Introduction

This book is developed for students and professionals interested in controlling 3d printing directly from Rhinoceros® and Grasshopper®. It is a manual to learn the basics of the connection between software and digital fabrication language in a detailed way, focusing on extrusion machines with material as clay, thermoplastics or any other material that can be extruded with a 3D printer.

Grasshopper® is the parametric environment of Rhinoceros®. It has become one of the most powerful tools for any designer as it allows you to start coding from scratch, in a visual and easy way. It is widely used on car, jewellery, architectural design and almost any design field.

Nowadays a complete digital designer is a multitasking individual capable of controlling the necessary tools (digital and physical) for the development of a design. This means that design and crafting technique should be together. This is not a new concept. Students from many fields such as architecture, design, arts and crafts, engineering... are forced to learn many different software in order to develop their ideas and integrate themselves into the uprising competitive professional working environment. Their designs have to go outside of the computer and so, nowadays we can find more laboratories integrated into universities and high-schools with digital fabrication tools. These laboratories' standard equipment usually includes laser cutters, milling machines and 3d printers but other tools such as vinyl cutters or robot arms could be found. It is interesting to see how students depend on these machines to develop physical mock-ups of their 3d models. What students usually expect from this technology is to get the most accurate mock-up of their model. We could say that this technology is mainly used as a definitory or last step to try to get the virtual into the physical but it is even more interesting to explore and experiment on these machines and materials as many new options open up in the fields of design and research.

In this book we will give solutions to some problems that present themselves when 3d printing, but we want to introduce the reader to also explore the possibilities of the code vs. design, and create a sensibility over design and its fabrication process. Aspects such as the geometry of the design vs. the behaviour of the material, may differ to what we expected, opening a new range of possibilities that where not foreseen. The aim of this book is also to have fun and work with the material in an experimental way where parameters such as gravity, fluidity, speed or flow rate create new possibilities that were not pre-empted in the design. At the beginning the reader will discover sculptural objects, unique on their features. A possible mass production could be proposed after controlling all aspects of the g-code evolving the 3d printing process of the production into a singular aspect.

For the development of the models we will work with a 3 axis 3d printer because this type of machine is very common in the laboratories of digital fabrication some readers may own one themselves – the near-weekly rate of new & affordable models appearing on the market makes possessing your own cheaper than ever.

Any brand of 3D printer could be used to follow the book. We will focus on the DeltaWASP 2040. It is a trustable machine that can be used to extrude plastic or clay just by changing the type of extruder. It uses a delta system considerably faster than a cartesian one. The printing area is a cylinder of 20cm. diameter by 40cm. height, hence its name.

Part I introduces to the reader C.N.C. technology.

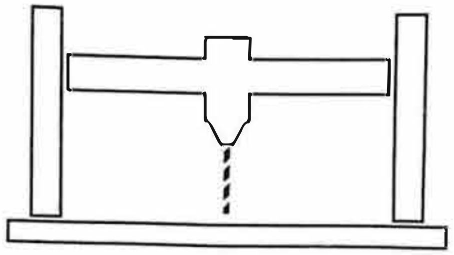
Part II explains how to prepare the clay for 3D printing.

Part III explains the standard workflow for 3D printing. It mainly consists of the following steps:

1. Create a 3D model in any 3D software
2. Export it as *.stl format
3. Open the *.stl file in a slicer software. It will make horizontal sections of our model with an embedded g-code generator, which will transform the sections into a text file that can be understood by C.N.C. technology.
4. Send it to a 3D printer.

Part IV shows a more custom way of 3D printing controlling the path for the 3D printer directly in Rhinoceros® and Grasshopper® and transforming the path into g-code directly from Grasshopper®, with no plug-ins. Non-planar 3D printing and drawing 3D printing can be done.

Part V shows parametric samples for 3D printing.



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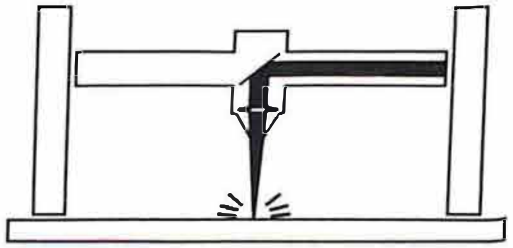

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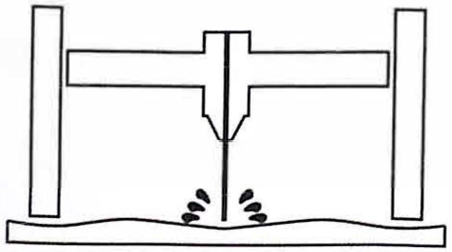

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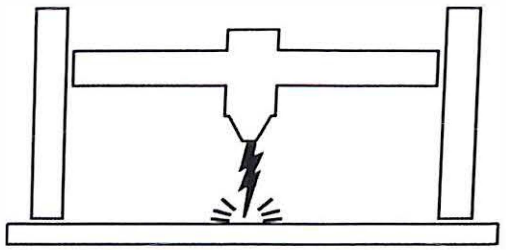

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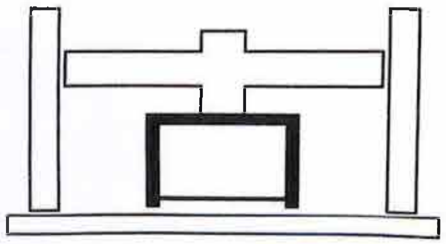

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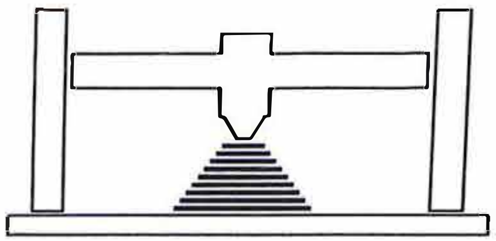


3D printing

PART I C.N.C. technology

C.N.C. stands for Computer Numerical Control. It is a technology that can move a machine in different directions or axis according to a set of defined instructions given to the machine by a text file. That file contains the points in space simplified to their X,Y,Z coordinates. The coordinates describe the movements and the subsequent paths created to make the physical model.

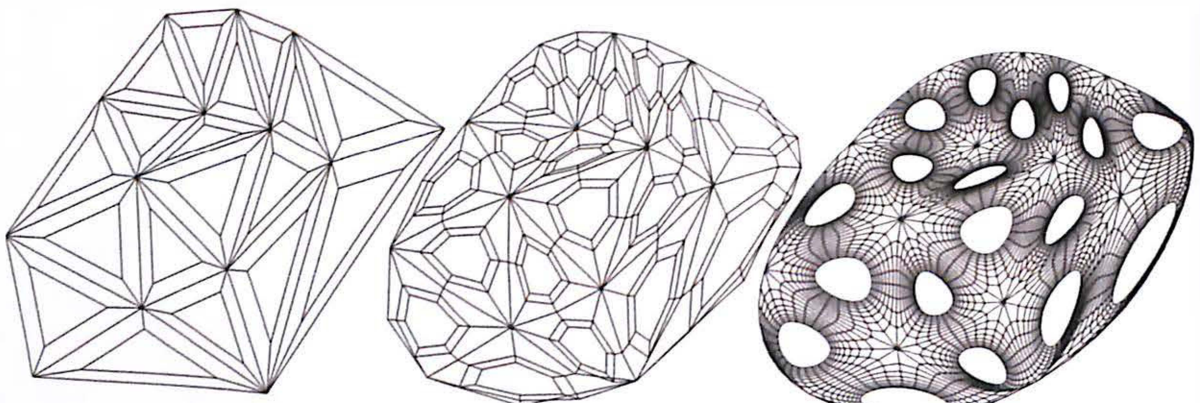
This technology has existed since 1980's and it has remained almost the same since then. What has really changed, is the software that creates the paths or polylines itself, making the user experience much easier.

As we design 3d models, it is necessary to transform them into points. A typical path is as following:

3D model → polylines → points → text file → 3D printer

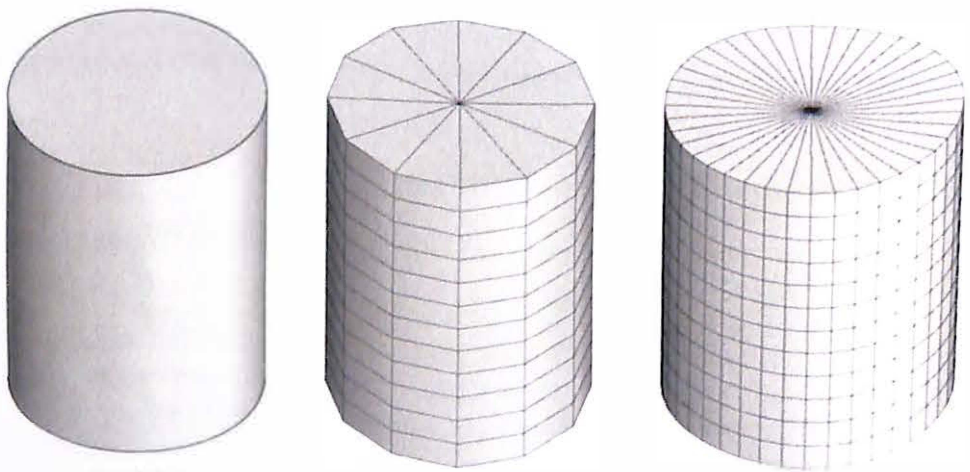
In accordance with the '3D model', we can mainly find two types of objects: Meshes and N.U.R.B.S.

A mesh is a 3D object made of points, joined with edges creating faces that are (mostly) quadrangular or triangular. Meshes are commonly used for animation, free organic modelling and other operations as form finding or structural analysis. Due to subdivision calculation algorithms as Catmull-Clark or Loop, it is relatively easy to start modelling a simple object and subdivide it into a smooth, rounded object. They are also necessary in order to evaluate an object for form finding strategies or calculation analysis. Forces and supports have to be applied to the vertices of a mesh (or to the equivalent linear element, the points of a polyline).

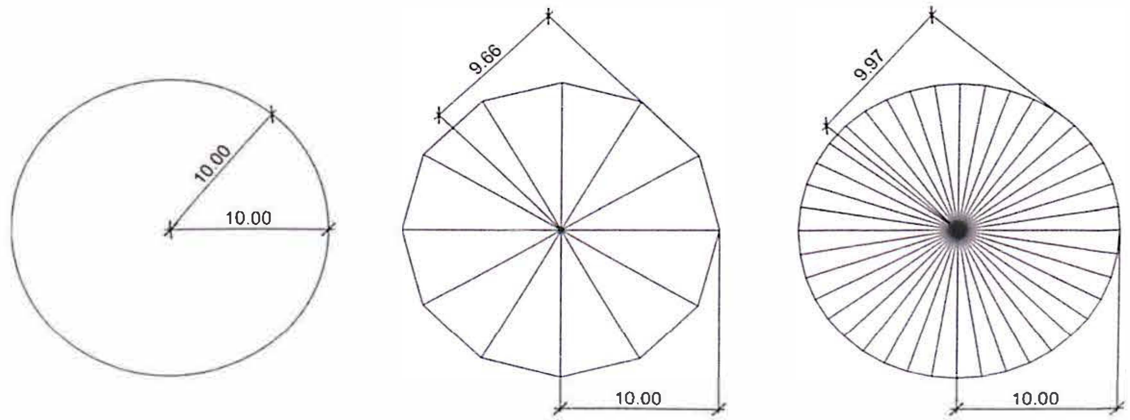


Mesh subdivision example.

A N.U.R.B.S. could be a curve or a surface (or of course a polysurface). Whatever the shape, it is a mathematical representation of an object. They are more precise than polylines or meshes as they attend to parameters. For example, all the points of the edge of a cylinder are at the same distance (radius) to the centre. In a polyline or mesh, the distance is slightly different. As N.U.R.B.S. are more accurate they are commonly used in the manufacturing industry were precision and tolerances are absolutely essential.



N.U.R.B.S. MESH MESH



In the pictures we can see the difference between a N.U.R.B.S. cylinder and a Mesh one with less and more faces.

N.U.R.B.S. are created based on the algorithm of Casteljau. We can say that this type of object has infinite points. This means that N.U.R.B.S. objects have to be modified to be understood by machines, moreover, Rhinoceros® creates polylines and meshes to visualize N.U.R.B.S. that can be manipulated at the Options in Rhinoceros®.

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Display mode set to "Shaded".
Creating meshes... Press Esc to cancel
Command:
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According to manufacturing, in general terms, a curve must be transformed into a polyline and a surface must be transformed into a mesh.

3D printers work under C.N.C. technology like many other manufacturing machines. We can differentiate two big groups of C.N.C. machines defining some of the most commonly used tools:

Subtractive tools: milling machine, laser cutter, waterjet cutter, plasma cutter, hot wire cutter, etc.

Additive tools (3D printers): Stereolithography technology (SLS, SLA, MJF), fused deposition (PLA, ABS, nylon...), extrusion (clay, concrete, chocolate, pizza ...).

Additive manufacturing is the opposite of subtractive, as during the 3D printing process the parts are created starting from an empty build plate where the printhead then adds or hardens material while subtractive techniques need a stock of material to subtract part of it.

3D printing is an old technology invented in the '80s by Chuck Hull.

In 2005 when the existent patent was expiring, a professor, Adrian Bowyer, in the university of Bath decided to make 3D printing open source, hence creating the RepRap project.

RepRap basically consisted of a 3D printer which was able to print the plastic parts required to make another 3D printer. Thanks to Bowyer and others pioneers like Vik Oliver, Alessandro Ranellucci and Joseph Prusa, the technology of 3D printing grew very fast. There are several different technologies related to 3D printing but all share a common feature: the object is created layer by layer.

Below is a quick overview of different kind of 3D printing technologies:

SLS: Selective Laser Sintering. A laser melts the powder of raw material in a tank and then a roller deposits another thin layer of powder on top of the exposed raw material.

SLA: Stereo Lithograpy Apparatus. A UV laser cures a thin layer of a special liquid resin in a tank. There are 2 variations:

> **DLP:** where the laser is substituted by a DLP projector that can project an image and cure an entire layer in the form of the image.
>
> **LCD**: where instead of the projector there is a 2k or 4k LCD screen modified with a UV light.

MJF: MultiJet Fusion is similar to a common Inkjet printer, where the machine deposits a special ink which is then cured with a UV light. Then, the build plate is moved along the Z axis and deposits another layer of ink which is cured again. This technology allows us to also print in colours.

FDM: Fused Deposition Modeling, is the most popular and cheapest technology, consist of an extruder that melts a plastic filament that is deposited following a path generated from software.

LDM: Liquid Deposition Modeling, very similar to FDM but uses fluid/dense material instead of the plastic filament. LDM is the technology used in this book to print in Clay with a Delta WASP 2040 model.

WASP

World Advances Saving Project is an Italian company born with the dream of helping poor people printing houses with raw and cheap material such as soil and vegetal fibers. They started in 2012 by developing a small cartesian 3D printer with a syringe extruder, which was able to print fluids like silicone and - of course - clay. They realized quickly the limits of the cartesian kinematics in printing big and with a lot of weight resting on the printhead, so they moved to another style of machine that was used before for a pick&place solution, the DeltaBot.

In cartesian 3D printers, each axis has its own motor, so to move the head in the x direction only the x motor is required, whereas in the delta style machine each movement is generated by the combination of the 3 arms working together. The big advantage of the Delta style printers is the easy scalability, faster movement and the possibility to increase the weight on the effector.

In this book we are using the **DeltaWASP 2040** with the Clay extruder. It is a 3D printer able to print both, plastic and Clay.

Image courtesy of WASP