LISTAHÁSKÓLI ÍSLANDS
Iceland Academy of the Arts

Hönnunar & Arkítektúrdeild

Vöruhönnun

What is the RepRap?

Origins and influences

Ritgerð til BA / MA-prófs í vöruhönnun
Corto Jabali
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Haust 2014

In 2004 Dr. Adrian Bowyer of Bath University conceptualized the RepRap 3d printer, which originated the booming desktop 3d printing industry. In this essay I attempt to explain the philosophy of the RepRap and reasoning behind its engineering. The many layers of the RepRap are unraveled. It´s history and processes detailed to enlighten the reader as to what the RepRap is and how it influenced the current 3d printing trend in maker culture.

Efnisyfirlit:

Introduction

The RepRap or replicating rapid prototyper is a project started by Dr. Adrian Bowyer at Bath University. Since its beginning it was thought of as an open source project, in other words the engineering of the printer itself was meant to be open to peer review rather than patented and worked on by a small group of scientists.[1]

In a very short time, thanks to its open source platform the project gained momentum and today the desktop 3d printer has gone from open hardware projects like Ultimaker[2] to closed source desktop 3d printers like Makerbot[3] as well as service based companies which will print almost any shape and function out of plastic or even metal.[4]

Early on the RepRap team theorized that a cheap, affordable 3d printer would enable people to produce part of their household items on their own. Cups, spoons etc… would no longer be bought in supermarkets but downloaded from the Internet and produced using a desktop 3d printer[5]. They viewed the relationship between the printer and user as an analogy of the symbiosis between bees and flowers, each benefiting from the other. In the case of the RepRap, it would produce household items and in return, people would replicate it and give it to their friends. Users would be the bees that help RepRaps "reproduce" like the pollinating flowers[6]. For this to work the team set out to design a plastic extrusion 3d printer that could print most of its parts on its own[7]. Though most parts of the RepRap can be printed out, other teams soon figured out that it was quicker and easier to work with other technologies like laser cutting or CNC routing to build the printer. [8]

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1 "About", RepRap, retrieved 7. November 2014, http://reprap.org/wiki/About.

2 John Abella, Eric chu, Matt griffin, "Ultimaker", in *Make: Ultimate guide to 3d printing,* 2013, pp. 70 - 71.

3 Emmanuel Mota, "Replicator 2", in *Make: Ultimate guide to 3d printing,* 2013, pp. 62 - 63.

4 "Materials", Shapeways, retrieved 7. Nóvember 2014, http://www.shapeways.com/materials?li=nav.

5 Adrian Bowyer, "RepRap", retrieved 15. October 2014, http://vimeo.com/5202148.

6 Adrian Bowyer, "RepRap".

7 Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer,"RepRap – the replicating rapid prototype*.",* in Robotica, Vol. 29, January 2011, pp. 179-180, retrieved 15. September 2014, http://journals.cambridge.org/action/displayFulltext?type=1&fid=7967176&jid=ROB&volumeId=29&issueId=01&aid=7967174.

8 Intervew, Corto Jabali with Halldór Úlfarsson, 25 November 2014.

The RepRap online community soon started new projects like Makerbot which is a more user friendly desktop 3d printer. It has the same plastic extrusion technology as the RepRap but is much easier to build and utilize. A member of the RepRap team and co-founder of Makerbot coded a website called thingiverse.com, which was an open blog that allows people to share what they are working on with their 3d printers, it is now an integral part of the Makerbot company[9]. As a product of these advances the desktop 3d printer became commercial, a sold commodity used by schools, designers, artists and hobbyists all over the world, the blog and Makerbot printer became a closed source after their acquisition by Stratasys, a commercial 3d printer company.

The original aims of the RepRap project, creating a symbiosis between man and a replicating machine where not fully met, to date 3d printing is a time consuming process and the objects that come out of the most common ABS and PLA plastic printers are often regarded as prototypes or toys rather than fully functional household items. Still RepRap projects like Ultimaker continue to experiment using the open hardware format and anyone can buy a starter kit and build their own customizable 3d printer.

Even though RepRap didn’t change the way we as consumers buy our products, it opened up a lot of possibilities for entrepreneurs and students, MIT´s FABLAB has helped a lot of communities create value using rapid prototyping machines like the desktop 3d printer[10], and schools use them to train students in cad programs[11]. As a prototyper, the 3d printer hasn´t lost any value, it has simply become cheaper than its industrial and more expensive brethren and has therefore opened up this technology to the wider public, as an open hardware project the RepRap has created an extremely interesting and vibrant community of people that are willing to experiment with the tool itself, in this respect the RepRap has popularized a very interesting kind of making, one that has created a lot of change in industry and culture, tool-making[12]. Before humanity started making objects, it had to create the tools to produce them.

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9 Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer,"RepRap – the replicating rapid prototype.", pp. 190

10 Zakaria, Fareed, “ On GPS: Future of digital fabrication”, CNN, retrieved 15. Október 2014, http://edition.cnn.com/video/data/2.0/video/bestoftv/2013/07/17/exp-gps-gershenfeld-3d-printing.cnn.html.

11 Interview, Corto Jabali with Joe Foley, 22. Oktober 2014.

12 Richard Sennet, The craftsman, 2. edition, Penguin Books, England, 2009, pp. 195.

1. Origins of the RepRap project and motivation

1.1 Origins

Dr. Bowyer first mentioned the RepRap online in 2004 and outlined it´s ideals as a self-replicating machine that would live and reproduce in symbiosis with it´s human users. He mentioned three main concepts on which he based the RepRap project. The first was synthesized in the phrase "Darwinian Marxism":

"Karl Marx and Frederick Engels wrote in the Communist Manifesto that, "By proletariat is meant the class of modern wage laborers who, having no means of production of their own, are reduced to selling their labor power in order to live." [13]

Dr. Bowyer agrees with this diagnosis but goes on to criticize the means with which the proletariat in the communist manifesto was meant to break free. And that was to take control over the resources through a violent revolution that ultimately led to many deaths. Instead he proposes another solution, a self-replicating machine, one that would bring the power of production into the hands of the proletariat.[14]

Self-replicating is a vague term, but in 2011 Dr. Adrian Bowyer and his colleagues published a paper on the RepRap where they explained this second concept in more detail:

> "*Self-reproduction:* A process by which a kinematic machine is able to create an approximate copy of itself, perhaps with either insignificant or significant errors. All living organisms are self-reproducers… *Self-manufacturing:* The ability of a kinematic machine to make some or all of its own parts from raw materials…
> *Self-Assembly:* This refers to the ability of a kinematic machine to manipulate a series of parts into an assembled copy of itself… *Autotrophic self-reproduction or self-replication:* The ability of a system to make a direct copy of itself from raw materials without assistance… *Assisted self-reproduction or self-replication:* A kinematic machine that includes at least one but not all of the critical subsystems required for autotrophic self-reproduction and so needs human (or other) intervention to reproduce."[15]

By these definitions the RepRap is an assisted self-replicating and self-reproducing kinematic machine. By contrast humans are autotrophic self-replicating, self-

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[13] Adrian Bowyer, "Wealth without money", RepRap, 2011, retrieved 7. November 2014, http://reprap.org/wiki/BackgroundPage.

[14] Adrian Bowyer, "wealth without money".

[15] Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer,"RepRap – the replicating rapid prototype." pp. 177–178.

reproducing and self-assembling. Plants on the other hand require assistance to reproduce, hence the analogy between the RepRap and the symbiosis between the bees and the flowers, the third concept, which drives the RepRap project[16]. For the flower to pollinate, it has to attract the bee with nectar, as the bee moves from flower to flower and then back to its hive it spreads the pollen and helps the flowers reproduce. For its help the bee is rewarded with nectar providing nutrition and building material for the hive.

The RepRap is the flower and its nectar is the potential to produce many household items that people would otherwise buy. In effect the RepRap is meant to put production in the hands of the proletariat, theoretically eliminating the need to mass-produce a large number of products. This concept has the potential to have a significant impact on the economy and the environment since the products would only be manufactured if they were necessary at the time of production, rather than stockpiling a large amount, which might or might not be sold.

At this point the RepRap was only a concept, the team still had to figure out the process and technology the RepRap was to be based on. Whether they had to invent a new one or use an already existing manufacturing process. The first choice was using rapid prototyping technology rather than for example CNC milling. The method of producing objects by machining them would be a difficult solution if the ReRap was meant to be used in homes rather than on factory floors. Therefore the RepRap team chose to work with rapid prototyping technologies, which require little force in comparison. According to them it was also the simplest computer aided technology.[17] This meant that learning how to make objects with the RepRap and using it in a functional manner was a simple and quick skill to learn, widening the spectrum of potential users even further.

Because of the intended market they also decided that any part that would not be reproduced by the RepRap had to be cheap and widely available. Rapid prototyping is a group of different manufacturing techniques and through process of elimination two of them stood out as a good choice for the RepRap project, laminated object manufacturing a process with which you can create three-dimensional shapes with cut and stacked paper, the other, Fused Deposition Modeling.

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16 Adrian Bowyer, "RepRap".

17 Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer,"RepRap – the replicating rapid prototype.", pp.181.

The first was quite interesting because of the ubiquity of its working material, paper. On the other hand FDM could print using more than one material, which meant that the machine could make more of its own components than could be built out of just one material[18]. This vector of approach supported the RepRaps ability to reproduce as many of its parts as possible and also increased the number of products it could potentially produce.

It is important to keep in mind that these choices where made because Dr. Bowyer felt it was crucial to the project that the machine be easily reproduced, since the production value of a self-replicating machine lies in its ability to produce an exponential number of objects[19].

With the conceptualization of the RepRap project ideals and its implementation as an engineering project the first open-source self-replicating desktop 3d printer was produced in 2007[20], the model name is Darwin and at its core is a plastic-extrusion head that prints PLA plastic objects layer by layer creating 3d shapes which have a wide variety of applications.

1.2 motivation

As a product design student, and as an intern I have had direct contact with desktop 3d printers and experienced its potential and the impact it has had on the world of design.

What interests me most is the RepRaps ability to evolve and change through self-initiated projects. The potential of having a desktop production devise in your studio with which you can effectively take over the manufacturing part of a product changes the role of designers. It means that we can have complete control over which material we use, how many units are made and because you can adapt the printer to meet your needs, it has many different applications, only limited by one´s imagination and technical ability. There are, for instance printers that knit[21], others can draw tattoos[22].

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[18] Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer, "RepRap – the replicating rapid prototyper", pp. 181.

[19] Adrian Bowyer, "wealth without money".

[20] Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer, "RepRap – the replicating rapid prototyper", pp. 182.

[21] “this-knitting-machine-is-like-a-3d-printer-for-clothes”, Motherboard, retrieved 7. November 2014, http://motherboard.vice.com/read/this-knitting-machine-is-like-a-3d-printer-for-clothes.

It is therefore, in my mind a very impressive tool. Unlike the hammer or the screwdriver it is a complete manufacturing method that enables you to produce an object using one process rather than many, there is no need for additive materials such as glue, screws or nails. Because of the method of production, which is to say 3d modeling an object on a computer, the level of skill needed to produce complex shapes is also greatly reduced, enabling designers and others to make complex, albeit fragile machine parts. For my first project working with a desktop 3d printer, I designed a working air pump with an imbedded Tesla valve. It is a one-way valvular conduit that doesn´t require movable parts like a faucet for instance. A marvel of engineering which I can to this day hardly understand, but because of the simplicity of this manufacturing technique I was able to model it on a computer and print a successful copy of it, further illustrating to me the potential of FDM 3d printers.

2. Rapid prototyping

2.1 Brief history

This chapter is a brief history and technical overview of the most commonly used Rapid prototyping, or additive manufacturing technologies. They are as follows SLA, SLS and DMLS. The last two are powder-based laser sintering processes but SLA uses a liquid polymer that solidifies via a laser beam. FDM or Fused deposition modeling is the additive manufacturing process used by the RepRap, it was patented and developed by S. Scott Crump the co-founder of Stratasys Inc. [23]

All of these processes are computer aided manufacturing technologies that require an stl file from a cad program to build objects. The stl file is a digital 3d model that has been sliced into cross-sections, 0.05mm to 0.1 mm thick so that the 3d printers can sequentially print layer upon layer using deposition modeling or laser sintering until the finished object is obtained. Rapid prototyping is an interesting process

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[22] "French designers hack a 3d printer to make a tattooing machine", Dezeen, 2014, retrieved 7. November 2014, http://www.dezeen.com/2014/10/28/appropriate-audiences-tatoue-hacked-3d-printer-tattoo-machine/.

[23] Crump, S Scott, "Apparatus and method for creating three-dimensional objects", US patent 5121329, 9. June 1992, retrieved 12. Desember 2014, https://www.google.com/patents/US5121329?dq=ininventor:%22S.+Scott+Crump%22+%2B+1991&hl=en&sa=X&ei=7Y1_VL_wLIrg7QbtzYHIBg&ved=0CDkQ6AEwBA.

because of its geometric building capabilities, since the shapes are built in layers, undercuts are easier to produce than in CNC routers or other machining processes.[24] It also makes it possible to build multiple part objects without post-assembly like the aforementioned air pump with an embedded Tesla valve.

Ideas similar to the ones found in modern rapid prototyping are more than a hundred years old. In the second half of the 19th century a technique called photo sculpture was used to create an exact three-dimensional replica of a subject. A Frenchman, Francois Willème did it quite successfully in 1860 by photographing a subject in the middle of a room encircled with 24 cameras. An artisan then carved 24 cylindrical portions of the silhouette of each photograph that where later assembled into a three dimensional model. [25]

In 1890 an other technique was proposed by a man named Blanther, This time it was to create a topographical map, the method consisted of impressing contour lines onto wax plates. After stacking and smoothing these sections, both a negative and a positive of the terrain lines was produced and a paper map was then pressed between the sections producing a three dimensional map. [26]

In the early 20th century further research into additive manufacturing was conducted and in 1971 Ciraud proposed a process that has some similarities to powder based rapid prototyping. In his proposal he described a process with which particles that are at least partially able to melt are deposited onto a matrix. A laser would than apply heat locally and fuse the particles together.[27]

In 1978, Householder wrote about the earliest form of powder-based laser sintering processes in a patent. In it he described a process in which layers where sequentially deposited onto a plane and solidified one after the other creating a three dimensional shape. [28]

Finally in 1981 the first objects made using a modern additive manufacturing technique where presented by Hideo Kodama of Nagoya Municipal Industrial Research Institute. The institute created the first photopolymer rapid prototyping

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[24] Thompson, Rob, *Manufacturing Processes for Design Professionals,* Thames&Hudson Inc., New York, 2007, pp.234.

[25] Caleb,“the-history-of-laser-additive-manufacturing”, Lasers today, 13. April 2012, retrieved 2. Desember 2014, http://www.laserstoday.com/2012/04/the-history-of-laser-additive-manufacturing/.

[26] Caleb,“the-history-of-laser-additive-manufacturing".

[27] Caleb,“the-history-of-laser-additive-manufacturing".

[28] Caleb,“the-history-of-laser-additive-manufacturing".

machine that could produce an object by selectively solidifying layers of polymer according to cross-sections of a model. [29]

2.2 processes overview

The technical overview of SLA, SLS and DMLS rapid prototyping processes that follows are direct quotes from the book *Manufacturing processes for design professionals:*

> "STEREOLITHOGRAPHY
> …The model is built 1 layer at a time by an UV laser beam directed by a computer-guided mirror onto the surface of the UV sensitive liquid epoxy resin. The UV light precisely solidifies the resin it touches. Each layer is applied by submersion of the build platform into the resin. The paddle sweeps across the surface of the resin with each step downwards, to break the surface tension of the liquid and control layer thickness. The part gradually develops below the surface of the liquid and is kept off the build platform by a support structure. This is made in the same incremental way, prior to building the first layer of the part.
>
> SELECTIVE LASER SINTERING
> In this layer-additive manufacturing process, a CO_2 laser fuses fine nylon powder in 0.1 mm (0.004 in.) layers, directed by a computer-guided mirror. The build platform progresses downwards in layer thickness steps. The delivery chambers alternately rise to provide the roller with a fresh charge of powder to spread accurately over the surface of the build area. Non-sintered powder forms a ´cake´, which encapsulates and supports the model as the build progresses. The whole process takes place in an inert nitrogen atmosphere at less than 1% oxygen to stop the nylon oxydizing when heated by the laser beam.
>
> DIRECT METAL LASER SINTERING
> A considerable amount of heat is generated during this process because a 250 watt CO_2 laser is used to sinter the metal alloy powders. An expendable first layer of the part is anchored to the steel plate to stop distortion caused by differing rates of contraction. Such a layer also means that the part is easier to remove from the steel plate when the build is complete. During the sintering process, the delivery chamber rises to dispense powder in the path of the paddle, which spreads a precise layer of build area. The build platform is incrementally lowered as each layer of metal alloy is sintered onto the surface of the part. The whole process takes place in an inert nitrogen atmosphere at less than 1% oxygen to prevent oxydization of the metal powder during the build."[30]

In 1989 S. Scott Crump filed a patent for the first FDM 3d printer[31], what follows is the abstract of said patent. It is included because it contains a precise and intuitive description of the FDM process as used in desktop 3d printers today:

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[29] Caleb,"the-history-of-laser-additive-manufacturing".

[30] Thompson, Rob, *Manufacturing Processes for Design Professionals, pp. 234-235.*

[31] Crump, S Scott, "Apparatus and method for creating three-dimensional objects".

> "**Apparatus and method for creating three-dimensional objects**
> **US 5121329 A**
> **ABSTRACT**
> Apparatus incorporating a movable dispensing head provided with a supply of material which solidifies at a predetermined temperature, and a base member, which are moved relative to each other along "X," "Y," and "Z" axes in a predetermined pattern to create three-dimensional objects by building up material discharged from the dispensing head onto the base member at a controlled rate. The apparatus is preferably computer driven in a process utilizing computer aided design (CAD) and computer-aided (CAM) software to generate drive signals for controlled movement of the dispensing head and base member as material is being dispensed.
> Three-dimensional objects may be produced by depositing repeated layers of solidifying material until the shape is formed. Any material, such as self-hardening waxes, thermoplastic resins, molten metals, two-part epoxies, foaming plastics, and glass, which adheres to the previous layer with an adequate bond upon solidification, may be utilized. Each layer base is defined by the previous layer, and each layer thickness is defined and closely controlled by the height at which the tip of the dispensing head is positioned above the preceding layer."[32]

S. Scott Crump is the co-founder of Stratasys Inc. A giant of the 3d printing world. They held a patent on FDM but when Dr. Adrian Bowyer and the RepRap team were researching technologies to use in their self-replicator the patent had expired. This came in handy for the team and fit in the concept of the RepRap project since contributors to the open hardware project would not have to pay royalties to Stratasys for using their invention, or be restricted to buying the printer-heads from them. It was cheaper to reproduce the hardware necessary to replicate the FDM process, since the lasers required for SLA, SLS and DMLS processes are very expensive.[33] The RepRap team coined a new term for FDM, fused filament fabrication or FFF. They did so because FDM was a term used exclusively by Stratasys and they did not want to risk lawsuits for using it.[34] This re-christening of the FDM process can be viewed as a symbol of the re-acquisition of production power by the proletariat as synthesized by Dr. Adrian Bowyer in the term Darwinian Marxism. Here, a pro-proletariat, socialist, open-hardware movement successfully took over a form of production from a capitalist entity and put it in the hands of the people, or in other words the RepRap online community.

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32 S. Scott Crump, "Apparatus and method for creating three-dimensional objects".

33 Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer,"RepRap – the replicating rapid prototype.", pp.181.

34 "Fused filament fabrication", RepRap, 14. January 2014, retrieved 12. December 2014,http://reprap.org/wiki/Fused_filament_fabrication.

3. Open source, the RepRaps development strategy.

3.1 Open source

Open Source is a term coined by software developers in the late 90´s following the announcement of the release to the public of Netscape´s source code[35]. It is an open software development strategy. Before that commercial programs and operating systems relied mostly on a cathedral strategy[36]. A closed group of programmers would attack the software or operating system and debug it[37], this method was very time-consuming and expensive since fewer hackers where working on the software. Open Source is about using the Bazaar strategy, that means, free release of software including its source code that a large pool of co-developers can collectively attempt to break and debug[38], the main difference is that a bug in the cathedral system is a complex problem that takes time to find and fix, in the bazaar system a bug is viewed as a shallow problem that takes a relatively short time to fix[39], since instead of ten developers you have hundreds, even thousands, attacking and debugging the software at the same time and most importantly for free since the co-developers are also the softwares clients. The Linux operating system for instance is much more than just software, it is also a large community of people, collectively co-creating one software that every single one of them is using[40]. Linus Torvalds is the founder of Linux but he only coded the original kernel[41], since its creation, thousands of geeks and hackers have sent in patches that he then used for subsequent releases of the software.

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35 "History of the OSI", Open Source Initiative, September 2012, retrieved 12. Desember 2014, http://opensource.org/history.

36 Eric Raymond, " The cathedral and the bazaar", in Knowledge, Technology & policy, vol. 12, no. 3, pp. 24. retrieved 12. December 2014, http://download.springer.com/static/pdf/121/art%253A10.1007%252Fs12130-999-1026-0.pdf?auth66=1418357388_330d167301fededeb3b4d4a6b67bc9a3&ext=.pdf.

37 Eric Raymond, " The cathedral and the bazaar", pp. 24.

38 Eric Raymond, " The cathedral and the bazaar", pp. 24.

39 Eric Raymond, " The cathedral and the bazaar", pp. 29.

40 Eric Raymond, " The cathedral and the bazaar", pp. 28.

41 Eric Raymond, " The cathedral and the bazaar", pp. 28.

Eric Raymond, one of the founders of the OSI and the author of the paper *Cathedral and the Bazaar*[42], wrote the following about Linus Torvald." Linus is not (or at least, not yet) an innovative genius of design in the way that, say, Richard Stallman or James Gosling (of NeWS and Java) are. Rather, Linus seems to me to be a genius of engineering and implementation, with a sixth sense for avoiding bugs and development dead-ends and a true knack for finding the minimum-effort path from point A to point B.".[43]

The Open Source Initiative or OSI, is an organization that advocates, educates and defines Open Source[44].

They outlined what an open source software is, by detailing how its license should be in the open source definition:

The software license should not inhibit the free redistribution of the software, which must include the source code. When it does not include the source code it should be accessible on the Internet and there should be clear information about where it is. The license must allow development of the software, that is changes to the source code, to be redistributed under the same license as the original software. The license may restrict the distribution of the source code, but only if it allows the distribution of patch files along with the software for the purpose of modifying it at build time. The license must not discriminate against any individual, group of people or fields of endeavor. The rights attached to the license apply to all that the software is distributed to.

The right attached to the program must not be specific to a product. That is, if the program is taken out of a product bundle, like Microsoft office, the license that was attached to the original software still applies regardless of the current method of distribution. The license must not inhibit the distribution of other software along with the open source program. And finally the license cannot restrict the software to any technology.[45]

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42 "History of the OSI", Open Source Initiative,

43 Eric Raymond, " The cathedral and the bazaar", pp. 29.

44 "About the Open Source Initiative", Open Source Initiative, retrieved 12 December 2014, http://opensource.org/about.

45 "Open source definition", Open Source Initiative, retrieved 15 October 2014, http://opensource.org/osd.

3.2 Open hardware

The OSI´s definition of open source and the past experiences of open source development implementations in software like Linux forms the bases for open source hardware projects like the RepRap.

Essentially, the theory remains the same, by using a large pool of co-developers, who have a stake in the object since they are its users, the development of the hardware will be quicker and more efficient. According to Eric Raymond, Sociologists call this phenomenon, *Delphi´s Law.* "…the averaged opinion of a mass of equally expert (or equally ignorant) observers is quite a bit more reliable a predictor than the opinion of a single randomly-chosen one of the observers."[46]

Experts in this context, refers to geeks. Originally this slang term meant a group of non-conformist people. But today its meaning has shifted to a person that is an expert in a field or is obsessed with an intellectual endeavor or hobby.

Open source hardware means that you have to release all design documentation and software for free, so that anyone can freely reproduce your hardware, as long as it is then shared with the online community attached to the project[47]. As Chris Anderson cleverly put it in his book *Makers: The new industrial revolution, "...give away the bits and sell the atoms*."[48] The software and design files are the bits that you give away to the community and the hardware is the atoms, which you sell for profit.

Building an open source community around your product, means that you can develop them a lot quicker, better and cheaper. It also means that your users form your customer support and development departments, instead of having a costly support center take care of your clients grievances, you form an online community that takes care of itself, and innovates[49].

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[46] Eric Raymond, " The cathedral and the bazaar", pp. 30.

[47] Andersson, Chris, *Makers: The new industrial revolution,* Crown business, New York, 2012, pp. 107.

[48] Andersson, Chris, *Makers: The new industrial revolution, pp. 107.*

[49] Andersson, Chris, *Makers: The new industrial revolution, pp. 109.*

4. The RepRap community

4.1

The reason Adrian Bowyer wanted the RepRap to be open source is because he embedded its principles within it from the beginning[50]. Darwin, the first RepRap as engineered by the core RepRap team is like the first edition of the Linux kernel developed by Linus Torvald. It was not meant to be perfect, it was meant to be at the core of a community that would make it evolve, improve and keep it up to date with cultural currents and innovations in technology. It was through open source development that the self-replicating machine would come into symbiosis with people, but as was mentioned earlier, it is mostly geeks that spend their time working on open hardware projects.

In the context of RepRap, two businesses come to mind that where born out of its online community. One is Makerbot, and the other Ultimaker. Makerbot started as a RepRap project with the aim of creating a more user-friendly desktop 3d printer to sell for profit[51]. Ultimaker, on the other hand went another path, they created a 3d printer which appeals to the geek community, enabling users to tinker with the machine and customize if they are so inclined[52]. One, appeals to people who want to use the machine in a simple and intuitive way. The other appeals to people who are interested in working on the machine itself. These represent in my mind two polar trends in the desktop 3d printing world. Both of them still have elements of their RepRap origins embedded in their respective concepts.

The earliest variation of Darwin, the original RepRap printer, was the Mendel. Using feedback from the RepRap community they simplified the design, making it cheaper and lighter. The Mendel also had the potential to produce 57 percent of its parts rather than 40 percent in the Darwin[53]. This means that the core RepRap

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[50] Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer,"RepRap – the replicating rapid prototype.", pp.180.

[51] Dale Dougherty, "Dreaming of 3d printers", in *Make: Ultimate guide to 3d printing,* 2013, pp. 6.

[52] Abella, John, Eric chu, Matt griffin, "Ultimaker", in *Make: Ultimate guide to 3d printing,* 2013, pp. 70.

[53] Jones Rhys, Patrick Haufe, Edward Sells, Pejman Iravani, Vik Olliver, Chris Palmer and Adrian Bowyer,"RepRap – the replicating rapid prototype.", pp.188.

developer team decided to expand the printers self-replicating capabilities for their second release.

As mentioned in the first chapter, the production value of a self-replicating machine lies in its ability to produce an exponential amount of objects; with each printer manufactured the production capabilities are increased. This means that in a relatively short amount of time the RepRap movement could have theoretically expanded at such a rate to threaten current production entity´s. Potentially taking production power out of the hands of the elite and putting it into the hands of the public.

This was the main goal of the RepRap project and one of its core concepts. However members of the RepRap community including one member of the core team, Zach Smith, soon figured out that it could potentially be accomplished even though the printer wasn´t self-replicating[54].

4.2

In 2009 Makerbot released the Cupcake CNC 3d printer[55], a printer that was more easily assembled and did not need as much tinkering as the RepRaps´ Darwin or Mendel.

The Makerbot team decided to focus on making a desktop 3d printer that everyone could use, which means that they discarded the original aim of self-replication, instead they wanted a production device that could be useful in every home, like an inkjet printer for instance. They still had the same vision as Dr. Adrian Bowyer, they wanted to give people the means of production, but they also knew that for that to work the printer had to be simpler and more intuitive, in other words, user-friendly. The cupcake was sold as a kit witch the user assembles.

In 2013, *Make:* magazine hailed the Cupcake for starting off the 3d printing revolution.[56]

It became the first commercially sold personal 3d printer. They remained true to their Open Source origin´s for a while but after they sold the company to Stratasys Inc. Makerbot industries decided to abandon open source development on their software and hardware because they were afraid of clones and lost profits.

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[54] Dale Dougherty, "A brief history of personal 3d printing", in *Make: Ultimate guide to 3d printing",* 2014, pp. 8.

[55]Dale Dougherty, "A brief history of personal 3d printing", in *Make: Ultimate guide to 3d printing",* 2014, pp. 8.

[56] Dale dougherty, "Dreaming of 3d printers", in *Make: Ultimate guide to 3d printing,* 2013, pp. 6.

This was extremely controversial and since the Makerbot had been open source from the beginning a lot of its users where co-developing the printer, which meant that Makerbot industries could lose a lot of its clients by going closed source. [57]

Two out of three original founders of Makerbot quit. Zach Smith and Adam Mayer, the former commented the following on the subject. “For me, personally, I look at a move to closed source as the ultimate betrayal."[58]

Ultimately the move to closed source after Makerbot released the “replicator 2” was viewed in a negative light, yet it still is one of the most intuitive desktop 3d printers available, and that is largely thanks to its open source origins.

I have worked mostly with Makerbot printers, and can say from first hand knowledge that it is relatively simple to use, I have never had to calibrate it or troubleshoot it, and the objects that come out of it are almost always exactly like the ones I model on my cad program. It is efficient and is regarded by make magazine as great purchase since it takes an average of 20 minutes to get it running out the box, and the print quality is excellent compared to similarly priced desktop 3d printers.
Overall Makerbot succeeded in making a “people´s” 3d printer. But they also opened up a market for similar closed source printers that they now compete with on a commercial level.

Soon other Desktop 3d printer projects from the RepRap community followed suit, taking notice of the Makerbots rapid rise to fame and fortune[59]. In my opinion the most notable one is the Ultimaker.

4.3

Ultimaker is a project that was started in 2011, by Erik de Bruijn, an early RepRap developer and one of the first to successfully replicate functional parts, Martijn Elserman a designer, and Protospace FabLab manager Siert Wijnia.[60]

The Ultimaker remains an open source 3d printer. It is a not a printer for people that want to take it out of the box and get it working straight away. It needs more tinkering[61], but on the other hand it is a tool that enables makers and geeks to play

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[57] "Replicator controversy", RepRap, retrieved 10. December 2014, http://reprap.org/wiki/Replicator_controversy.
[58] "Replicator controversy", RepRap.
[59] Dale dougherty, "Dreaming of 3d printers", pp. 6.
[60] Goli Mohammadi, Mike Senese, "Faces of 3d printing", in *Make: Ultimate guide to 3d printing",* 2014, pp. 27.
[61] John Abella, Eric chu, Matt griffin, "Ultimaker", in *Make: Ultimate guide to 3d printing,* 2013, pp. 71.

around, creating a platform of experimentation to be openly shared online with the Ultimaker open hardware community[62].

Interestingly enough, once you get it working it has overall better printing resolution and is also the fastest personal 3d printer currently available, getting better marks than Makerbot and other similar printers. It´s not out of the box printing since it takes anywhere from 6 to 20 hours to assemble the kit, but it proves the case for an open source development strategy. [63]

The reason for Ultimakers success is largely the open source community surrounding the product. Because they adopted the Bazaar strategy they develop their products faster and better than the competition, perhaps, their secret lies in the ability of its founders to make sense of the chaos of tweaks and ideas sent in by their co-developers. Like Linus Torvalds, Erik de Bruijn and his colleagues successfully produce the simplest and most effective design, by finding the quickest path from A to B.

This year they launched the Ultimaker 2, according to *make:* it is quickly catching up to the intuitivity of the Replicator 2 which is as of now Makerbots last open source printer[64]. What is notable is that according to reviews, Ultimaker is Makerbots rival, even though they cater to an open source community which mainly wants to work on the tool itself, they have also designed a functional and intuitive tool for beginners, enthusiasts or designers who are seeking an easy to use desktop 3d printer[65].

Conclusion

What is interesting to me as a designer is that a tool like the RepRap or Ultimaker desktop 3d printers demand that you get to know it better, you don´t just learn to use the production process, as a user you have to work on the tool itself.

Richard Sennet in his book *The craftsman,* identifies two types of tools, the all-purpose tool and the fit-for-purpose tool. The former is an abstract object which doesn´t tell you exactly what its meant for since it has many applications. The latter

[62] "community", Ultimaker, retrieved 12 December 2014, http://umforum.ultimaker.com.

[63] John Abella, Eric chu, Matt griffin, "Ultimaker", pp. 71.

[64] Anderson Ta, Blake Maloof, "Replicator 2", in *Make: ultimate guide to 3d printing,* 2014, pp. 68 - 69.

[65] Eric Chu, "Ultimaker 2", in *Make: Ultimate guide to 3d printing,* 2014, pp. 66 - 67.

has a specified job to do, like the screwdriver for instance. It´s shape tells you what its for and how to use it, its intuitive and simple. The quality of the all-purpose tool is that it challenges you, ignites your creativity and open´s the users eyes to opportunities that the fit-for-purpose tool might not.[66]

Consider this, the Ultimaker enables users to work with additive manufacturing from the standpoint of the maker. The imperfections and frustrations of working with a kit assembled 3d-printer along with the possibility of taking part in its development community tempting the user to delve deeper, the knowledge gained might enable change in the tool itself, working with it´s potential to evolve and adapt.

The Makerbot on the other hand is a fit-for-purpose tool, its just what you get out of the box and is not meant for you to fix or tweak, you cannot experiment with the 3d printer as a medium using the Replicator 2. On the other hand you can easily print shapes and functions, but because you don´t know the tool you are working with, a lot of knowledge might get lost in translation.

I haven´t come to the conclusion that the Makerbot, an out-of-the-box 3d-printer is better or worse than the RepRap or Ultimaker. For me the simple fact is that the FFF process isn´t interesting on its own, it´s the possibilities afforded by a fundamentally open tool design, that is enticing. As I mentioned in the introduction, tool-making is a powerful medium of change in industry, tools effect what we produce and how we produce, it affects what kind of shapes we envision when designing an object and what kind of materials fill up our spaces. The RepRap also makes a great case for open source development, 7 years after Adrian Bowyer and his team made the Darwin, desktop 3d printing has become a huge industry. Through open source development, the desktop 3d printer has taken many shapes, it´s ready-to-use, kit-assembled, do-it-yourself, large, mobile, open source and closed source. It´s entirely up to the buyer to choose which type of desktop 3d printer fits his or her need[67].

[66] Richard Sennet, *The craftsman, pp. 94-95.*

[67] Anna Kaziunas France, "3d printing buyer´s guide", in *Make: Ultimate guide to 3d printing.* 2014, pp. 56.

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