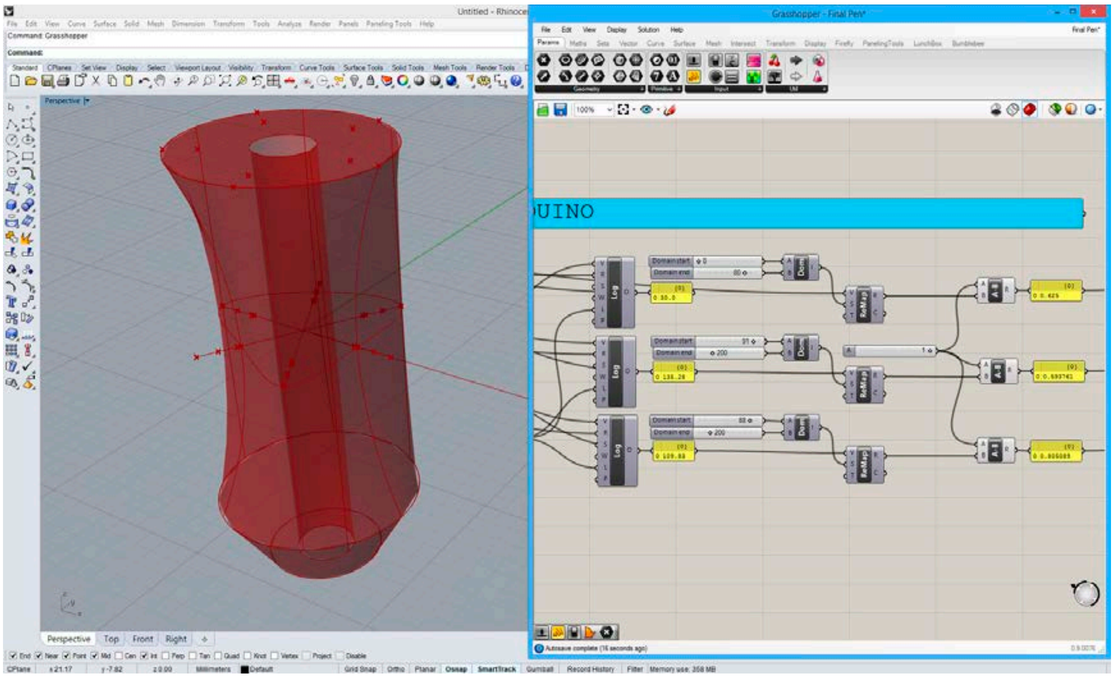

Figure 7. Novak, James. “MyPen grip detail in Rhino – grip captured.” 2015.

MyPen – Custom Aesthetic

The second part of the MyPen creation requires the customer to use the testing pen to draw an enclosed 2D shape on a piece of paper. An instruction sheet has been used to graphically explain to participants how this shape will affect their design as shown later in figure 9, and also limit the size for ease of digitising. This physical drawing is captured by a standard webcam, again using a tool from Firefly shown in figure 8 (right side window), with a series of algorithms translating the captured JPEG image into a single closed polyline within the 3D CAD environment as shown in the left window of figure 8. As with the grip detail, this translation of data occurs in real time, and the user does not see the outputs shown in figure 8; they instead see the entire 3D form of the pen generate as the webcam image is captured and added to the grip detail already created. It is important to note that the software does not attempt to recognise the shape and apply a perfect 2D representation of it; the shape generated will closely mimic the imperfections and proportions of the sketch physically produced.

Essentially this two-step design process is completely controlled by the customer, with a CAD operator simply walking them through the process and switching the sensors and webcam on or off at each step. With ongoing development, this workflow will be completely automated to give customers independence during their design process. Upon completion, the file is exported into STL format, the native file type for all 3D printers, and ready to be returned to the physical world via 3D printing. The final results from two participants can be seen in figure 9, showing both the 3D printed custom MyPen produced on a desktop 'Up! Plus 2' machine, and physical sketch used to generate the aesthetic component of the product. Figure 10 demonstrates the differences in the ergonomic grip detail between both the examples, emphasising the subtle variations that may be difficult to visualise, but perceptible when held by the users. Ultimately the ability to capture a physical drawing and translate this into a custom lattice structure offers numerous possibilities for the future development of products and creative works, and represents a new method of CAD manipulation for people with limited or no training.

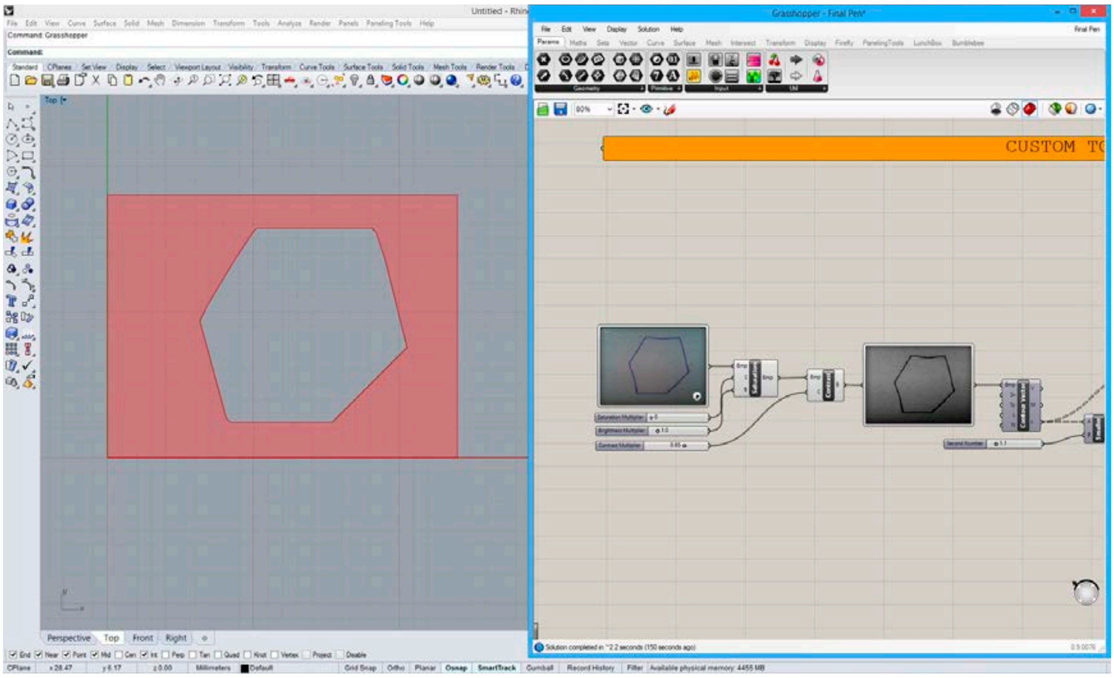

Figure 8. Novak, James. "Rhino and Grasshopper translations of webcam-captured sketch." 2015.

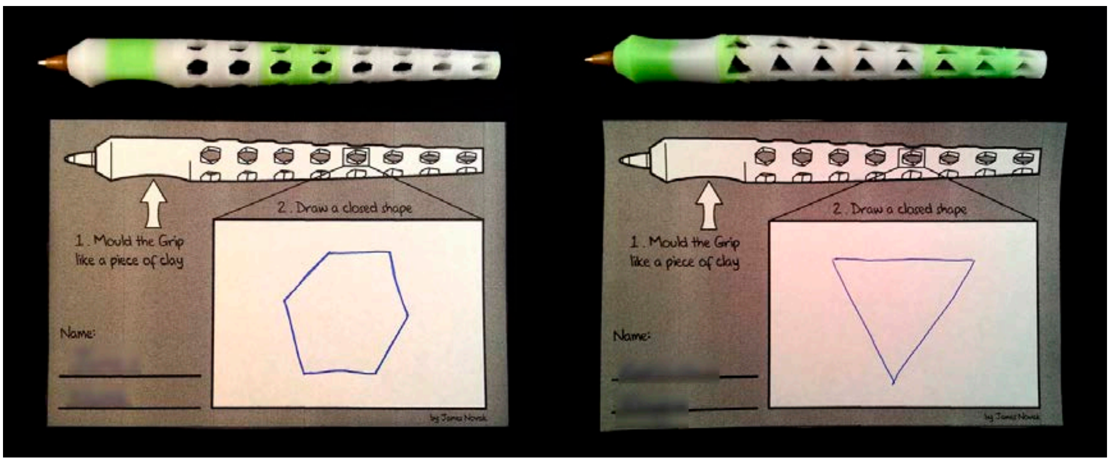

Figure 9. Novak, James. "Completed MyPen's by 2 participants." 2015.

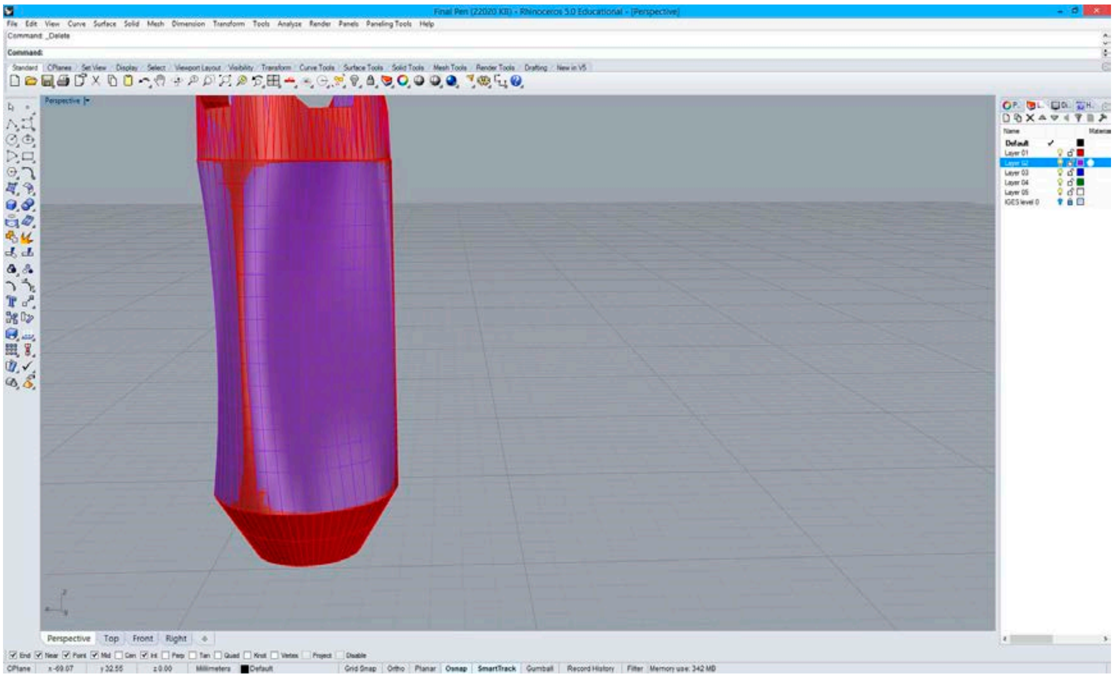

Figure 10. Novak, James. “Comparison of geometries between both participants from figure 9.” 2015.

Conclusion

Many of the traditional tools to communicate both 2D and 3D ideas, such as drawing or sculpting, are rapidly being merged with hybrid digital processes combining code and algorithms that generate new forms “quite literally, beyond one’s imagination” (Klanten, Ehmann, and Hanschke 2011, 5). 3D printing now allows for the rapid production of these complex forms, and for custom one-off objects to be affordably manufactured on demand. As these tools rapidly find their way into the home and small manufacturing hubs emerge within this new paradigm, tools to aid consumers translate their ideas into 3D digital files are needed, with current CAD software options having prohibitively steep learning curves unlikely to appeal to the average untrained designer. MyPen is an innovative tool that appeals to the innate ability of all humans to pick up a pen and draw something, yet combined with algorithms and electronics, allows for aesthetically complex and functional products to be generated without any need for CAD knowledge. The significance of the project is largely in the *sketch-to* *fabrication* and *interactive fabrication* workflows, translating physical 2D drawing and sensor information into 3D data within a CAD environment, and then returning this data to the physical world through 3D printing. In this way the pen becomes both a tool for communication in the physical world, and for generating infinite possible customised versions of itself. Moving forward, the potential to reduce the size of electronic sensors and combine wireless technology into the MyPen system may result in a more seamless system as a part of the Internet of Things.

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Image Reference List

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