

# Toward a Network Based 3D Printing Service

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# Toward a Network Based 3D Printing Service

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# Abstract

This bachelor's thesis has given us an opportunity to gain insight into how to create a service from scratch and to develop it into a fully functional service. The 3D printer service starts when a customer uploads a file containing the 3D design that they want to have made via a website. The file is stored and the printing request is placed into a queue. After that the client simply waits until the object is printed, with all of the various steps being handled automatically.

The uploaded file containing the 3D design is automatically converted into Gcode by using the software Skeinforge. Gcode is the language that the printer interprets. The printer itself is controlled by the ReplicatorG program. The ReplicatorG program transfers the Gcode commands to the printer to print the desired object. This Gcode includes commands to warm up the automated build platform where the object will be created and to warm up the extruder head – through which plastic will be extruded to create the 3D object. If the customer wants to see the object while it is being printed – we have made this possible via a network attached camera. This camera is placed next to the printer. Once the object has been printed the automated build platform is allowed to cool and a motor driven belt advances to eject the object from the platform.

In an ideal system the object would be put directly into a bag or other package – with a pre-printed label, thus it would be ready for shipping to the customer. This portion of the system has not yet been realized and is left as future work.

**Keywords:** 3D-printing, MakerBot Thing-o-Matic, Replicatorg, LAMP, OpenSuse



# Abstrakt

Detta kandidatexamensarbete har gett oss en möjlighet att få en inblick i hur det är att skapa en tjänst från grund och sedan bygga på den tills en fullt fungerande tjänst var skapad. 3D printertjänsten drar igång då en kund laddar upp den önskade filen via hemsidan, som sedan lagras och läggs i en eventuell kö. Från detta behöver inte kunden eller någon annan göra något mer utan allt sköts automatiskt. En konvertering av kundens STL fil till språket Gcode som skrivaren kan tolka sker med hjälp av programmet Skeinforge. Själva skrivaren styrs av programmet ReplicatorG där allt bestäms och slutligen ger order till skrivaren att börja skriva ut det som önskas. Om kunden vill så finns en möjlighet att med hjälp av en IP kamera även se sina produkter live då de tillverkas. Idén om att objekt direkt ska landa i en förpackning som är redo att skickas till kunden lämnas för framtida arbeten.

**Nyckelord:** 3D-skrivare, MakerBot Thing-o-Matic, ReplicatorG, LAMP, OpenSuse



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# List of Acronyms and Abbreviations

3D	three dimensional
CAD	computer-aided design
CNC	Computer Numerical Control
HTML	Hypertext Markup Language
IP	Internet Protocol
LAMP	Linux Apache MySQL PHP
LAN	Local Area Network
OS	Operating System
PHP	Hypertext Preprocessor
STL	STereoLithography
URL	Uniform Resource Locator
WYSIWYG	what you see is what you get



# 1 Introduction

A 3D printer is a device that can print solid three dimensional (3D) objects as specified in a digital format by a designer. One of the most common formats is the STereoLithography (STL) format developed by 3D Systems. Using a 3D printer one can produce complex customobjects. A large variety of such designs can be seen at MakerBot Industries' Thingiverse<sup>®</sup>[1].

3D printers have been used for the last decade by companies mainly to create prototypes before they finalize a design to be produced on a production line. This use is called rapid prototyping. Although the cost of making a prototype with a 3D printer is high, it is much lower than the cost of the tool and die making that is needed to mass produce an object. The prototype can be used to evaluate the design before committing to mass production. However, with the decreasing cost of 3D printing there is increased use of 3D printers to directly manufacture items – especially highly customized items.

To decrease the printing time it is possible in some cases to divide the design into several parts that can be printed on different printers in parallel. Additionally, the division into different parts enables different types of 3D printers to be used. Today it is possible to do 3D printing using a variety of different materials – as will be explained in detail in Chapter 2.

The objects to be printed can be designed with computer-aided design (CAD) or other modeling software. This software generally supports a process called “what you see is what you get” (WYSIWYG). Connecting this design process to 3D printing realizes the translation of the virtual model to a physical object, making it truly WYSIWYG.

In addition to using CAD or other modeling software it is possible to scan existing objects with a 3D scanner. The 3D scanner analyzes the object and collects data not only about its shape, but also the color(s) of the surface of the object. By scanning an object in one place and printing it in another one can provide virtual “teleportation”[2].

An amazing future for the 3D printing is waiting. For example imagine a world where people that need a body part can have a new one made that is a perfect fit. The costs of replacement mechanical parts will decrease enormously and there will be a thriving business in making custom objects. While one can get an idea of this future in fiction, such as Daniel Suarez's novels[3–5], one can also see the development of a market in models in communities such as MakerBot's Thingiverse<sup>®</sup>[1].

## 1.1 Problem definition

The problem being addressed in this Bachelor's thesis project is 3D printing as a network service. The idea is to enable users to submit designs in STL format to a service that will print the design on a 3D printer. This service could be realized in many ways, for example the service might print the object and mail the finished object to the user (a form of “overnight printing”), the service might be used to print objects for later physical pick up (for example a number of designers could submit their designs and when they came to work the next day the objects would have been printed), the service might be used to distribute parts of the object to be made to a number of printers in a neighborhood to allow rapid construction of a group project (in the spirit of the electronic gun described in [3]), etc.

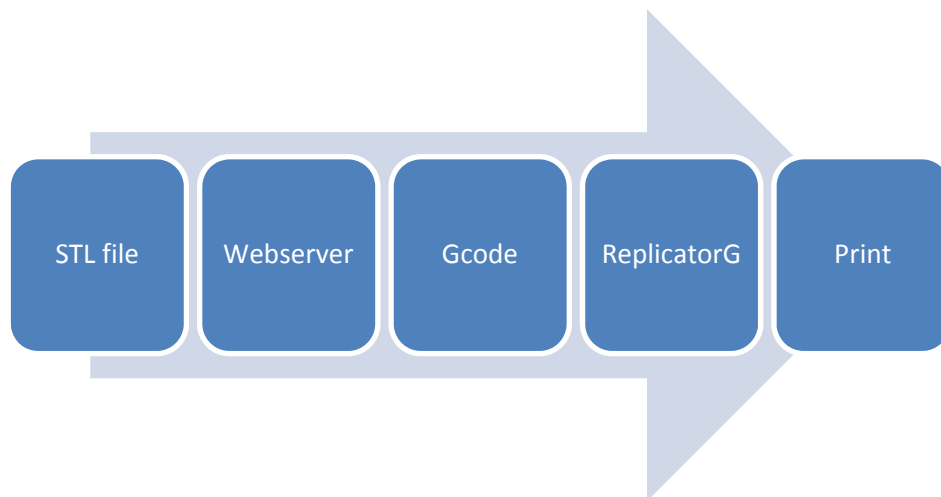


## 1.2 Goal

The goal of this project is to develop a service for people and companies to which they could send a STL file of their desired object. After receiving this file the service would send a verification e-mail to the customer with the approximate time when the final object will be ready to be shipped to them or the e-mail could provide the user with a URL which they could use to access the status of their object's production (perhaps even enabling the customer to see a web camera feed during the production of the object). If there are many files in the queue for printing it is obvious that it will take longer for the customer to get their object. As an added service one might imagine prioritizing production of some objects in the queue – of course in a commercial setting it might cost the customer more to get a higher priority.

All the files that are received will first be stored by the service, and then each file will be converted into a file in the appropriate format to control the 3D printer. In the case of the MakerBot Thing-o-Matic 3D printer that is being used for this thesis project, this format is called gcode and the program that controls the 3D printer is called ReplicatorG™. When it is time to make a given object the gcode for this object is transferred either directly to the 3D printer or to an internal SD memory card in the printer. Further details of the printer that we have used will be given in Section 2.2.

The overall system architecture is shown in Figure 1-1.



**Figure 1-1: System flow diagram**

## 1.3 Limitations

In this thesis the 3D printer being used is a MakerBot Industries LLC Thing-O-Matic, therefore the objects being printed are made of plastic. Additionally, the volume of the largest object that can be made when using the automated build platform is 10 cm x 10 cm x 10 cm, hence the objects being printed cannot exceed these dimensions.

A number of extensions that could potentially be added to the service were not possible because of the limited time available for this thesis project.

## **1.4 Structure of the thesis**

This first chapter introduced the concept of a 3D printer and the proposed network service. It also stated the goals that we wished to achieve and described some of the limitations of this thesis project.

The second chapter starts with some background, and continues by describing the different operations and manufacturing functions that can be performed with these 3D printers. A detailed description of the MakerBot Industries Thing-o-Matic printer is included, as this is the specific 3D printer that has been used in this project. At the end of the chapter the different tools used during the project are described.

A method description is presented in the third chapter. This is followed by a chapter containing an evaluation of our prototype service. Finally, the thesis concludes with some conclusions and future work. This final chapter also puts the thesis into a broader social and economic context.



## 2 Background

This chapter provides background information that will help the reader to understand the following chapters in this thesis. The chapter begins by describing what a 3D printer is in general, and then describes the particular printer that we will be using. Following this is an introduction to the Apache web server followed by a short introduction to PHP – as we have used PHP to develop the form that the user will fill in to order the object that they have designed. This is followed by a more in depth description of the gcode used by the specific 3D printer that we have used. Finally, the chapter concludes with a description of the ReplicatorG™ program that is used to control the 3D printer.

### 2.1 3D Printer operations

Additive manufacturing (AM) is often referred to as 3D printing. The primary advantage of additive fabrication is its ability to create almost any shape or geometric feature from scratch. The models are typically built layer by layer. The means of producing a given layer include extruding plastic (as used in this thesis project); sintering metal or ceramic material; laser induced cross-linking of a polymer; etc. Each layer must be fabricated with the desired precision and accuracy in order to realize the final object with the desired precision and accuracy. An error in one layer can potentially affect all subsequent layers.

As described above there are lots of different methods of additive manufacturing. The difference in technologies enables the use of different materials. The wide choice of materials and processing methods enable people and companies to optimize their choice of printer to meet their requirements. Additionally, there are a wide variety of printers in different price ranges – ranging from a few hundred U.S. dollars to hundreds of thousands of dollars.

These simple in order to more complex kind of printers are on the market available for people to have at home as a hobby, but still they are capable of producing complex items.

### 2.2 MakerBot Thing-o-Matic

The MakerBot Thing-o-Matic is a 3D printer that comes in the form of a kit. As a result this 3D printer does not cost too much. The assembled device is shown in Figure 2-1. Additionally, it uses a readily available material: plastic welding rod. This plastic thread is pushed into a heated head that has a small round opening (in our printer this hole is 0.3 mm in size). Pushing additional plastic thread into the heated head pushes out molten material through the extruder's head. This extruded plastic is used to form the object layer by layer. The head is heated to the appropriate temperature for extruding the specific plastic to be used, and when the extruded material cools it hardens to a solid form.

In order for the printer to know exactly when to extrude the plastic and how fast it should extrude the plastic a program is used to control the printer. The MakerBot Thing-o-Matic is controlled by the ReplicatorG software and the Thing-o-Matic is controlled by a local microcontroller that interprets the gcode commands that it is set. This software moves the extruder head forward and backward and left to right with respect to a build platform, so that a layer can be created. Additionally, the head can be moved up and down, so that once a layer has been laid out the head is moved up and another layer is extruded.

The main parts of MakerBot Thing-o-Matic 3D printer are:

- Motherboard with microcontroller (v2.4) (firmware motherboard v2.81)
- Extruder controller v3.6 (firmware v2.92)
- Tool head (MK6), and
- Automated Build platform.

Each of these parts will be described in a subsection below.

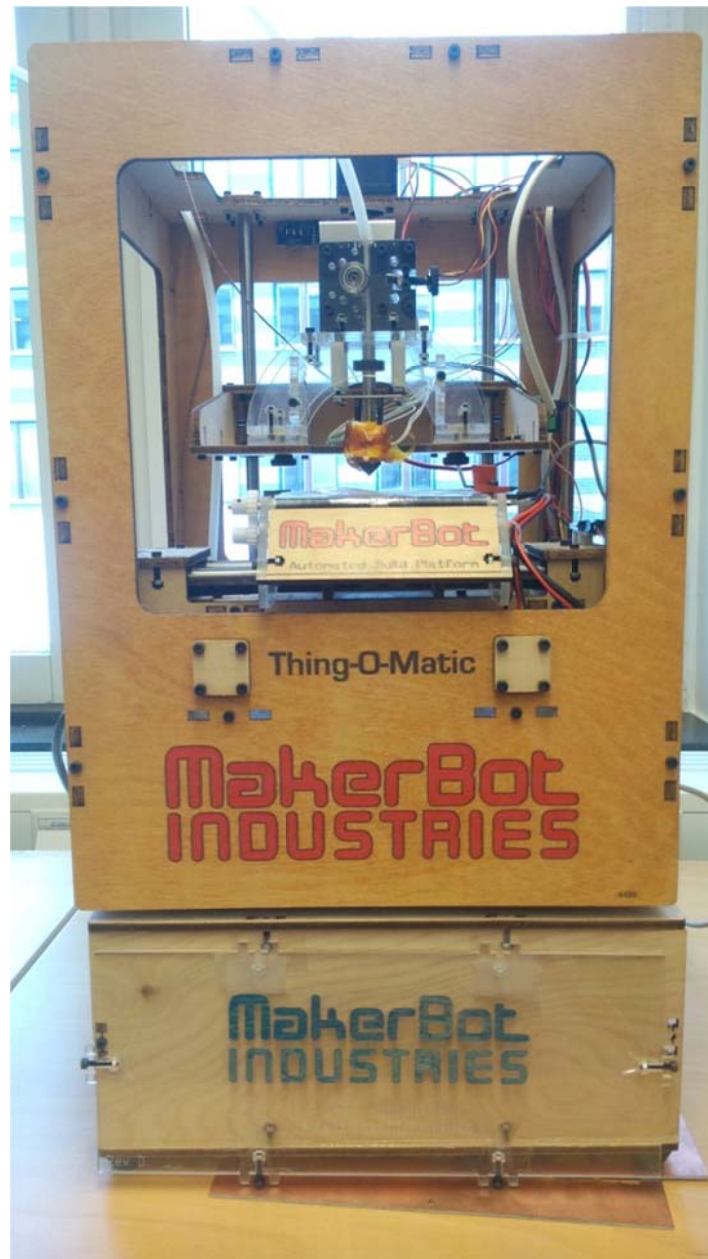


Figure 2-1: The Thing-O-Matic printer

## 2.2.1 Motherboard (v2.4)

The MakerBot Motherboard v2.4[6] is connect to a microcontroller (Arduino MEGA[7]). The microcontroller executes a gcode interpreter. The microcontroller either receives data directly from a computer via a Universal Serial Bus (USB) port or reads the gcode file from a Secure Digital Card (SD-card). The commands required to render the 3D model are sent from the motherboard to the X,Y, and Z axis stepper motor controllers (Stepper Driver v3.3[8]) via ribbon cables and to the extruder controller via a RS-485 serial connection. The motherboard sends commands to the stepper motor controller boards, which each generate the appropriate high current pulses to operate the stepper motors.

The firmware loaded into the motherboard was v2.81. New firmware can be downloaded to the motherboard via the USB interface and a special bootloader that has been flashed into the microcontroller.

The stepper motors enable the tool head to move relative to the build platform in three dimensions (x,y,z). The x stepper motor controller moves the platform from side-to-side, and the y stepper motor controller moves the platform forward and backwards. The z stepper motor controller moves the (MK6) tool head vertically.

The motors used in the x-and y-directions can move as little as 0.02 millimeters and the motor used in the z-step 0.005 millimeters [7], the resulting interaction between the movements of the automated build platform and the extruded plastic results in a very detailed three dimensional object.

## 2.2.2 Extruder controller (v3.6)

The extruder controller[9] is a board containing electronics that drives the extruder and the automated build platform. This board is also connected to a thermocouple that is used to monitor the temperature of the extruder head. This board has a number of Metal Oxide Semiconductor Field Effect Transistors (MOSFET) to power the heater of the extruder tool head and to power the heater of the automated build platform.

The firmware in the extruder controller was v2.92. New firmware can be downloaded to the motherboard via a separate USB interface using a special bootloader that has been flashed into the microcontroller on the extruder controller.

### 2.2.3 Tool head (MK6)

The tool head MK6 [10] feeds plastic thread into a heated chamber using a stepper motor. The chamber is heated to a specific temperature to melt the plastic. Forcing more thread into the heated chamber causes molten plastic to be pushed through the extruder's nozzle in a narrow flow. The MK6 extruder with a 0.3 mm nozzle can be used to create layers that are 0.3 mm thick. The MK6 extruder is shown in Figure 2-2.

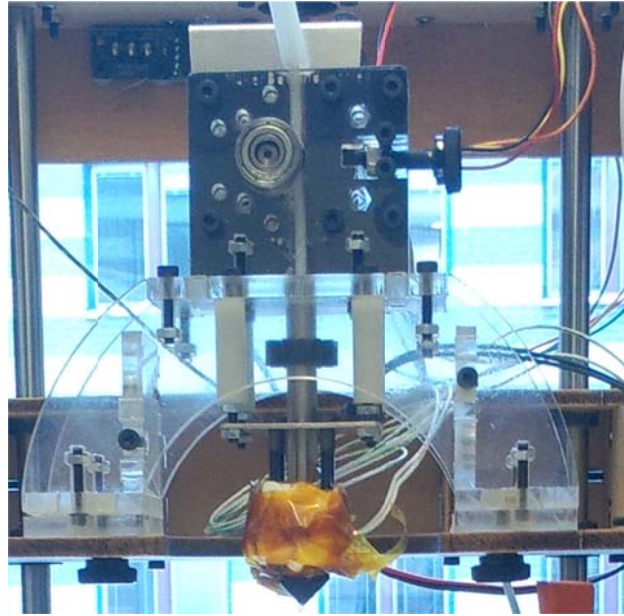


Figure 2-2: MK6 Extruder

## 2.2.4 Automated build platform

The automated build platform is a heated platform equipped with a conveyor belt (see Figure 2-3). This conveyor belt makes it possible to automatically print products, one after another. The build volume is 10 cm x 10 cm x 10 cm[11]. When an item is done the conveyor belt is advanced to eject the object off the platform making place for the new object that is going to be printed. In this project this processing continues until all objects in the queue are printed.



Figure 2-3: Automated Build Platform

## 2.3 Web server

The main customer interaction with the system is via a website that we have constructed. In order to request that we print a 3D object the user fills in an order form via their web browser and uploads their design in STL format. All of the communications between the user's browser and our web server utilize the HTTP protocol. In order to ensure the privacy of this communications, the HTTP traffic should be sent over the transport layer security (TLS) protocol which runs on top of the transport control protocol (TCP). A production version of this service should utilize a public key signed by a well-known certificate authority. For testing purposes we have not used TLS, but as future work tests should be made with a self-signed certificate which could manually be loaded into the client.

### 2.3.1 Web server

The website that we have created needs a web server to run on. Such a web server includes both the hardware (computers/data center) and software (the computer applications) necessary to deliverer the web pages to the user and to take the data entered by the user and insert it into a database and to take the STL files uploaded by the user and pass these file on to



the scripts that we have written. These scripts convert the STL file into the commands necessary to control the 3D printer. These scripts also deal with entering the user's order into a queue and process the queued requests.

The hardware that we have used is a Dell OptiPlex™ 755 computer that is connected to the laboratory's local area network. This computer is also connected to the MakerBot Thing-o-matic printer via a USB interface, although another computer on the same local area network could easily have been used to control the 3D printer.

The software used to realize our network service is described in detail in the following subsections. The computer that was connected to the 3D printer was running Linux, specifically openSUSE 12.1[12], therefore we have utilized this operating system as the base for our software development and execution environment. Further details about the operating system can be found at <http://www.opensuse.org/>.

### 2.3.2 LAMP

A web server often utilizes several different pieces of software which work together. The Apache web server often operates together with MySQL and PHP, Perl, or Python. This combination of software products is called AMP (Apache, MySQL, and PHP/Perl/Python). Nowadays, there are a number of AMP solution stacks for all major operating systems(OSs): WAMP for Microsoft's Windows, LAMP for Linux, MAMP for Macintosh, SAMP for Solaris and FAMP for FreeBSD.

LAMP is used to build a web server to operate a dynamic web site. The web server does not need to be connected to an external server to run PHP scripts, as it can run these scripts locally. LAMP is an acronym for the following software:

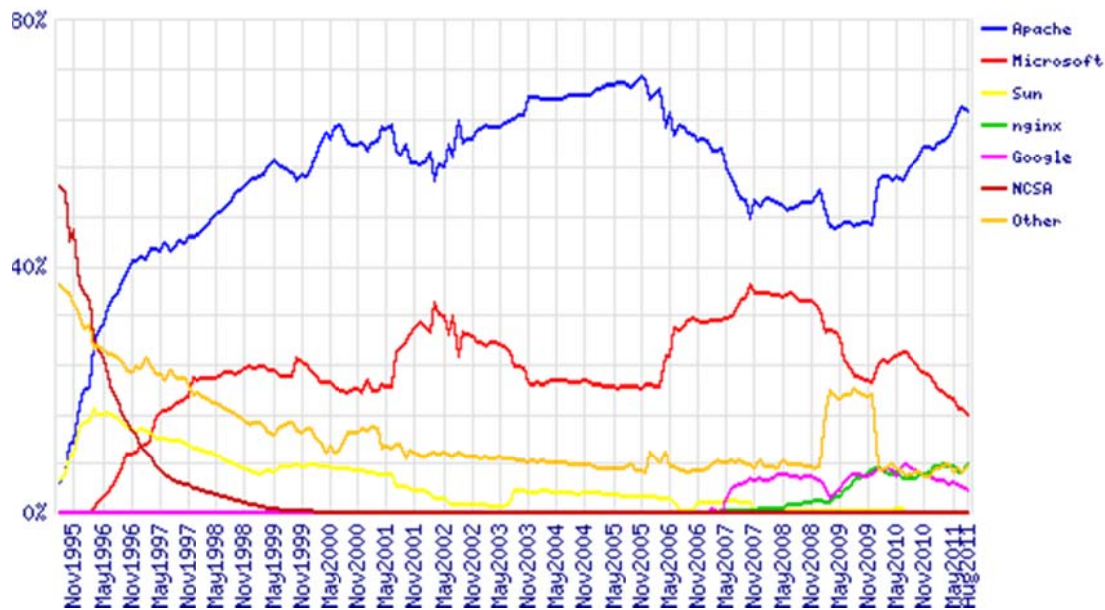
- Linux is the operating system of the computer where the server is installed.
- Apache is an open source web server.
- MySQL is a database management system.
- PHP communicates with MySQL in order to produce dynamic web pages and to save the orders that the customers have entered via a web page.

### 2.3.3 Apache

The Apache HTTP server is common called simply Apache. This is free web server software that is developed and maintained by Apache Software Foundation[13]. This web server software can be freely downloaded from <http://httpd.apache.org/>. Apache is one of the most popular web server with around 58% of the web server market in 2012[14]. Table 2-1 shows the top 4 web server pages as of September 2012 in terms of the number of web servers and the packages market share. Figure 2-4 shows the market share of the top web server packages over the period from November 1995 to September 2012[14]. Initially, this software ran only on Unix OSs, but now it can run on many different OSs such as Microsoft's Windows.

**Table 2-1: Market share for top web September 2012 (data taken from [14])**

Developer	September 2012	Percent
Apache	362,714,083	58.49%
Microsoft	97,368,803	15.70%
nginx	73,976,009	11.93%
Google	21,576,233	3.48%



**Figure 2-4: Market share for Top Servers across all domains August 1995 - September 2012 [14]**

The great advantage of Apache is that it can support many different modules. These modules give the web server extra functionality. For example, one of these modules can be used to enable secure communication between the web browser and web server by using certificates and TLS.

There are many interfaces languages that are supported by Apache, such as PHP, Perl, Python, Ruby, and Tcl. This enables developers to easily add new functionality.

Another great advantage of this web server software is its ability to act as Virtual Host[20]. The Virtual Host functionality allows a single web server to host different web sites while using a single IP address[15]. This avoids wasting IP addresses. This has become increasingly important as IPv4 addresses have become harder to get. In Europe IP addresses are distributed by RIPE. RIPE officially exhausted its /8 pool of addresses as of 14-Sep-2012 [16]. The different web sites are differentiated by their name. Virtual hosting was made possible due to the introduction of HTTP/1.1[17].

Apache server receives the GET URL request sent by the client through their web browser. Based upon this request Apache run a PHP program which sends back a HTML web page to the client web browser. The details of this processing are described in the next chapter.

### 2.3.4 MySQL

As mentioned above, MySQL is a database management system which stores and organizes data. MySQL is an implementation of the Structure Query Language (SQL), a programming language used to manage data in a database. MySQL is freely available under the GNU General Public License for non-commercial use, but a license fee must be paid for commercial use. Hence if a commercial service were to utilize the 3D printing service developed in this thesis project, the company would need to license MySQL.

MySQL has become one of the most popular database management due to fact that is free software and because it is available for many different OS platforms, such as Microsoft's Windows (95, 98, NT, 2000, XP, Vista,7, and 8), Linux, Mac OS X, AIX, BSDi, FreeBSD,

HP-UX, eComStation, i5/OS, IRIX, NetBSD, Novell NetWare, OpenBSD, OpenSolaris, OS/2Warp, QNX, Solaris, Symbian, SunOS, SCO OpenServer, SCO UnixWare, Sanos, and Tru64. MySQL is also popular since the database is accessible from many different programming languages, including C, C++, Delphi/Kylix, Eiffel, Java, Perl, PHP, Python, and Tcl.

MySQL is a powerful database management since the developer can easily configure a MySQL server and add additional functions according to their needs. MySQL offers good performance and popular websites can use it to respond to up to one billion requests per minute[21]. Another fundamental feature of MySQL is security. Secure Sockets Layer (SSL) and Secure Shell(SSH) protocols are used to ensure safe and secure connections between the database server and client. The encryption and decryption of data ensures the security of data against unauthorized access.

## 2.4 PHP

Hypertext Preprocessor (PHP) is a free scripting language. This language can be easily used by a HTTP server, such as Apache. PHP is also a server-side programming language which is often used to build websites with dynamic web pages.

In 1994, RasmusLerdorf, a Danish programmer who was involved in development of Apache, created the PHP language for his own website. Since it worked well he decided to publish PHP as an open source language. The language was an immediate success and the growth of users grows by millions each year as shown by the growth curve, found on the PHP project's official home page. A version of this graph is shown in Figure 2-5.

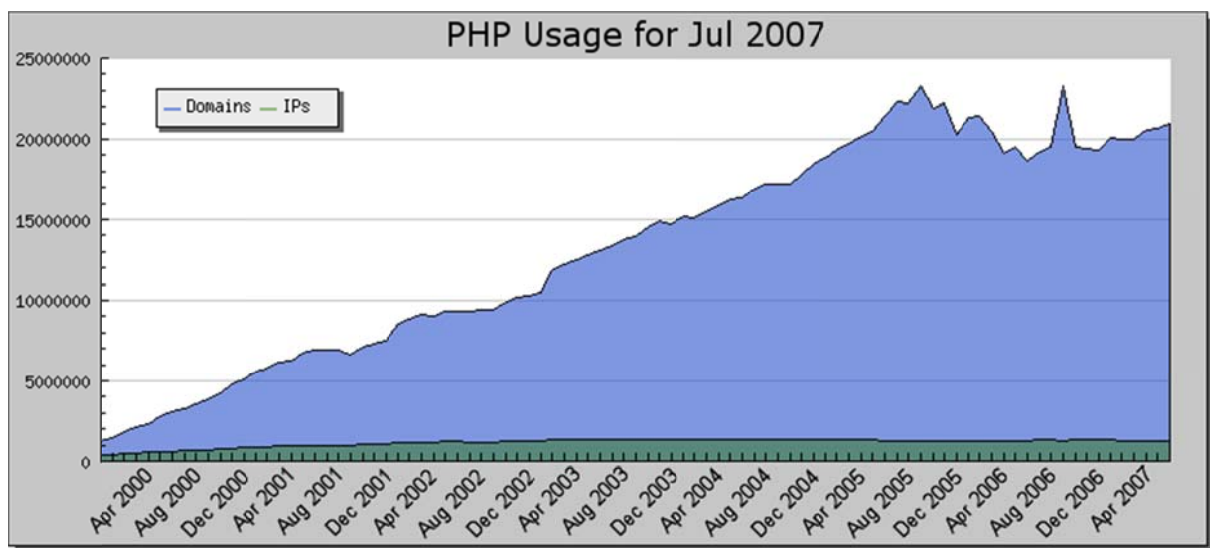
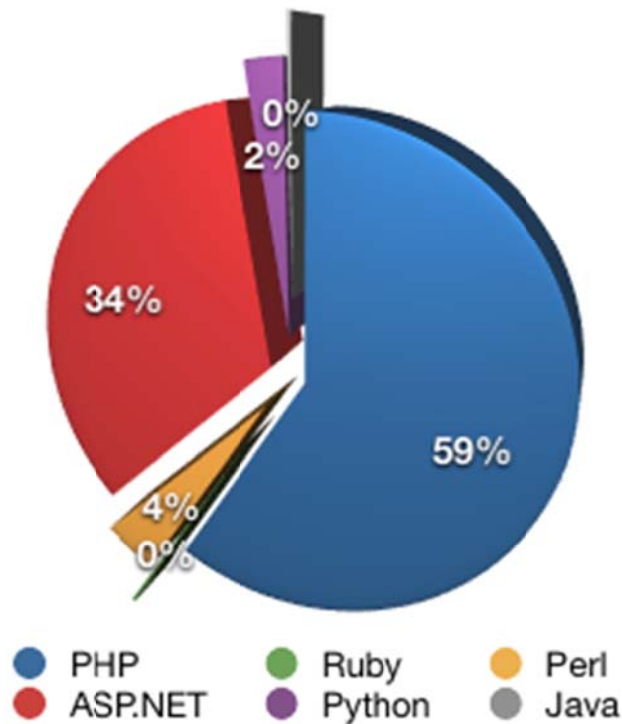


Figure 2-5: Growth of number of PHP users by domain and IP address[15]

PHP is available for different web servers, particularly for the most popular servers: Apache HTTP Server, Microsoft Internet Information Server and Netscape Enterprise Server. PHP runs on both UNIX and Microsoft's Windows OSs. The popularity of using PHP with web servers is shown in Figure 2-6.

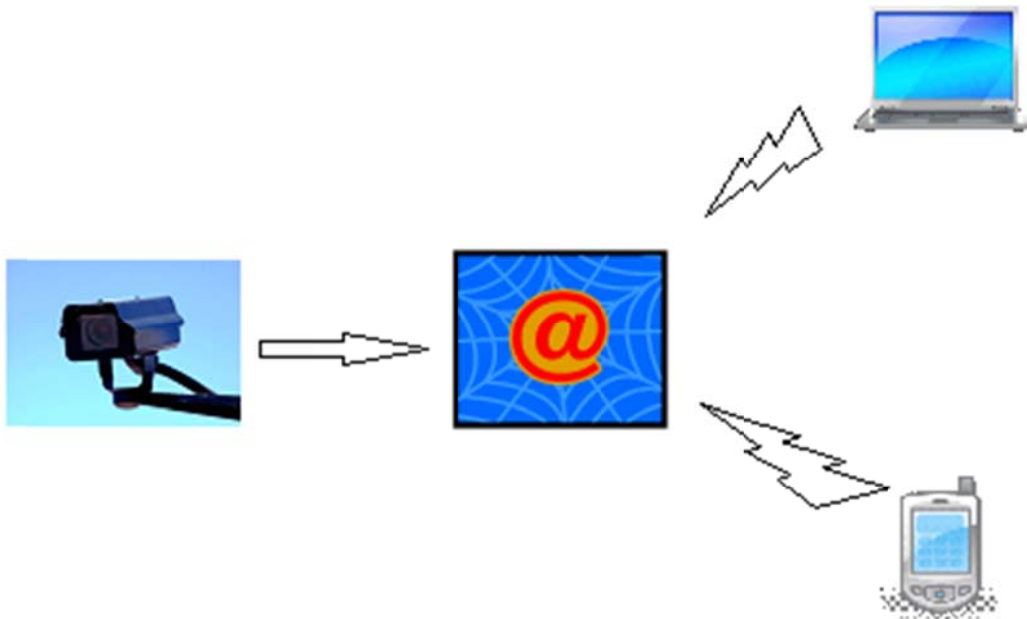


**Figure 2-6: Number of PHP users by domain and IP address November 2010 [22]**

PHP is embedded in HTML. The PHP code is delimited with “<?php” at the beginning and “?>” at the end. The PHP interpreter executes only the code within these delimiters. The advantage of embedding the PHP code in this way is that the same PHP code can be embedded in the different languages, such as XML, as long as it is within the delimiters. Similar to other scripting languages, PHP does not need a compiler.

## 2.5 Internet Protocol camera

An internet protocol camera, commonly called an IP camera, is a digital video camera used to send images via an internet or LAN. Unlike a web camera, IP cameras are not connected to a computer, but rather they are directly connected to the internet or LAN. This enables the camera to stream live video via IP packets. Once an IP camera is connected to the internet, video streams can be accessed remotely by a web browser or software developed for this data stream. An IP camera can have a fixed IP address or use a dynamic DNS service to enable clients to learn its current address. A single IP camera can stream data to different clients at the same time as shown in Figure 2-7.



**Figure 2-7: Network attached camera streaming data to multiple clients**

In our project we have used an Axis Communications model Axis NetEye 200 camera. In our configuration we have connected this camera via a second ethernet interface to the same computer that is acting as our web server and that controls the 3D printer. In this way we can proxy the stream from the camera to deliver video only to the customer whose part is being printed.

## 2.6 Crontab

Crontab is a text file which contains the different commands that will be run. Cron is the name of a linux daemon that enables users to execute tasks automatically at specified times or dates. This task scheduler executes these commands in the background. Each command specifies the actions and times when it will be executed. Cron is started only once and stays dormant until it is time to run the next task. To schedule tasks the system administrator simply edits the Crontab. Note that in this project we have edited the system crontab (i.e., /etc/crontab) rather than using a user crontab, as our assumption is that this system is being used just to support our 3D printing service.

## 2.7 STL

The STereoLithography (STL) format was developed by 3D Systems. An example of an ASCII STL describing a 20mm calibration box is shown below. This file was converted from binary to ASCII using Meshlab[18].

```
solid vcg
  facet normal 0.000000e+000 0.000000e+000 -1.000000e+000
    outer loop
      vertex 9.999995e+000 9.999994e+000 0.000000e+000
      vertex 9.999995e+000 -9.999995e+000 0.000000e+000
      vertex -9.999996e+000 -9.999993e+000 0.000000e+000
    endloop
  endfacet
  facet normal 0.000000e+000 0.000000e+000 -1.000000e+000
    outer loop
      vertex 9.999995e+000 9.999994e+000 0.000000e+000
```

```

    vertex -9.999996e+000 -9.999993e+000 0.000000e+000
    vertex -9.999991e+000 9.999999e+000 0.000000e+000
  endloop
endfacet
facet normal 0.000000e+000 0.000000e+000 1.000000e+000
  outer loop
    vertex 1.000000e+001 9.999990e+000 1.000000e+001
    vertex -9.999994e+000 9.999995e+000 1.000000e+001
    vertex -9.999999e+000 -9.999991e+000 1.000000e+001
  endloop
endfacet
facet normal 0.000000e+000 0.000000e+000 1.000000e+000
  outer loop
    vertex 1.000000e+001 9.999990e+000 1.000000e+001
    vertex -9.999999e+000 -9.999991e+000 1.000000e+001
    vertex 9.999989e+000 -1.000000e+001 1.000000e+001
  endloop
endfacet
facet normal 1.000000e+000 -5.722048e-007 -4.768374e-007
  outer loop
    vertex 9.999995e+000 9.999994e+000 0.000000e+000
    vertex 1.000000e+001 9.999990e+000 1.000000e+001
    vertex 9.999989e+000 -1.000000e+001 1.000000e+001
  endloop
endfacet
facet normal 1.000000e+000 0.000000e+000 6.675720e-007
  outer loop
    vertex 9.999995e+000 9.999994e+000 0.000000e+000
    vertex 9.999989e+000 -1.000000e+001 1.000000e+001
    vertex 9.999995e+000 -9.999995e+000 0.000000e+000
  endloop
endfacet
facet normal -4.768374e-007 -1.000000e+000 -5.722049e-007
  outer loop
    vertex 9.999995e+000 -9.999995e+000 0.000000e+000
    vertex 9.999989e+000 -1.000000e+001 1.000000e+001
    vertex -9.999999e+000 -9.999991e+000 1.000000e+001
  endloop
endfacet
facet normal -9.536748e-008 -1.000000e+000 1.907348e-007
  outer loop
    vertex 9.999995e+000 -9.999995e+000 0.000000e+000
    vertex -9.999999e+000 -9.999991e+000 1.000000e+001
    vertex -9.999996e+000 -9.999993e+000 0.000000e+000
  endloop
endfacet
facet normal -1.000000e+000 2.384187e-007 -2.861023e-007
  outer loop
    vertex -9.999996e+000 -9.999993e+000 0.000000e+000
    vertex -9.999999e+000 -9.999991e+000 1.000000e+001
    vertex -9.999994e+000 9.999995e+000 1.000000e+001
  endloop
endfacet
facet normal -1.000000e+000 2.384187e-007 -2.861022e-007
  outer loop
    vertex -9.999996e+000 -9.999993e+000 0.000000e+000
    vertex -9.999994e+000 9.999995e+000 1.000000e+001
    vertex -9.999991e+000 9.999999e+000 0.000000e+000
  endloop
endfacet
facet normal 2.384187e-007 1.000000e+000 4.768370e-007
  outer loop
    vertex 1.000000e+001 9.999990e+000 1.000000e+001

```

```

        vertex 9.999995e+000 9.999994e+000 0.000000e+000
        vertex -9.999991e+000 9.999999e+000 0.000000e+000
    endloop
endfacet
facet normal 2.861024e-007 1.000000e+000 3.814698e-007
    outer loop
        vertex 1.000000e+001 9.999990e+000 1.000000e+001
        vertex -9.999991e+000 9.999999e+000 0.000000e+000
        vertex -9.999994e+000 9.999995e+000 1.000000e+001
    endloop
endfacet
endsolid vcg

```

## 2.8 Gcode

Gcode or as it often is called the G programming language, is used to control the 3D printer. The gcode not only tells the machine how to move, but also how fast it will move to different areas. The printer needs commands of what to do for each layer. For a complex object it takes long time to convert a STL file to gcode.

The conversion of an STL file to gcode is done by a program called Skeinforge. Skeinforge is written in Python, a high level programming language. Skeinforge converts the STL file into fabricator commands. In this conversion a STL file is translated into a gcode file (in our processing a file with the name “name.STL” is output in gcode to a file named ”name\_export.gcode”). After the gcode file has been generated it is time for the next step, in this step ReplicatorG controls the MakerBot to produce the object that has been designed.

Part of the gcode for the 20mm cablibration box shown in the previous section is shown below in three parts. Part 1 is the initial code that sets up the machine, warms up the automated build platform and wipes off the extruder nozzle. Part 2 consists of the gcode to make the box. Part 3 is the end gcode to allow the build platform to cool down, eject the object that has been made, etc. Parts 1 and 3 will be the same code for each individual object that is made with the Thing-o-Matic equipped with an automated build platform and a MK6 extruder.

The gcodes supported by ReplicatorG are described in section 2.9.

### 2.8.1 Part 1 of gcode: start gcode

```

(<alteration>)
(**** beginning of start.gcode ****)
(This file is for a MakerBot Thing-O-Matic)
(**** begin initialization commands ****)
G21 (set units to mm)
G90 (set positioning to absolute)
M108 R1.98 (set extruder speed)
M103 (Make sure extruder is off)
M104 S225 T0 (set extruder temperature)
M109 S125 T0 (set heated-build-platform temperature)
(**** end initialization commands ****)
(**** begin homing ****)
G162 Z F500 (home Z axis maximum)
G92 Z10 (set Z to 0)
G1 Z0.0 (move z down 10)
G162 Z F100 (home Z axis maximum)
G161 X Y F2500 (home XY axes minimum)
M132 X Y Z A B (Recall stored home offsets for XYZAB axis)
(**** end homing ****)
(**** begin pre-wipe commands ****)
G1 X52.0 Y-57.0 Z10.0 F3300.0 (move to waiting position)

```

```

M6 T0 (wait for toolhead parts, nozzle, HBP, etc., to reach
temperature)
M101 (Extruder on, forward)
G04 P5000 (Wait t/1000 seconds)
M103 (Extruder off)
(**** end pre-wipe commands ****)
(**** end of start.gcode ****)
(</alteration>)

```

## 2.8.2 Part 2 of gcode: the object a rendered by Skeinforge

Only part of the object is shown here, the complete gcode for this object is shown in Appendix D.

```

(<creation> skeinforge </creation>)
(<version> 10.11.05 </version>)
(<extruderInitialization>)
(<craftTypeName> extrusion </craftTypeName>)
M105
(<bridgeWidthMultiplier> 1.0 </bridgeWidthMultiplier>)
(<decimalPlacesCarried> 3 </decimalPlacesCarried>)
(<layerThickness> 0.36 </layerThickness>)
(<threadSequenceString> loops perimeter infill
</threadSequenceString>)
(<operatingFeedRatePerSecond> 30.0 </operatingFeedRatePerSecond>)
(<operatingFlowRate> 1.577 </operatingFlowRate>)
(<orbitalFeedRatePerSecond> 15.0 </orbitalFeedRatePerSecond>)
(<travelFeedRatePerSecond> 40.0 </travelFeedRatePerSecond>)
(<perimeterWidth> 0.545 </perimeterWidth>)
(<profileName> ABS </profileName>)
(<procedureDone> carve,bottom</procedureDone>)
(<procedureDone> preface </procedureDone>)
(<procedureDone> inset </procedureDone>)
(<procedureDone> fill </procedureDone>)
(<procedureDone> speed </procedureDone>)
(<procedureDone> raft </procedureDone>)
(<procedureDone> comb </procedureDone>)
(<procedureDone> cool </procedureDone>)
(<procedureDone> outline </procedureDone>)
(<procedureDone> reversal </procedureDone>)
(<procedureDone> export </procedureDone>)
(</extruderInitialization>)
(<extrusion>)
;M113 S1.0
M108 R1.577
(<layer>0.48 )
(<surroundingLoop>)
(<boundaryPerimeter>)
(<boundaryPoint> X-10.0 Y-10.0 Z0.48 </boundaryPoint>)
(<boundaryPoint> X10.0 Y-10.0 Z0.48 </boundaryPoint>)
(<boundaryPoint> X10.0 Y10.0 Z0.48 </boundaryPoint>)
(<boundaryPoint> X-10.0 Y10.0 Z0.48 </boundaryPoint>)
(<loop>outer )
G1 X12.73 Y-12.73 Z0.48 F1080.0
M101
G1 X-12.73 Y-12.73 Z0.48 F1080.0
G1 X-12.73 Y12.73 Z0.48 F1080.0
G1 X12.73 Y12.73 Z0.48 F1080.0
G1 X12.73 Y-11.38 Z0.48 F1080.0
M108 R35.0

```



```

M102
G1 X12.73 Y-12.73 Z0.48 F1080.0
M108 R1.577
M103
G1 X2.25 Y-9.81 Z0.48 F1800.0
M108 R35.0
M101
G1 X0.0 Y-9.18 Z0.48 F1800.0
M108 R1.577
G1 X9.18 Y-9.18 Z0.48 F1350.0
G1 X9.18 Y9.18 Z0.48 F1350.0
G1 X-9.18 Y9.18 Z0.48 F1350.0
G1 X-9.18 Y-9.18 Z0.48 F1350.0
G1 X0.0 Y-9.18 Z0.48 F1350.0
M103
(</loop>)
(<perimeter>outer )
G1 X0.0 Y-9.73 Z0.48 F1440.0
M101
G1 X9.73 Y-9.73 Z0.48 F1080.0
G1 X9.73 Y9.73 Z0.48 F1080.0
G1 X-9.73 Y9.73 Z0.48 F1080.0
G1 X-9.73 Y-9.73 Z0.48 F1080.0
G1 X-1.35 Y-9.73 Z0.48 F1080.0
M108 R35.0
M102
G1 X0.0 Y-9.73 Z0.48 F1080.0
M108 R1.577
M103
(</perimeter>)
(</boundaryPerimeter>)
G1 X6.4 Y-9.07 Z0.48 F1800.0
M108 R35.0
M101
G1 X8.73 Y-8.83 Z0.48 F1800.0
M108 R1.577
G1 X8.73 Y8.83 Z0.48 F1350.0
G1 X8.18 Y8.83 Z0.48 F1350.0
G1 X8.18 Y-8.83 Z0.48 F1350.0
G1 X7.64 Y-8.83 Z0.48 F1350.0
...
G1 X-8.18 Y-8.83 Z0.48 F1350.0
G1 X-8.73 Y-8.83 Z0.48 F1350.0
G1 X-8.73 Y8.83 Z0.48 F1350.0
M103
(</surroundingLoop>)
(</layer>)
(<layer>0.84 )
(<surroundingLoop>)
(<boundaryPerimeter>)
(<boundaryPoint> X-10.0 Y-10.0 Z0.84 </boundaryPoint>)
(<boundaryPoint> X10.0 Y-10.0 Z0.84 </boundaryPoint>)
(<boundaryPoint> X10.0 Y10.0 Z0.84 </boundaryPoint>)
(<boundaryPoint> X-10.0 Y10.0 Z0.84 </boundaryPoint>)
(<loop>outer )
G1 X-8.73 Y9.18 Z0.84 F2400.0
M101
G1 X-9.18 Y9.18 Z0.84 F1800.0
G1 X-9.18 Y-9.18 Z0.84 F1800.0
G1 X9.18 Y-9.18 Z0.84 F1800.0
G1 X9.18 Y9.18 Z0.84 F1800.0
G1 X-8.73 Y9.18 Z0.84 F1800.0
M103

```

```

(</loop>)
(<perimeter>outer )
...
(</surroundingLoop>)
(</layer>)
(</extrusion>)
M104 S0
(<alteration>)

```

## 2.8.3 Part 3 of gcode: end gcode

```

(**** Beginning of end.gcode ****)
(This file is for a MakerBot Thing-O-Matic)
(*** begin settings ****)
M109 S95 T0 (set heated-build-platform temperature)
(**** end settings ****)
(**** begin move to cooling position ****)
G1 X0.0 F3300.0 (move to cooling position)
G1 X0.0 Y55.0 F3300.0 (move to cooling position)
(**** end move to cooling position ****)
(**** begin filament reversal ****)
M108 R1.98
M102 (Extruder on, reverse)
G04 P2000 (Wait t/1000 seconds)
M108 R1.98
M103 (Extruder off)
(**** end filament reversal ****)
M18 (Turn off steppers)
(**** begin eject ****)
M6 T0 (wait for toolhead parts (nozzle, HBP, etc) to reach
temperature)
M106 (conveyor on)
G04 P14000 (wait t/1000 seconds)
M107 (conveyor off)
(**** end eject ****)
(**** begin cool for safety ****)
M104 S225 T0 (set extruder temperature)
M109 S100 T0 (set heated-build-platform temperature)
(**** end cool for safety ****)
(**** end of end.gcode ****)
(</alteration>)
;M113 S0.0

```

## 2.9 ReplicatorG™

ReplicatorG is the software that drives the MakerBot Thing-o-Matic, it connects the computer to the 3D printer. This software can also drive other computer numerical control (CNC) machines. With ReplicatorG it is possible to position, scale and rotate the model. Also the temperature of the head and the build platform are controlled by ReplicatorG. A list of the gcodes supported by one version of ReplicatorG are shown in Table 2-2.

**Table 2-2: List of the gcodes supported in ReplicatorG 0038 Beta**

G0	Rapid Positioning
G1	Coordinated Motion
G2	Clockwise Arc
G3	Counter Clockwise Arc
G4	Dwell
G10	Create Coordinate System Offset from the Absolute one
G20	Use Inches as Units
G21	Use Milimeters as Units
G28	Home given axes to maximum
G53	Set absolute coordinate system
G54	Use coordinate system from G10 P0
G55	Use coordinate system from G10 P1
G56	Use coordinate system from G10 P2
G57	Use coordinate system from G10 P3
G58	Use coordinate system from G10 P4
G59	Use coordinate system from G10 P5
G70	Use Inches as Units
G71	Use Milimeters as Units
G90	Absolute Positioning
G91	Relative Positioning
G92	Define current position on axes
G97	Spindle speed rate
G130	Set given axes potentiometer Value
G161	Home given axes to minimum
G162	Home given axes to maximum
M0	Unconditional Halt, not supported on SD?
M1	Optional Halt, not supported on SD?
M2	End program
M3	Spindle On - Clockwise
M4	Spindle On - Counter Clockwise
M5	Spindle Off
M6	Wait for toolhead to come up to reach (or exceed) temperature
M7	Coolant A on (flood coolant)
M8	Coolant B on (mist coolant)
M9	All Coolant Off
M10	Close Clamp
M11	Open Clamp
M13	Spindle CW and Coolant A On
M14	Spindle CCW and Coolant A On
M17	Enable Motor(s)
M18	Disable Motor(s)
M21	Open Collet
M22	Close Collet
M30	Program Rewind
M40	Change Gear Ratio to 0
M41	Change Gear Ratio to 1

M42	Change Gear Ratio to 2
M43	Change Gear Ratio to 3
M44	Change Gear Ratio to 4
M45	Change Gear Ratio to 5
M46	Change Gear Ratio to 6
M50	Read Spindle Speed
M70	Display Message On Machine
M71	Display Message, Wait For User Button Press
M72	Play a Tone or Song
M73	Manual Set Build %
M101	Turn Extruder On, Forward
M102	Turn Extruder On, Reverse
M103	Turn Extruder Off
M104	Set Temperature
M105	Get Temperature
M106	Turn Automated Build Platform (or the Fan, on older models) On
M107	Turn Automated Build Platform (or the Fan, on older models) Off
M108	Set Extruder's Max Speed (R = RPM, P = PWM)
M109	Set Build Platform Temperature
M110	Set Build Chamber Temperature
M126	Valve Open
M127	Valve Close
M128	Get Position
M131	Store Current Position to EEPROM
M132	Load Current Position from EEPROM
M140	Set Build Platform Temperature
M141	Set Chamber Temperature (Ignored)
M142	Set Chamber Holding Pressure (Ignored)
M200	Reset driver
M300	Set Servo 1 Position
M301	Set Servo 2 Position
M310	Start data capture
M311	Stop data capture
M312	Log a note to the data capture store
T0	Set Current Tool 0
T1	Set Current Tool 1

The interface to ReplicatorG is shown in Figure 2-8, where the different icons in the green field are the main buttons. Temperature and model adjustments can also be made by editing the gcode.

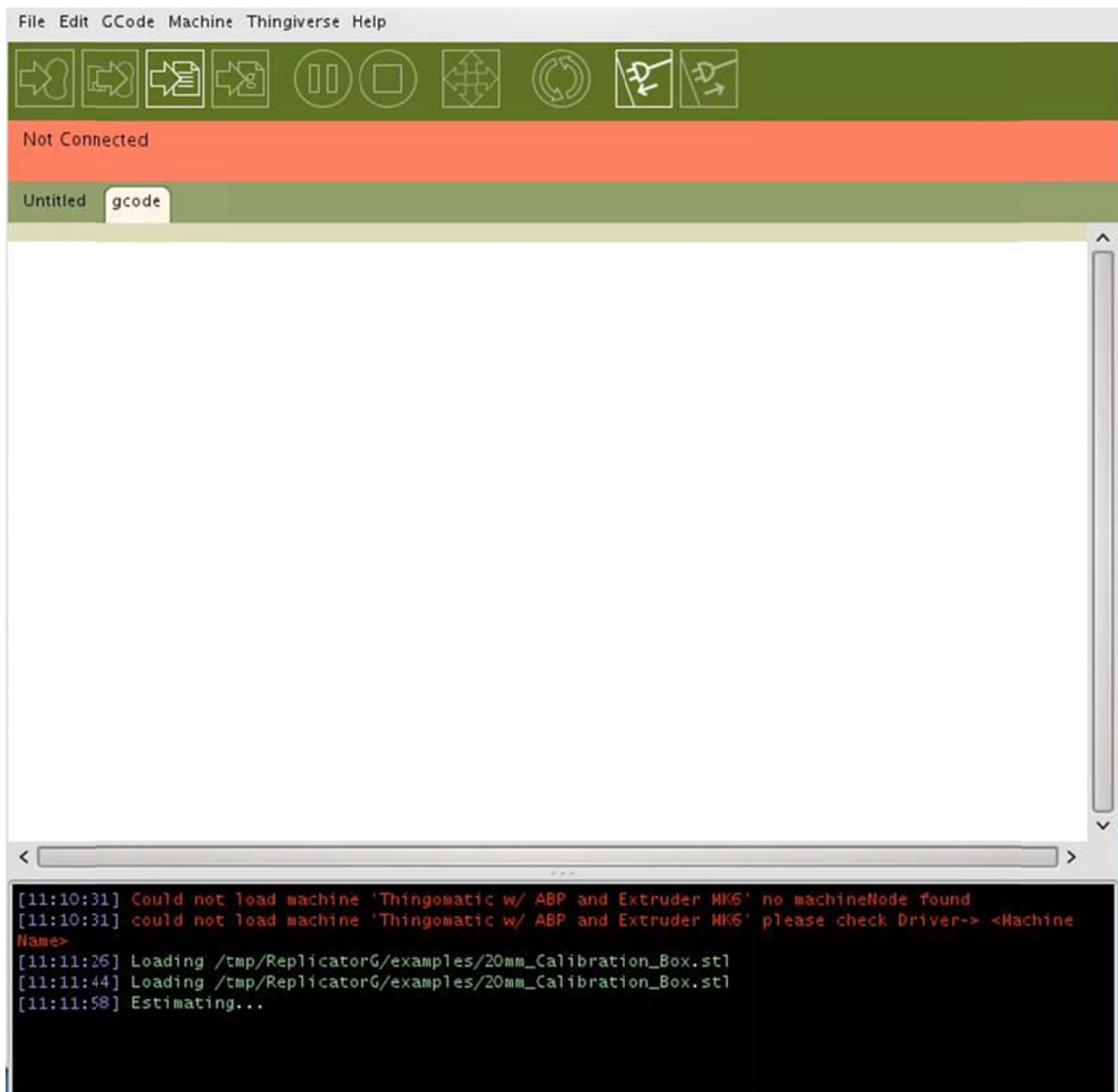


Figure 2-8: Basic ReplicatorG interface - when not connected to the 3D printer

## 3 Method

This chapter described both what we did and why we decided to do it. The chapter starts with a description of how and why we built a website to realize our network services. After this we describe the use of the IP camera and how we built Replicator from source code and how we used a subset of this code to control the printing of the objects submitted by customers. Finally the chapter ends with a description of how we optimized the system to support construction of a set of objects that are in the queue to be made.

### 3.1 Creation and implementation of the website

The first section of this chapter describes the installation of the different softwares needed during the creation of the website. The customer interface of the website is shown, and the associated code can be found in Appendix A. The last part explains the conversion of an STL file to gcode.

#### 3.1.1 Installation of LAMP

OpenSUSE was the operating system of the computer used in the project. Therefore a version of LAMP suitable for Opensuse was downloaded. The installation steps are described on the official website of Opensuse[19]. If the installation of Apache has been successfully, browse to 127.0.0.1 and the web browser of the computer should come up with a page as shown in Figure 3-1.

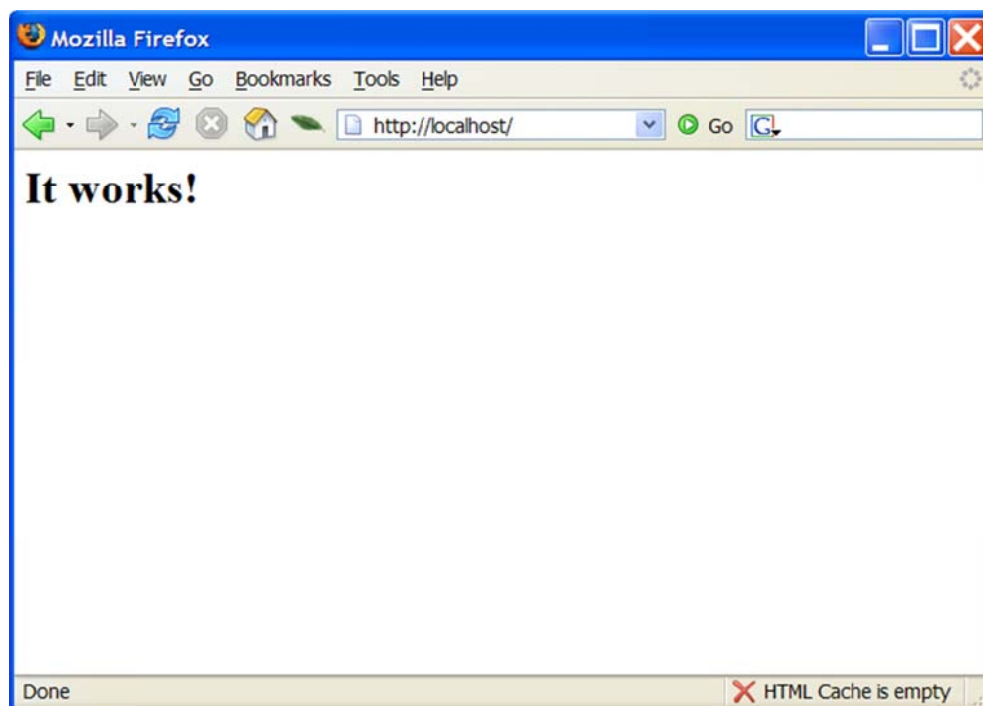


Figure 3-1: Successful installation of Apache server on OpenSuSE

The homepage of LAMP contains information about the installed version of LAMP and the different enabled modules. The homepage of LAMP is reached by browsing <http://localhost> in any web browser installed on the computer.

### 3.1.2 Customer interface

The website is the public part of the project. It has a simple and sober design (see Figure 3-2) where the clients has to register their name, company name and of course upload the STL file. The code which implements this web server and its interface is shown in Appendix A.

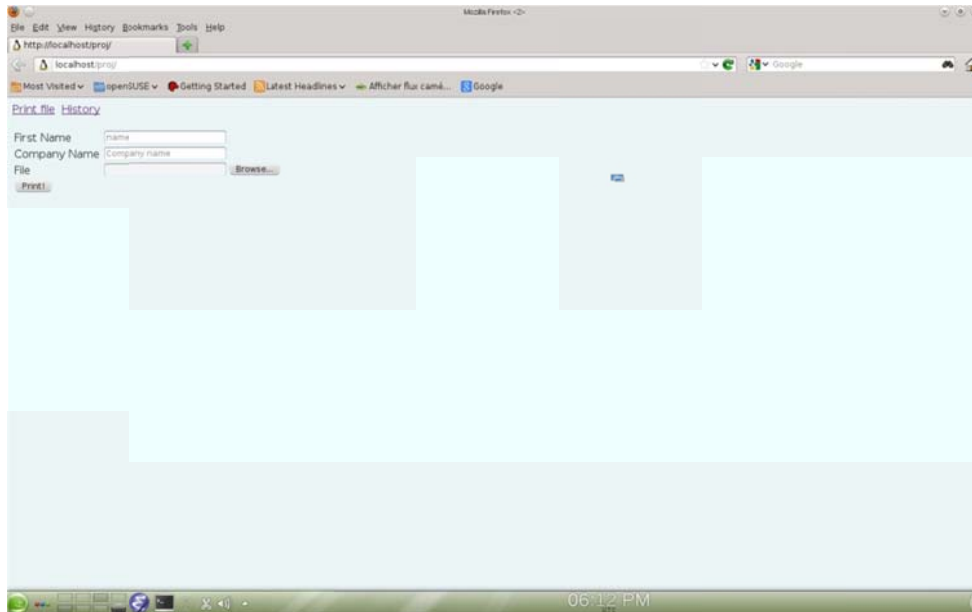


Figure 3-2: Website interface

### 3.1.3 Converting STL file to Gcode

The PHP program of the website changes the name of the STL file and save it in a map (directory). The new name will be the old name with the hour and date added to it. This means that the first file to be uploaded will be the first file to be printed.

Once the STL file is uploaded in a map, it will be automatically changed into Gcode and saved in another map. There are three steps to transform a STL file into Gcode:

1. Crontab will automatically run the file `runrunskeinforge.sh`. This file will move the STL file into another map, once the STL file has been transformed into Gcode. The other function of the `runrunskeinforge.sh` is to call another file `runskeinforge.sh`.
2. The file `runskeinforge.sh` is a script that the system uses to call `skeinforge.sh`.
3. The `skeinforge.sh` is the program which will convert the STL file into Gcode.

More information about the operation of Crontab can be found by entering “`man crontab`” into a shell console.

The `runskeinforge.sh` file and the code to automatically run `replicatorG` are shown in Appenices B and C.

## 3.2 Set up the camera

An AXIS NetEye 200 IP camera was installed and pointed to the printer. The camera streams video over the internet on a website that the manufacturer of the camera has built for this fact,thus the customers can watch the printing of their objects online.A detailed installation guide can be found on the official website of Axis.[23]

### 3.3 Building ReplicatorG

The first step is downloading the source code and to be able to edit the source code, the needed tools has to be installed. The tools are Git, a Java development kit(JDK) and Ant, a collection of all download links [24].

The software making it possible to keep track of the software revisions and allow a lot of developers to work on the project is Git. The java programs are compiled with the JDK. Ant is the program that controls the build.

The project was built with Eclipse, where the steps are explained on the website [25]. All the steps are explained in approved manner except the description of how to run ReplicatorG from Eclipse. The problem was figuring out the correct Virtual Machine(VM) argument since the one on the website was wrong, and would give an error as shown in Figure 3-3.

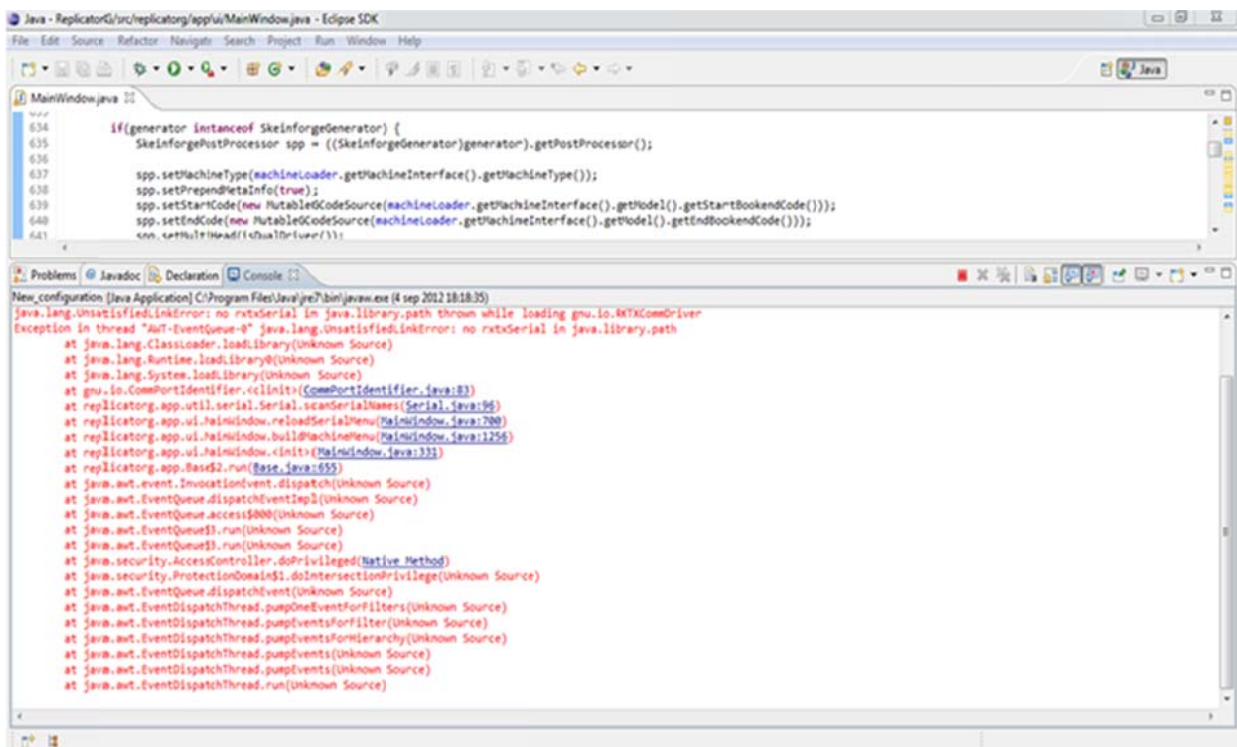


Figure 3-3: Error

“java.lang.UnsatisfiedLinkError: no rxtxSerial in java.library.path thrown while loading gnu.io.RXTXCommDriver etc”. The error occurs since according to the website the VM argument for Linux x86-64 systems should be “

```
-ea -  
Djava.library.path=${workspace loc:ReplicatorG}/build/linux/dist/lib  
-x86 64 -Dreplicatorg.app-  
resources=${workspace loc:ReplicatorG}/build/shared/lib -  
Djava.library.path=/usr/lib/jni”
```

The working VM argument:

```
-ea -  
Djava.library.path=${workspace loc:ReplicatorG}/build/linux/dist/lib  
-x86 64 :/home/mabdulla/ReplicatorG/build/linux/dist/lib-  
x86 64 :/home/mabdulla/ReplicatorG/build/shared/lib -  
Dreplicatorg.app-  
resources=${workspace loc:ReplicatorG}/build/shared/lib
```



Where the colon in Linux systems works as a separator, in this case it separates the two paths that were needed to be combined.

## 3.4 Optimizing the system

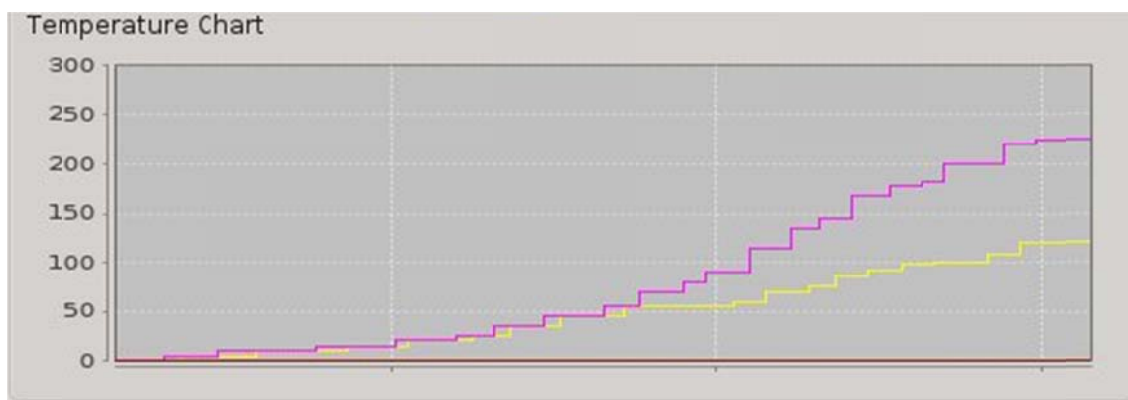
This section describes how we optimized our system to produce a series of objects that are in our queue. The key to this optimization is to reduce the idle time, i.e., the time during which the 3D printer is not actively printing. A secondary optimization is to avoid unnecessary movement of the tool head and to optimize the necessary movements.

### 3.4.1 Reducing idle time

While watching the machine printing a number of objects we noticed that after printing an object the gcode caused the printer for wait for some period of time before ejecting the part and that after ejecting the part that the gcode turned off the heating of the automated build platform and the heating of the extruder. In order to print another object we need to turn both heaters back on and wait for everything to come back up to their operating temperatures. From the start gcode we can see the two commands that turn on both headers:

```
M104 S225 T0 (set extruder temperature)
M109 S125 T0 (set heated-build-platform temperature)
```

Thus the extruder has to return to 225°C and the build platform has to return to 125°C. Based upon a series of measurements we found that the time to initially reach these temperatures from a room temperature of 24°C were 188 seconds for the extruder and 310 seconds for the build platform. A plot of the temperature of the build platform (yellow) and extruder (pink) as a function of time is shown in Figure 3-4.



**Figure 3-4: Temperature as a function of time**

From this curve we can note that by limiting how much we allow the platform to cool down between jobs we can decrease the idle time when we are not printing. To achieve this we modify the end gcode inserted after the object is made to limit the cooling – as shown below:

```
M104 S225 T0 (set extruder temperature)
M109 S100 T0 (set heated-build-platform temperature)
```

## 4 Evaluation

The performance of the system is dependent upon the time to perform each individual operation and the degree to which multiple operations can be done in parallel. This chapter describes our measurements of the time to do each process for a number of different examples (when there is a difference in time depending upon the object) and the overall time to submit an object when the queue is empty until it is finished. After this we describe the time to make a second object that is enqueued immediately after the first object.

The chapter ends with an analysis of the results of the optimizations that we have suggested.

### 4.1 Time to make the first object

The time required to make the first object can be decomposed into the following components:

1. Time to upload the object
2. Time to process the request for this object
3. Time to convert the object from STL to gcode
4. Time to transfer the object to the 3D printer
5. Time for the 3D printer to warm up
6. Time to print the object on the 3D printer
7. Time to cool off and eject the object from the 3D printer

### 4.2 Time to make the second object

If a second object is placed in the queue immediately after the first, then we can be converting this object to gcode while printing the previous object. If it takes less time to do this conversion than it takes to print the previous object – then we are able to completely parallelize this conversion – hence removing this processing time from the overall delay since the delay will be dominated by the printing time of the previous object.

### 4.3 Optimized time to make the second object

Since the printer is already on and warm after the first object is made, by changing the gcode in ReplicatorG we can set up the desired temperatures for the extruder and the platform. This by changing the following gcode: To set the extruder temperature M104 Sxxxx and the platform M109 Sxxxx where the xxxx are the desired temperatures one would like them to be. This though is not a permanent fix to the problem, since with this method a change in the gcode will have to be done each time a new object is going to be built thus this will not be automated but manual.

As permanent solution to this we made a change in Skeinforges *start* and *end* gcode. In the end gcode we set the temperature for the extruder and the platform as mentioned above by changing the following lines: M104 (extruder) and M109 (platform) and if we set the temperatures that currently are at 0 degrees, to 100 degrees the item that is in the printing queue will be printed right after the first one thus the time loss for the platform and extruder to cool down to 0 degrees then being warm up will be spared.

To optimize our service, we programmed our code to run two works in the same time. Instead of waiting that the first object is printed completely before beginning with the second, the program will convert the second STL file into Gcode as mentioned above in section 3.1.3.

# 5 Conclusions and Future work

## 5.1 Conclusions

In this project a 3D service which works automatically was built. The process, from the file is uploaded on the website until the object is printed works automatically. The only human intervention is to upload the file. The emphasis on this project was placed to reduce idle time. The modification of the different source code of the material used on this project allows reducing idle time lost between printings two objects and maximizes the speed of the service.

The project contained both practical and theoretical work thus expertise in both areas was gained, also an insight on the important combination between learning and applying in work were received. The biggest challenge in this project was to work in Linux; which was an unknown environment before the project.

## 5.2 Future work

During the testing carried out in this thesis project we have not used TLS for securing the interaction with the web server. An obvious near term effort is to carry out tests with a self-signed certificate which could manually be loaded into the web browser (client).

The 3D printing age has just begun and there are a lot of improvements left to do generally. In view of this thesis some improvements regarding the idle time are left for future work. A creation of a system that makes it possible for the printed object being ejected to land directly in a package ready to be shipped to the customer. Also an optimization of the motion of the tool head is left for future work.

A message with the approximate time until the object is done should be sent to the customer. One can figure out how long the jobs in queue will take to be printed by counting the time it takes to print 1 gram of plastic, hence by adding the total weight of the objects an approximate time should be possible to get.

In this service the customers could only send an STL file thus a lot of desired details the customers might have can't come through, however if the customers could send in a skeinforge file with detailed specifications it would be possible to the customers that for instance get a cube that is totally filled or even more complex desired details.

To reduce the idle time even more, one could set the building platform to cool down after the first layers are built, since the following layers are independent of the platform thus having it warm until the whole object is finished is not only a waste of time but also bad for the environment and the economy.

As mentioned earlier in the thesis the entire process could be automated including label printing and placing the printed item into an appropriate sized package for mailing. This should be the topic of another thesis project, as it would even further reduce the human effort needed to realize a network based 3D printing service.

## 5.3 Required reflections

The growth of 3D printers and 3D printer technology will change the world. The printers can mass produce objects thus the printers can replace humans, which leads to the fact that people will lose their jobs. At the same time new job opportunities will be created, an increase of 3D designers which we already notice, for instance hundreds of new objects are uploaded on the thingiverse website by different people[1]. Also developers of 3D printers and other technologies associated to 3D printers are needed. In the book Makers the industrial revolution[26], an interesting line from a novel called Makers is cited “The days of companies with names like “General Electric and “General Mills” and “General Motors” are over”. The money on the table is like krill: a billion little entrepreneurial opportunities that can be discovered and exploited by smart, creative people.”[27]

People could print objects at home instead of going to the store and buy it, it actually could be cheaper to print it at home depending on what object it is. Custommade products will be cheap. The price on a lot of products will fall since the production will be cheaper and some products will have more competitors since everyone with a printer can compare whether it's cheaper to buy the product or just produce it at home. One should consider that products being mass produced in factories gets cheaper the greater amount being made, while printed products always cost the same, if no account is taken to the printing materials can get cheaper the bigger amount is purchased.

The medical and dental care has advanced; custom hearing aids and dental features are being made. The technology are developing, for instance people in need of a certain organ have to wait in a queue that in some cases are so long that the person in need dies before getting the organ. Instead of organ donors, the organs could be printed and people in need would be able to have a new organ [28].

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# A Code for website

## A.1. Store.php

```
<html>
<head>
<meta http-equiv="REFRESH" content="5;url=index.html"></HEAD>
</head>
<body>
<?php

date_default_timezone_set('Europe/Stockholm');
if (($FILES["file"]["type"] == "application/octet-stream") &&
($FILES["file"]["size"] < 999999999999999999))
{
    if ($FILES["file"]["error"] > 0)
    {
        echo "Return Code: " . $FILES["file"]["error"] . "<br />";
    }
    else
    {
        $date = date('mdY', time());
        $time = date('His', time());
        $compname = $_POST['company'];
        $name = $_POST['namn'];
        $newname = $date . "_" . $time . "_" . $compname . "_" . $name;
        $oldfile = $FILES["file"]["tmp_name"];
        $newfile = "/srv/www/htdocs/proj/todo/" . $newname . ".stl" ;

        echo "First name is: " . $_POST['namn'] . " <br>";
        echo "Company name is: " . $_POST['company'] . " <br>";
        echo "Send it; Date: " . $date . " " . "Time: " . $time . "
<br>";
        echo "Upload: " . $newname . " <br />";
        echo "Type: " . $FILES["file"]["type"] . " <br />";
        echo "Size: " . ($FILES["file"]["size"] / 1024) . " Kb <br />";
        echo "Temp file: " . $FILES["file"]["tmp_name"] . " <br />";

        copy($oldfile,$newfile) or die("Unable to copy $oldfile to
$newfile");

        echo "<h2>File uploaded....</h2><br>";
        echo "<p>Sending back to index page</p><br>";
    }
}
else
{
    echo "Invalid file";
}
?>
</body>
</html>
```



## A.2. Index.htm

```
<html>
<head>
</head>
<body bgcolor="#EBF5F5">
<div style="float:left;"><a style="margin-right:10px;"
href="index.html">Print file</a><a
href="hist.html">History</a></div><br><br>
<form action="/proj/store.php" method="post"
enctype="multipart/form-data">
<table>
<tr><td><label>First Name</label></td><td><input name="namn"
type="text" placeholder="name" /></td></tr>
<tr><td><label>Company Name</label></td><td><input name="company"
type="text" placeholder="Company name" /></td></tr>
<tr><td><label>File</label></td><td><input type="file" name="file"
/></td></tr>
<tr><td colspan="2"><input type="submit" value="Print!"></td></tr>
</table>
</form>

</body>
</html>
```

## B Runrunskienforge

```
#!/bin/sh

TODO=/srv/www/htdocs/proj/todo/
WORK=/srv/www/htdocs/proj/work/

files=`ls "$TODO"`

for file in $files; do
mv "$TODO/$file" "$WORK/$file"
    if [ "${file##*.}" = "stl" ]; then
        # operation for txt files here
        /home/mabdulla/replicatorg/makerbot-ReplicatorG-
9769144/skein_engines/skeinforge-
47/skeinforge_application/runskeinforge.sh "$WORK/$file"
    else
        if [ "${file##*.}" = "STL" ];then
            /home/mabdulla/replicatorg/makerbot-ReplicatorG-
9769144/skein_engines/skeinforge-
47/skeinforge_application/runskeinforge.sh "$WORK/$file"
        fi
    fi
done
```



# C Code to run Replicatorg automatically

```
/*NAME:
 *   AutoPrint - Print objects automatically with MakerBot
 *
 *
 * DESCRIPTION:
 *
 *           The goal of AutoPrint is to verify if a new file has
been uploaded and then print it.First, we get
 *   the name and the path of the file and then we select it with
"editor.handleOpen()".If there is more
 *   than one file which has been uploaded, these files will be
printed one after the other by using
 *   "editor.handleBuild()". Finally, the printed file will moved
to another directory.
 *
 * AUTHOR
 *   LaurierNdikuriyo
 *
 *
 */

package replicatorg.app.ui;
import java.io.*;

    publicclass AutoPrint extends Thread {
        MainWindow editor;
        privatefinal long SLEEP_TIME = 300*1000; /*The program will check
if a new file has been uploaded every 5 minutes*/
        privateboolean runSignal = true;
        String file;
File folder = newFile("/srv/www/htdocs/proj/Gcode");/*The folder
with the file to be printed*/
        publicvoid run() {
            while(runSignal){
                File[] listOfFiles = folder.listFiles();
                for (int i = 0; i < listOfFiles.length;i++){

                    /*Get the name and the path of the file to
be printed*/
                    file = listOfFiles[i].getName();
                    File gcode =
newFile("/srv/www/htdocs/proj/Gcode/"+ file);
                    String path =
gcode.getAbsolutePath();
                    /* Select the file to be printed*/
                    editor.handleOpen(path);

                    /* Print the selected file*/
                    editor.handleBuild();
                    /*Remove the printed file in another
folder*/
```

```

        File done =
newFile("/srv/www/htdocs/proj/done/"+ file);
        gcode.renameTo(done);
    }
    /*Sleep if there is no file to print*/
    doSleep();
}

privatevoid doSleep(){
    try {
        sleep(SLEEP_TIME);
    } catch (InterruptedException e) {
        // TODO Auto-generated catch block
        e.printStackTrace();
    }
}

publicvoid stopRunning() {
    this.runSignal = false;
}

publicstaticvoid main(String[] args) {

    AutoPrint autoprint = newAutoPrint();
    autoprint.start();

}
}

```

# D Gcode for 20mmbox.gcode

```
(<creation> skeinforge </creation>)
(<version> 10.11.05 </version>)
(<extruderInitialization>)
(<craftTypeName> extrusion </craftTypeName>)
M105
(<bridgeWidthMultiplier> 1.0 </bridgeWidthMultiplier>)
(<decimalPlacesCarried> 3 </decimalPlacesCarried>)
(<layerThickness> 0.36 </layerThickness>)
(<threadSequenceString> loops perimeter infill
</threadSequenceString>)
(<operatingFeedRatePerSecond> 30.0 </operatingFeedRatePerSecond>)
(<operatingFlowRate> 1.577 </operatingFlowRate>)
(<orbitalFeedRatePerSecond> 15.0 </orbitalFeedRatePerSecond>)
(<travelFeedRatePerSecond> 40.0 </travelFeedRatePerSecond>)
(<perimeterWidth> 0.545 </perimeterWidth>)
(<profileName> ABS </profileName>)
(<procedureDone> carve,bottom</procedureDone>)
(<procedureDone> preface </procedureDone>)
(<procedureDone> inset </procedureDone>)
(<procedureDone> fill </procedureDone>)
(<procedureDone> speed </procedureDone>)
(<procedureDone> raft </procedureDone>)
(<procedureDone> comb </procedureDone>)
(<procedureDone> cool </procedureDone>)
(<procedureDone> outline </procedureDone>)
(<procedureDone> reversal </procedureDone>)
(<procedureDone> export </procedureDone>)
(</extruderInitialization>)
(<extrusion>)
;M113 S1.0
M108 R1.577
(<layer>0.48 )
(<surroundingLoop>)
(<boundaryPerimeter>)
(<boundaryPoint> X-10.0 Y-10.0 Z0.48 </boundaryPoint>)
(<boundaryPoint> X10.0 Y-10.0 Z0.48 </boundaryPoint>)
(<boundaryPoint> X10.0 Y10.0 Z0.48 </boundaryPoint>)
(<boundaryPoint> X-10.0 Y10.0 Z0.48 </boundaryPoint>)
(<loop>outer )
G1 X12.73 Y-12.73 Z0.48 F1080.0
M101
G1 X-12.73 Y-12.73 Z0.48 F1080.0
G1 X-12.73 Y12.73 Z0.48 F1080.0
G1 X12.73 Y12.73 Z0.48 F1080.0
G1 X12.73 Y-11.38 Z0.48 F1080.0
M108 R35.0
M102
G1 X12.73 Y-12.73 Z0.48 F1080.0
M108 R1.577
M103
G1 X2.25 Y-9.81 Z0.48 F1800.0
M108 R35.0
M101
G1 X0.0 Y-9.18 Z0.48 F1800.0
M108 R1.577
G1 X9.18 Y-9.18 Z0.48 F1350.0
```

```

G1 X9.18 Y9.18 Z0.48 F1350.0
G1 X-9.18 Y9.18 Z0.48 F1350.0
G1 X-9.18 Y-9.18 Z0.48 F1350.0
G1 X0.0 Y-9.18 Z0.48 F1350.0
M103
(</loop>)
(<perimeter>outer )
G1 X0.0 Y-9.73 Z0.48 F1440.0
M101
G1 X9.73 Y-9.73 Z0.48 F1080.0
G1 X9.73 Y9.73 Z0.48 F1080.0
G1 X-9.73 Y9.73 Z0.48 F1080.0
G1 X-9.73 Y-9.73 Z0.48 F1080.0
G1 X-1.35 Y-9.73 Z0.48 F1080.0
M108 R35.0
M102
G1 X0.0 Y-9.73 Z0.48 F1080.0
M108 R1.577
M103
(</perimeter>)
(</boundaryPerimeter>)
G1 X6.4 Y-9.07 Z0.48 F1800.0
M108 R35.0
M101
G1 X8.73 Y-8.83 Z0.48 F1800.0
M108 R1.577
G1 X8.73 Y8.83 Z0.48 F1350.0
G1 X8.18 Y8.83 Z0.48 F1350.0
G1 X8.18 Y-8.83 Z0.48 F1350.0
G1 X7.64 Y-8.83 Z0.48 F1350.0
G1 X7.64 Y8.83 Z0.48 F1350.0
G1 X7.09 Y8.83 Z0.48 F1350.0
G1 X7.09 Y-8.83 Z0.48 F1350.0
G1 X6.54 Y-8.83 Z0.48 F1350.0
G1 X6.54 Y8.83 Z0.48 F1350.0
G1 X6.0 Y8.83 Z0.48 F1350.0
G1 X6.0 Y-8.83 Z0.48 F1350.0
G1 X5.45 Y-8.83 Z0.48 F1350.0
G1 X5.45 Y8.83 Z0.48 F1350.0
G1 X4.91 Y8.83 Z0.48 F1350.0
G1 X4.91 Y-8.83 Z0.48 F1350.0
G1 X4.36 Y-8.83 Z0.48 F1350.0
G1 X4.36 Y8.83 Z0.48 F1350.0
G1 X3.82 Y8.83 Z0.48 F1350.0
G1 X3.82 Y-8.83 Z0.48 F1350.0
G1 X3.27 Y-8.83 Z0.48 F1350.0
G1 X3.27 Y8.83 Z0.48 F1350.0
G1 X2.73 Y8.83 Z0.48 F1350.0
G1 X2.73 Y-8.83 Z0.48 F1350.0
G1 X2.18 Y-8.83 Z0.48 F1350.0
G1 X2.18 Y8.83 Z0.48 F1350.0
G1 X1.64 Y8.83 Z0.48 F1350.0
G1 X1.64 Y-8.83 Z0.48 F1350.0
G1 X1.09 Y-8.83 Z0.48 F1350.0
G1 X1.09 Y8.83 Z0.48 F1350.0
G1 X0.55 Y8.83 Z0.48 F1350.0
G1 X0.55 Y-8.83 Z0.48 F1350.0
G1 X-0.0 Y-8.83 Z0.48 F1350.0
G1 X0.0 Y8.83 Z0.48 F1350.0
G1 X-0.55 Y8.83 Z0.48 F1350.0
G1 X-0.55 Y-8.83 Z0.48 F1350.0
G1 X-1.09 Y-8.83 Z0.48 F1350.0
G1 X-1.09 Y8.83 Z0.48 F1350.0

```

```

G1 X-1.64 Y8.83 Z0.48 F1350.0
G1 X-1.64 Y-8.83 Z0.48 F1350.0
G1 X-2.18 Y-8.83 Z0.48 F1350.0
G1 X-2.18 Y8.83 Z0.48 F1350.0
G1 X-2.73 Y8.83 Z0.48 F1350.0
G1 X-2.73 Y-8.83 Z0.48 F1350.0
G1 X-3.27 Y-8.83 Z0.48 F1350.0
G1 X-3.27 Y8.83 Z0.48 F1350.0
G1 X-3.82 Y8.83 Z0.48 F1350.0
G1 X-3.82 Y-8.83 Z0.48 F1350.0
G1 X-4.36 Y-8.83 Z0.48 F1350.0
G1 X-4.36 Y8.83 Z0.48 F1350.0
G1 X-4.91 Y8.83 Z0.48 F1350.0
G1 X-4.91 Y-8.83 Z0.48 F1350.0
G1 X-5.45 Y-8.83 Z0.48 F1350.0
G1 X-5.45 Y8.83 Z0.48 F1350.0
G1 X-6.0 Y8.83 Z0.48 F1350.0
G1 X-6.0 Y-8.83 Z0.48 F1350.0
G1 X-6.54 Y-8.83 Z0.48 F1350.0
G1 X-6.54 Y8.83 Z0.48 F1350.0
G1 X-7.09 Y8.83 Z0.48 F1350.0
G1 X-7.09 Y-8.83 Z0.48 F1350.0
G1 X-7.64 Y-8.83 Z0.48 F1350.0
G1 X-7.64 Y8.83 Z0.48 F1350.0
G1 X-8.18 Y8.83 Z0.48 F1350.0
G1 X-8.18 Y-8.83 Z0.48 F1350.0
G1 X-8.73 Y-8.83 Z0.48 F1350.0
G1 X-8.73 Y8.83 Z0.48 F1350.0
M103
(</surroundingLoop>)
(</layer>)
(<layer>0.84 )
(<surroundingLoop>)
(<boundaryPerimeter>)
(<boundaryPoint> X-10.0 Y-10.0 Z0.84 </boundaryPoint>)
(<boundaryPoint> X10.0 Y-10.0 Z0.84 </boundaryPoint>)
(<boundaryPoint> X10.0 Y10.0 Z0.84 </boundaryPoint>)
(<boundaryPoint> X-10.0 Y10.0 Z0.84 </boundaryPoint>)
(<loop>outer )
G1 X-8.73 Y9.18 Z0.84 F2400.0
M101
G1 X-9.18 Y9.18 Z0.84 F1800.0
G1 X-9.18 Y-9.18 Z0.84 F1800.0
G1 X9.18 Y-9.18 Z0.84 F1800.0
G1 X9.18 Y9.18 Z0.84 F1800.0
G1 X-8.73 Y9.18 Z0.84 F1800.0
M103
(</loop>)
(<perimeter>outer )
G1 X-8.73 Y9.73 Z0.84 F2400.0
M101
G1 X-9.73 Y9.73 Z0.84 F1800.0
G1 X-9.73 Y-9.73 Z0.84 F1800.0
G1 X9.73 Y-9.73 Z0.84 F1800.0
G1 X9.73 Y9.73 Z0.84 F1800.0
G1 X-6.48 Y9.73 Z0.84 F1800.0
M108 R35.0
M102
G1 X-8.73 Y9.73 Z0.84 F1800.0
M108 R1.577
M103
(</perimeter>)
(</boundaryPerimeter>)

```



G1 X5.71 Y8.9 Z0.84 F2400.0  
M108 R35.0  
M101  
G1 X8.83 Y8.73 Z0.84 F2400.0  
M108 R1.577  
G1 X-8.83 Y8.73 Z0.84 F1800.0  
G1 X-8.83 Y8.18 Z0.84 F1800.0  
G1 X8.83 Y8.18 Z0.84 F1800.0  
G1 X8.83 Y7.64 Z0.84 F1800.0  
G1 X-8.83 Y7.64 Z0.84 F1800.0  
G1 X-8.83 Y7.09 Z0.84 F1800.0  
G1 X8.83 Y7.09 Z0.84 F1800.0  
G1 X8.83 Y6.54 Z0.84 F1800.0  
G1 X-8.83 Y6.54 Z0.84 F1800.0  
G1 X-8.83 Y6.0 Z0.84 F1800.0  
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G1 X7.27 Y-8.83 Z1.2 F1355.616
G1 X3.03 Y-8.83 Z1.2 F1355.616
G1 X3.64 Y-5.66 Z1.2 F1355.616
G1 X3.64 Y7.27 Z1.2 F1355.616
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G1 X0.61 Y8.83 Z1.2 F1355.616
G1 X1.21 Y2.42 Z1.2 F1355.616
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G1 X2.42 Y-8.83 Z1.2 F1355.616

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G1 X-4.24 Y8.83 Z1.2 F1355.616
G1 X-3.64 Y2.42 Z1.2 F1355.616
G1 X-3.64 Y-7.27 Z1.2 F1355.616
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G1 X-8.31 Y2.42 Z1.56 F1260.881
G1 X-6.24 Y4.04 Z1.56 F1260.881
G1 X-5.88 Y4.04 Z1.56 F1260.881
G1 X-3.81 Y2.42 Z1.56 F1260.881
G1 X-3.46 Y2.42 Z1.56 F1260.881

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G1 X8.83 Y7.27 Z2.28 F1260.881
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M102
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M108 R35.0
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G1 X6.06 Y2.42 Z4.8 F1376.873
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G1 X7.27 Y-8.83 Z4.8 F1376.873

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G1 X-8.48 Y8.83 Z4.8 F1376.873
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M108 R35.0
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M108 R35.0
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G1 X-8.83 Y7.27 Z5.16 F1681.175

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G1 X-5.88 Y4.04 Z5.16 F1260.881  
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G1 X3.46 Y-2.42 Z5.16 F1260.881  
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G1 X8.83 Y7.88 Z5.16 F1260.881

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G1 X-9.25 Y9.73 Z5.52 F1376.873
M108 R35.0
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G1 X3.64 Y7.27 Z5.52 F1376.873
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G1 X0.61 Y8.83 Z5.52 F1376.873
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G1 X2.42 Y-8.83 Z5.52 F1376.873
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G1 X-1.21 Y7.27 Z5.52 F1376.873

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G1 X-8.24 Y-9.73 Z5.88 F1260.881
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M102
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M108 R1.105
M103
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G1 X-1.03 Y4.04 Z5.88 F1260.881
G1 X1.03 Y2.42 Z5.88 F1260.881

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G1 X-1.21 Y7.27 Z6.24 F1376.873
G1 X0.0 Y8.83 Z6.24 F1376.873
G1 X-4.24 Y8.83 Z6.24 F1376.873
G1 X-3.64 Y2.42 Z6.24 F1376.873
G1 X-3.64 Y-7.27 Z6.24 F1376.873
G1 X-2.42 Y-8.83 Z6.24 F1376.873
G1 X-6.06 Y-8.83 Z6.24 F1376.873
G1 X-6.06 Y7.27 Z6.24 F1376.873
G1 X-4.85 Y8.83 Z6.24 F1376.873
G1 X-8.48 Y8.83 Z6.24 F1376.873
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G1 X-8.31 Y2.42 Z6.6 F1260.881
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G1 X8.83 Y-2.42 Z6.6 F1260.881
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G1 X-6.24 Y7.27 Z6.6 F1260.881
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G1 X9.18 Y9.18 Z6.96 F1376.873

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M108 R35.0
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G1 X1.21 Y-7.27 Z6.96 F1376.873
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G1 X-1.21 Y7.27 Z6.96 F1376.873
G1 X0.0 Y8.83 Z6.96 F1376.873
G1 X-4.24 Y8.83 Z6.96 F1376.873
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G1 X-3.64 Y-7.27 Z6.96 F1376.873
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M103
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G1 X5.88 Y-0.81 Z7.32 F1260.881
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G1 X3.46 Y-2.42 Z7.32 F1260.881
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G1 X-5.88 Y-5.66 Z7.32 F1260.881
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M108 R1.105
M103
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M108 R1.206
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G1 X7.27 Y-8.83 Z7.68 F1376.873
G1 X3.03 Y-8.83 Z7.68 F1376.873
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G1 X0.61 Y8.83 Z7.68 F1376.873
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M103
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M103  
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G1 X-5.88 Y4.04 Z8.04 F1260.881  
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G1 X3.03 Y-8.83 Z9.12 F1376.873
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M103
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G1 X-8.66 Y2.42 Z9.48 F1260.881

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G1 X-3.27 Y8.83 Z9.84 F1800.0
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G1 X-6.0 Y-8.83 Z9.84 F1800.0
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G1 X-7.64 Y8.83 Z9.84 F1800.0
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G1 X-8.18 Y-8.83 Z9.84 F1800.0
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G1 X-9.18 Y-9.18 Z10.2 F1800.0
G1 X9.18 Y-9.18 Z10.2 F1800.0
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G1 X-8.73 Y9.18 Z10.2 F1800.0
M103

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(</loop>)
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G1 X-9.73 Y-9.73 Z10.2 F1800.0
G1 X9.73 Y-9.73 Z10.2 F1800.0
G1 X9.73 Y9.73 Z10.2 F1800.0
G1 X-6.48 Y9.73 Z10.2 F1800.0
M108 R35.0
M102
G1 X-8.73 Y9.73 Z10.2 F1800.0
M108 R1.577
M103
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M108 R35.0
M101
G1 X8.83 Y8.73 Z10.2 F2400.0
M108 R1.577
G1 X-8.83 Y8.73 Z10.2 F1800.0
G1 X-8.83 Y8.18 Z10.2 F1800.0
G1 X8.83 Y8.18 Z10.2 F1800.0
G1 X8.83 Y7.64 Z10.2 F1800.0
G1 X-8.83 Y7.64 Z10.2 F1800.0
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G1 X-8.83 Y-1.64 Z10.2 F1800.0
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G1 X8.83 Y-2.18 Z10.2 F1800.0
G1 X-8.83 Y-2.18 Z10.2 F1800.0
G1 X-8.83 Y-2.73 Z10.2 F1800.0

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G1 X-8.83 Y-7.09 Z10.2 F1800.0
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G1 X-8.83 Y-8.18 Z10.2 F1800.0
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G1 X8.83 Y-8.73 Z10.2 F1800.0
G1 X-6.58 Y-8.73 Z10.2 F1800.0
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M102
G1 X-8.83 Y-8.73 Z10.2 F1800.0
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