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REPRAP MAGAZINE

Practical exploration of 3D printing

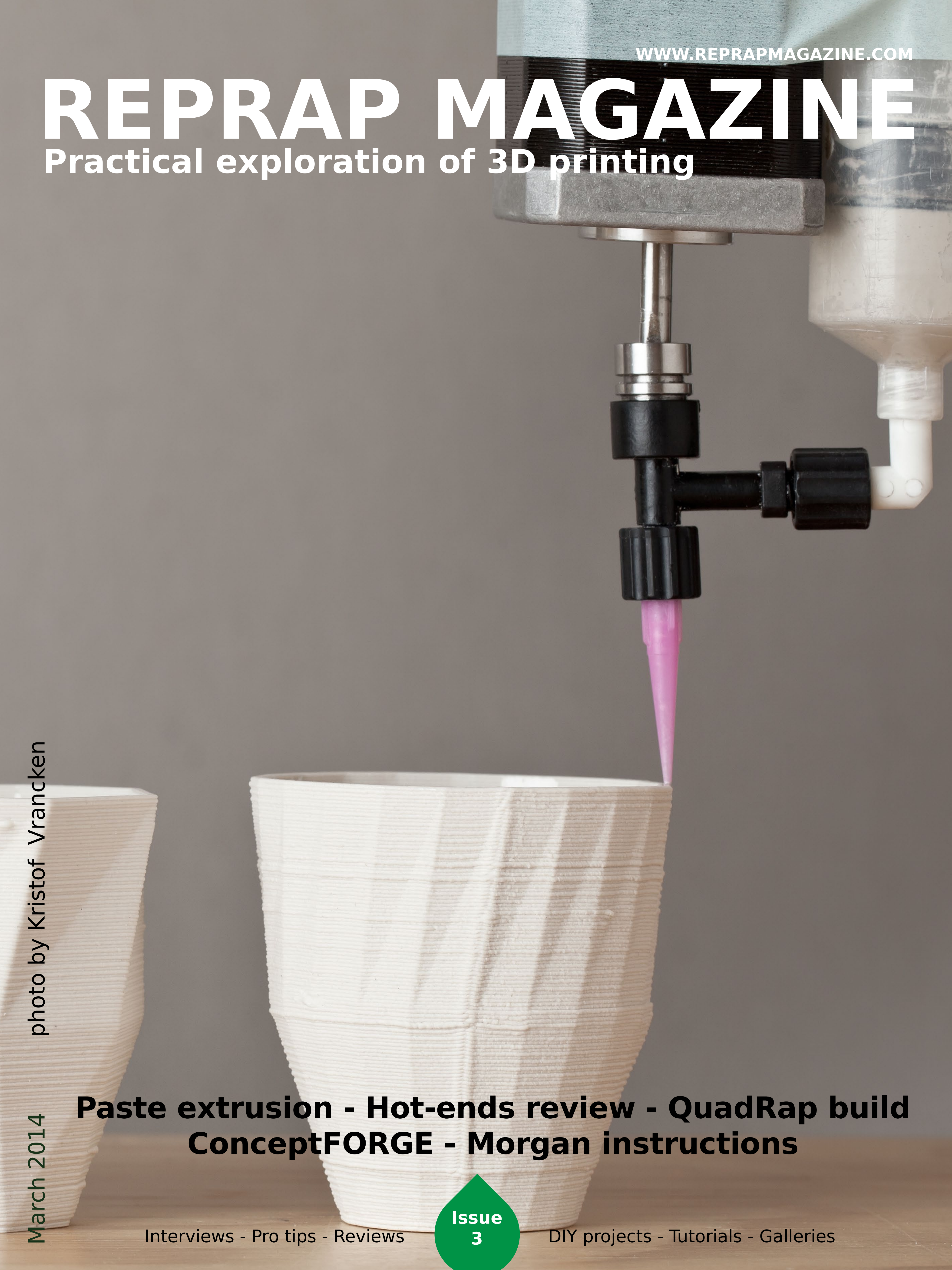

photo by Kristof Vrancken

Paste extrusion - Hot-ends review - QuadRap build
ConceptFORGE - Morgan instructions

March 2014

Issue 3

Interviews - Pro tips - Reviews

DIY projects - Tutorials - Galleries

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Practical exploration of 3D printing

Web:

www.reprapmagazine.com

Magazine team

Developers

Paulo Gonçalves
Gary Hodgson
Richard Horne
Viktor Dirks
Scott Latheine

Contacts

general@reprapmagazine.com

editorial@reprapmagazine.com

RepRap Forums

Reprap Magazine

RepRap Magazine

Happy anniversary!

This issue marks the passage of the first year of existence for our magazine. We know its been a while since our last issue but between these two issues there was one special event that took many of our efforts to organize and it took place last September in the TCT + Personalize show in Birmingham.

It was a great way to meet some of our readers, but when it was over we resumed back the efforts and here it is the third issue, with two features articles: Hot-Ends and Paste extrusion.

In this issue we focus the *In the works* section on the work of Nicolas Seward and his project Concept Forge. For those who have been following his work you will see a more personal perspective of his works.

Enjoy this issue and stay tuned as we are working on delivering some news this year!

Paulo Gonçalves
Editor

Our mission

To the readers

We want to have a close relationship with our readers. For that we encourage you to participate in this project. Send us photos of your best prints and your setup for possible publication to our email at general@reprapmagazine.com.

Also take part at the discussion at the http://forums.reprap.org/list.php?305.

To the contributors

This is an open magazine, and for that we encourage you to submit your articles for possible publications to our email at general@reprapmagazine.com. If you are also a developer of a tool that RepRap users use you can also send an email to be in our database for future contacts.

Independent

We are 100% independent. The manufacters of the products featured do not determine our content nor our opinions.

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This issues team

Shauki Bagdadi

Gary Hodgson

Richard Horne

Dries Verbruggen

Paulo Gonçalves

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www.reprapmagazine.com

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OPEN-SOURCE LAB by J.Pearce

Overall this is a book which is focused on the development of Laboratory equipment, mainly using open-source hardware such as RepRap 3D printers and Arduino microcontrollers. It will guide the inexperienced reader making him comfortable to embrace this technological and social advances in a very practical way, resulting in very significant cost reductions for researchers and teachers.

Open-source lab will focus its readers on building his own laboratory hardware to reduce research costs. The book will start by introducing the readers to a brief resume of what is Free and Open-source Software (FOSS) and from there takes it to the free and open source hardware (FOSH) and points some of the potential when they are combined.

Divided in 7 chapters, the first being the introduction mentioned before, it takes its readers progressively on the benefits of sharing and the open licensing (chapters 2 and 3 respectively). These chapters are interesting enough for even those who have been part of the Open source movement for some time now, but are really interesting for people who are just starting to join this movement.

The reader will be introduced to the several licenses and chapter 3 will end talking about the Continued IP Challenges and its relation with open-source licenses and development.

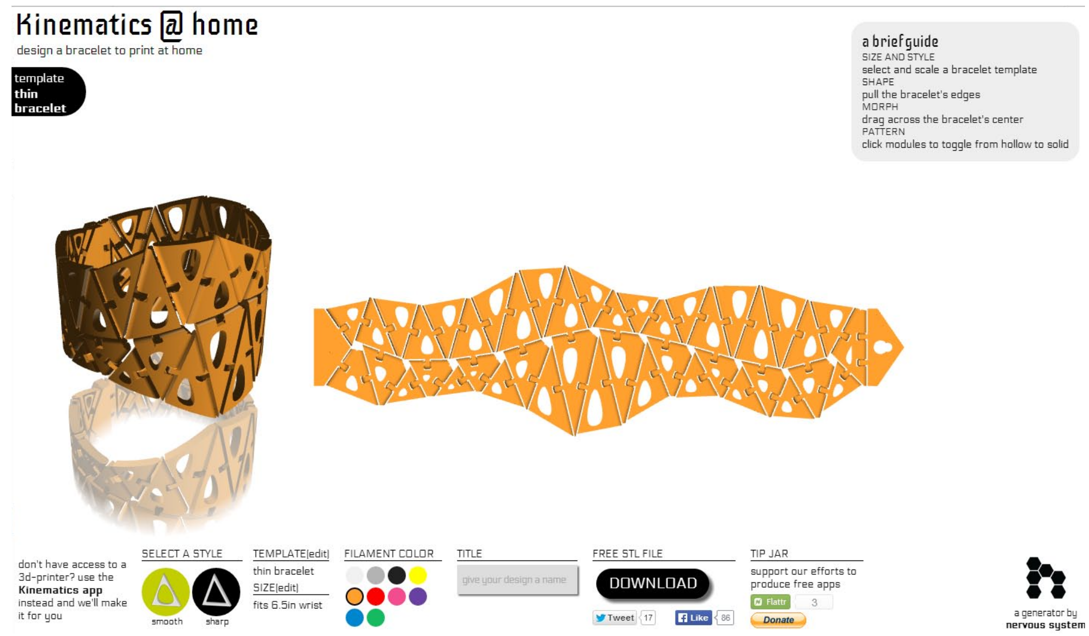
After this first 3 chapters of more theoretical content we get to the “hands on” part of the book! First we will start with the open-source micro controllers, with the available family and then focus on Arduino with a practical example “the polar bear open-source environmental chamber (chapter 4).

Getting to chapter 5 we reach the RepRap project. This chapter shows the assembly of a printer, a Prusa Mendel reengineered primarily by Jerry Anzalone at Michigan Tech. After this chapter, the author focus on Digital designs and Scientific hard ware taking us through out many different scientific tools created with the things reviewed on the previous chapters and the book ends with some thought on the Future of Open-Source Hardware and Science.

Design and print bracelets.

Nervous System has a new online app that lets you customize three bracelets templates and download them as .STL or print using their services.

The Kinematics app is the only one with the option to download .STL files, but there are other interesting apps available if you want to use their printing services.

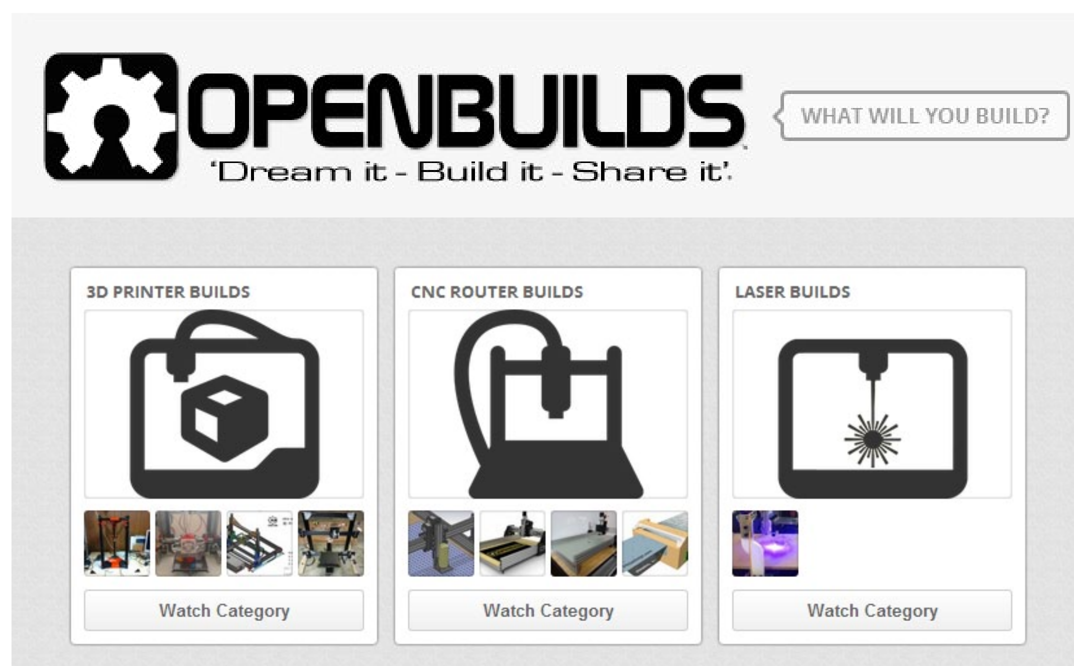


http://n-e-r-v-o-u-s.com/kinematicsHome/

New community sharing site.

OpenBuilds has unveiled their new platform for opensorce design sharing with a focus on OpenSorce machines.

It has several categories of machines going from 3D printers, to laser, vacuum forming and scanners. It is also possible to upload other projects and the site includes a forum.

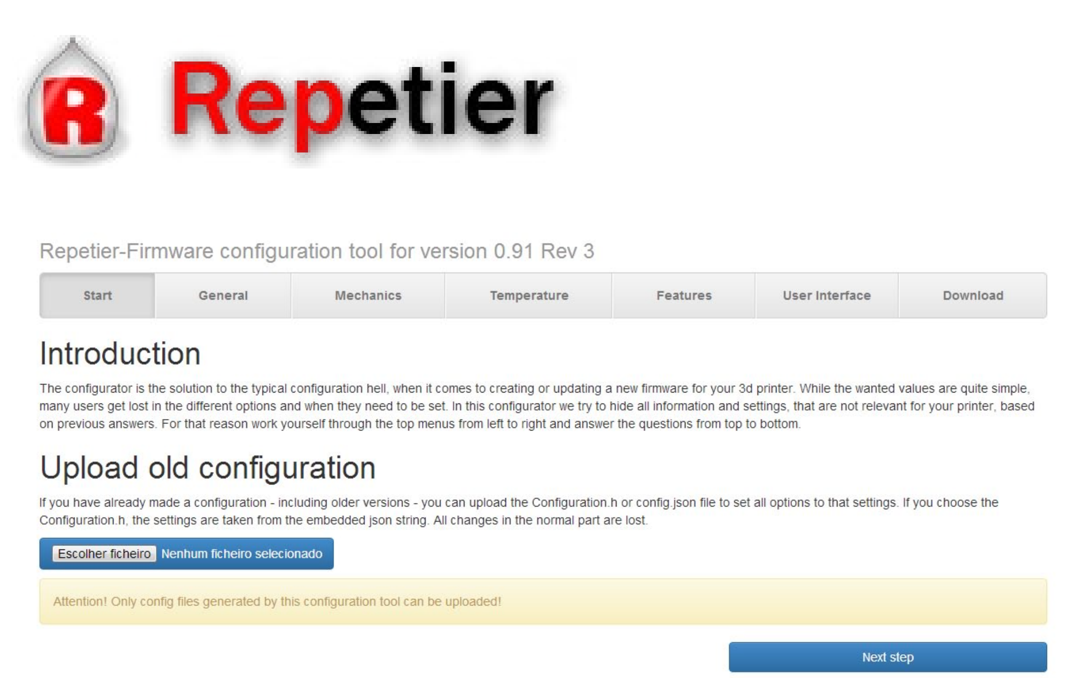


http://www.openbuilds.com

Repetier firmware new tool.

Repetier has a new online tool that allows its users to configurate Repetier firmware in a much more user friendly enviroment.

Like they mention on the webpage: “In this configurator we try to hide all information and settings, that are not relevant for your printer, based on previous answers.”



http://www.repetier.com/firmware/

Print to improve life quality!

Competition Results

We asked our readers to come up with new designs to improve the life quality, and here are the results of this challenge!

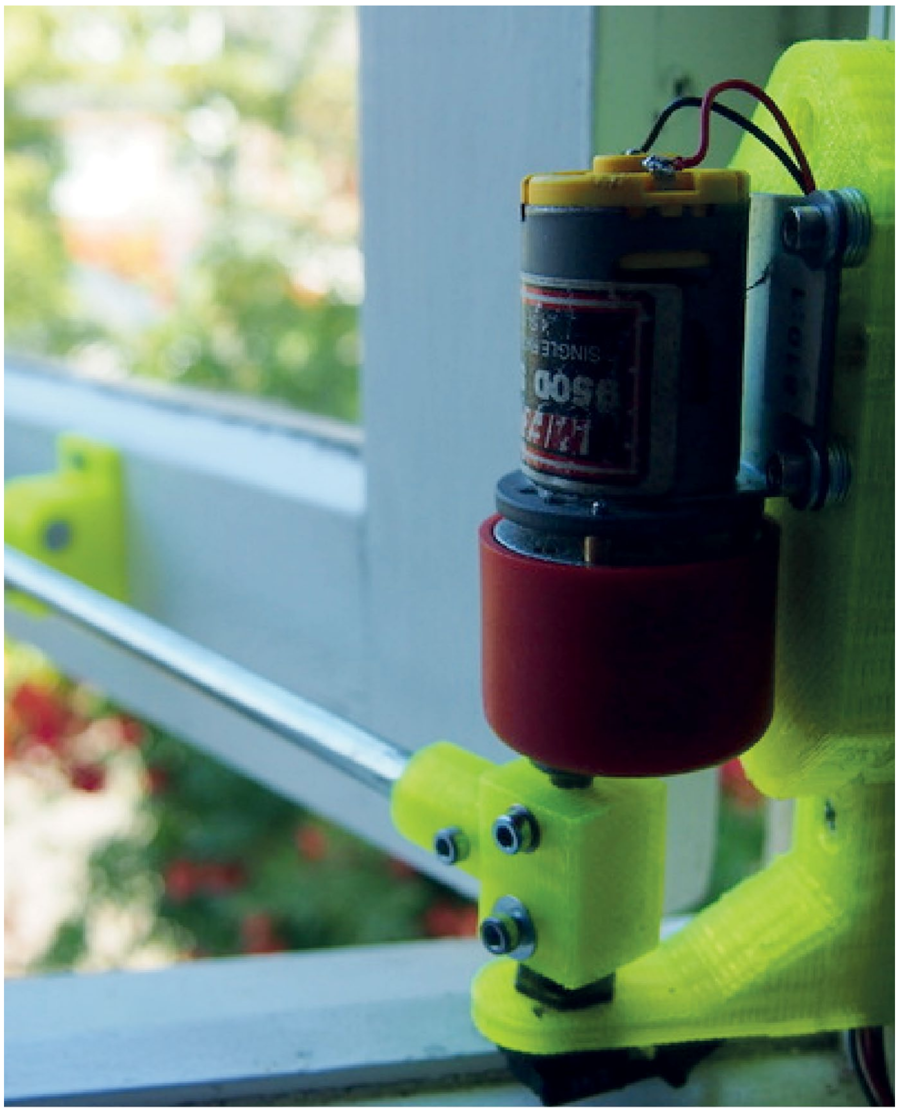
A special thanks goes to those who participated in our first competition and also for the competition sponsors.

1º Prize Winner

Name: Benjamin Leclerc
Alias: proto.user

Customizable hand crank device. With a splined output shaft like on a tractor, and a curvy crank.

RepRapPro Huxley hardware Kit. Shipping included.



2º Prize

Name: Roelof Grootjans
Alias: RoelofG

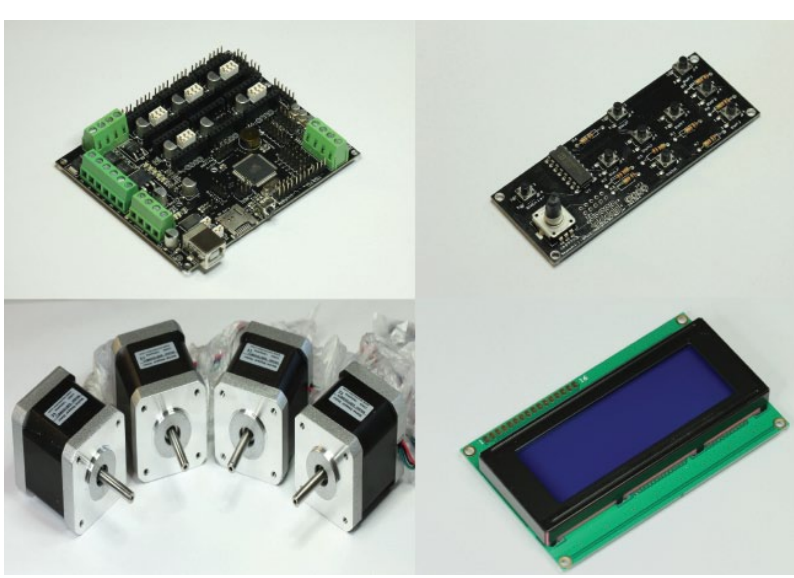
Automatic window opening robot.

Plastic2Print speciality plastics bundle. Shipping included.

3º Prize

Name: Dave Akkerman
Alias: Wavetracer

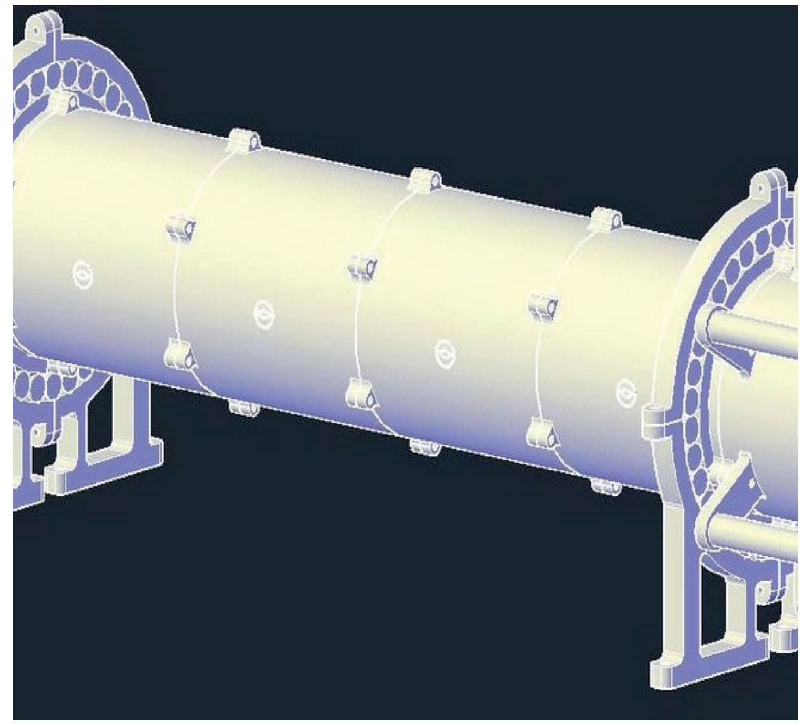
A shopping-trolley coin and a clip to hold your shopping-list.



RepRapWorld bundle.
Shipping included.

4º

5º



6º

7º

4º to 7º Prize

4º - Gert Galjoen (ggaljoen)
Kitchen robot add-on

5º - David Schulze (unasone)
Belt Clip

6º - Peter Fisher (stonefisher)
Modular Water Screw

7º - *Benjamin Minerds* (PuZZledDucK)
White cane

Faberdashery four £50 vouchers worth of plastic.

Universal 3D printing filament spool standard 2014

Richard Horne campaign with the support of the 3D Printing Association.

Coils and coils of lovely 3D printing filament, I'm usually surrounded by them, I struggle with them and often spend time and energy mounting, clamping, switching and feeding them into various printers.

There has to be a better way. (lets please all find a better way)

The problem

Every single one is different, bare coils or reels, some are even different being from the same manufacturer.

Just to point out here, this is only a tiny selection of 3D printing filament reels available, these are the ones I happen to still have around me. Even the long list on RepRap.org of filament suppliers is a fraction of what's actually available.

The closest thing we have to a 'standard' reel is based around the use of 3mm plastic welding rod/coils for automotive repair industry, these very large coils have been used with 3D printing for many years. They have a lot of benefits, but also plenty of negative aspects. Mostly being heavy and big whilst also using more than 300g of ABS to make each one.

Different coils and reels

The Question?

Would it be possible for manufacturers to have a set filament standard for spool size, shape and mounting?

Can the 3D printing community help develop that standard?

Can we make it Eco-friendly and recyclable?

Does anyone want it?

Lets find out. If you want to get involved (and please do), a discussion thread on the RepRap Forum has started *here.*

Start discussions wherever you want, and spread the word, lets make something happen.

Ideas spark more ideas!

We can see that many reels already have a 50mm mounting hole diameter, so this looks like a reasonable starting point.

The inner diameter, bigger is better, but you need to allow enough room for filament without also having a very large outer diameter. A size of around 120mm for the internal seems to work well for most types of plastics and filled materials in both 3mm and 1.75mm sizes.

A diameter of 220mm for the outer will allow for a typical quantity of filament depending on the width of the spool, 75mm shown here.

Cardboard spool concept, 1Kg spool or 3 x 250g based on the same specification of mounting hole and overall size.

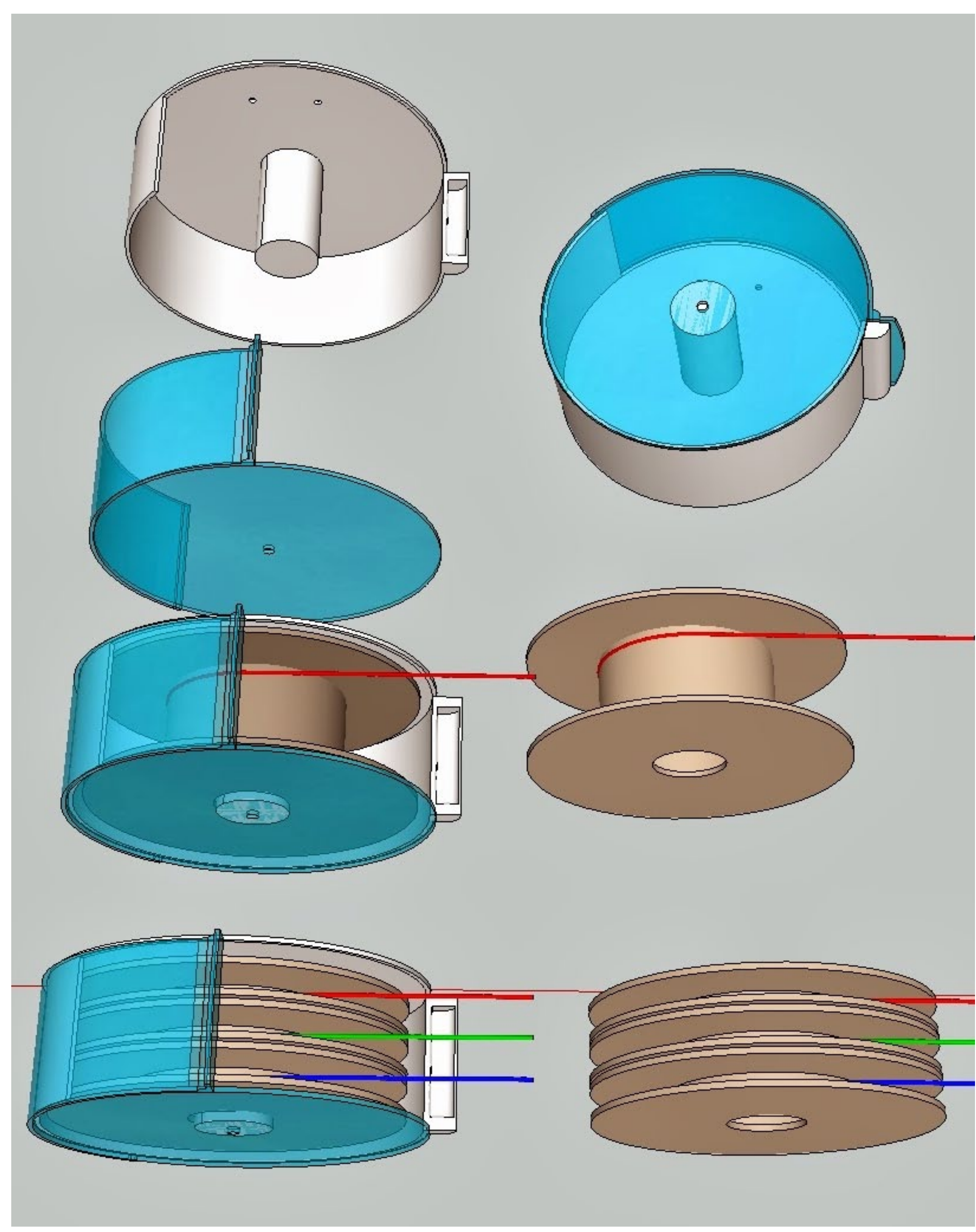
The plastic dust cover/case is an item I would also like to see available (or 3D printed) - make it easy to mount on / in a 3D printer and refill with the recyclable cardboard filament spools.

How you can help

Ask your filament supplier if they can support the standard, if they say no, ask them why and let people know the reasons. If you manufacture a 3D printer, what do you require from a filament spool? Sketch or design something, say what would work for you and your 3D printer, what's not working now and how you solve it (or not).

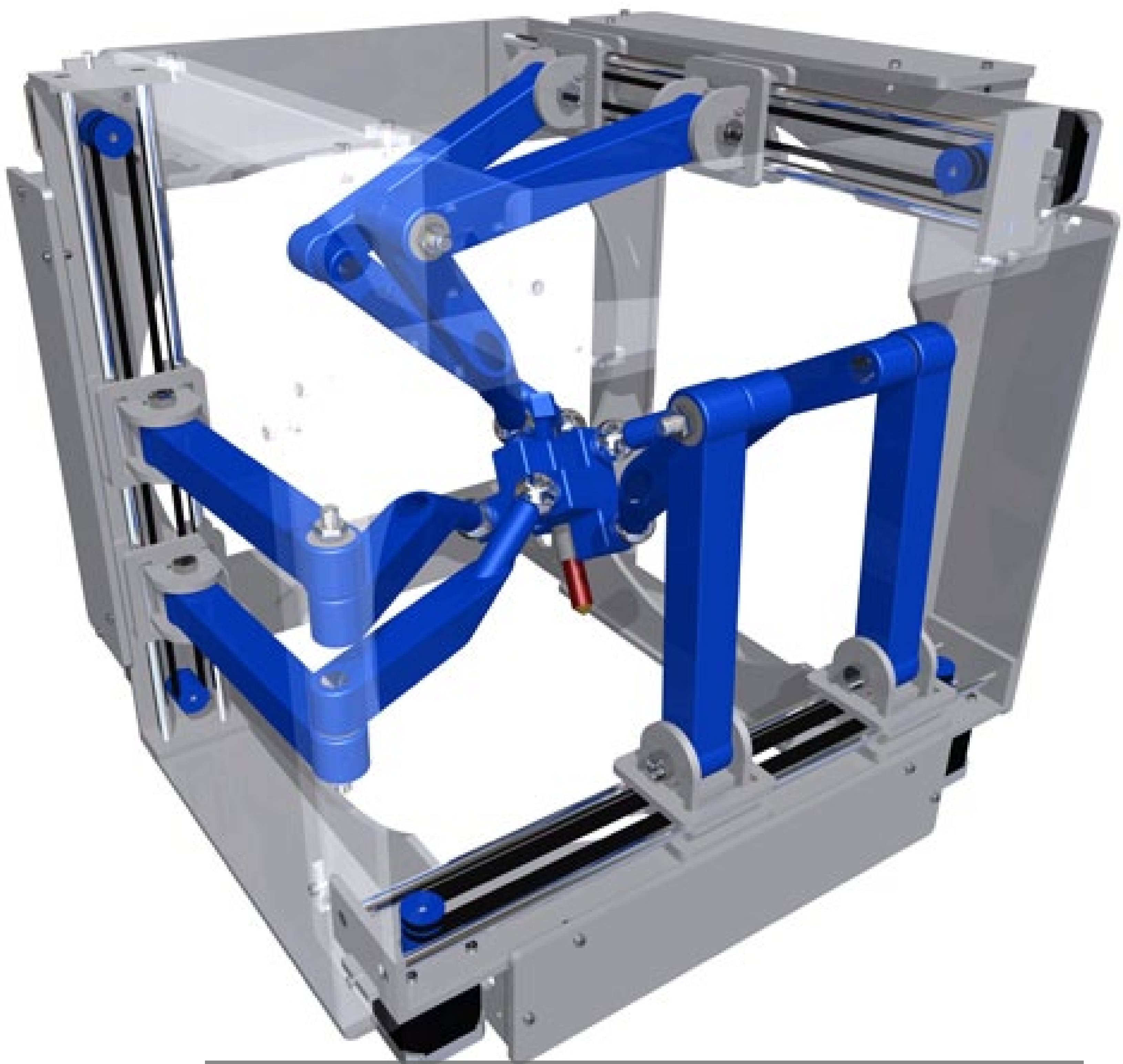
The 3D Printing Association

The 3D Printing Association is providing support for this project and also looking for feedback and ideas to help with this campaign, both from filament manufacturers and everyone in the community.



Cardboard spool concept

In the works



Many in the Maker community are always looking for new and interesting projects to follow and perhaps take part in, and so this section gives a brief look at up-and-coming projects from in and around the RepRap community.

It should be noted that unless otherwise stated these projects are most definitely works in progress and not ready for general consumption.

If you like to live on the cutting edge then these projects might be for you.

by Gary Hodgson

The Wally and Simpson printer designs of Nicholas Seward shows how effective open-source, rapid prototyping can be. Within a month of introducing his experimental delta design on the RepRap forums [0] the design had been discussed, modified and improved into a working machine already able to produce very respectable prints.

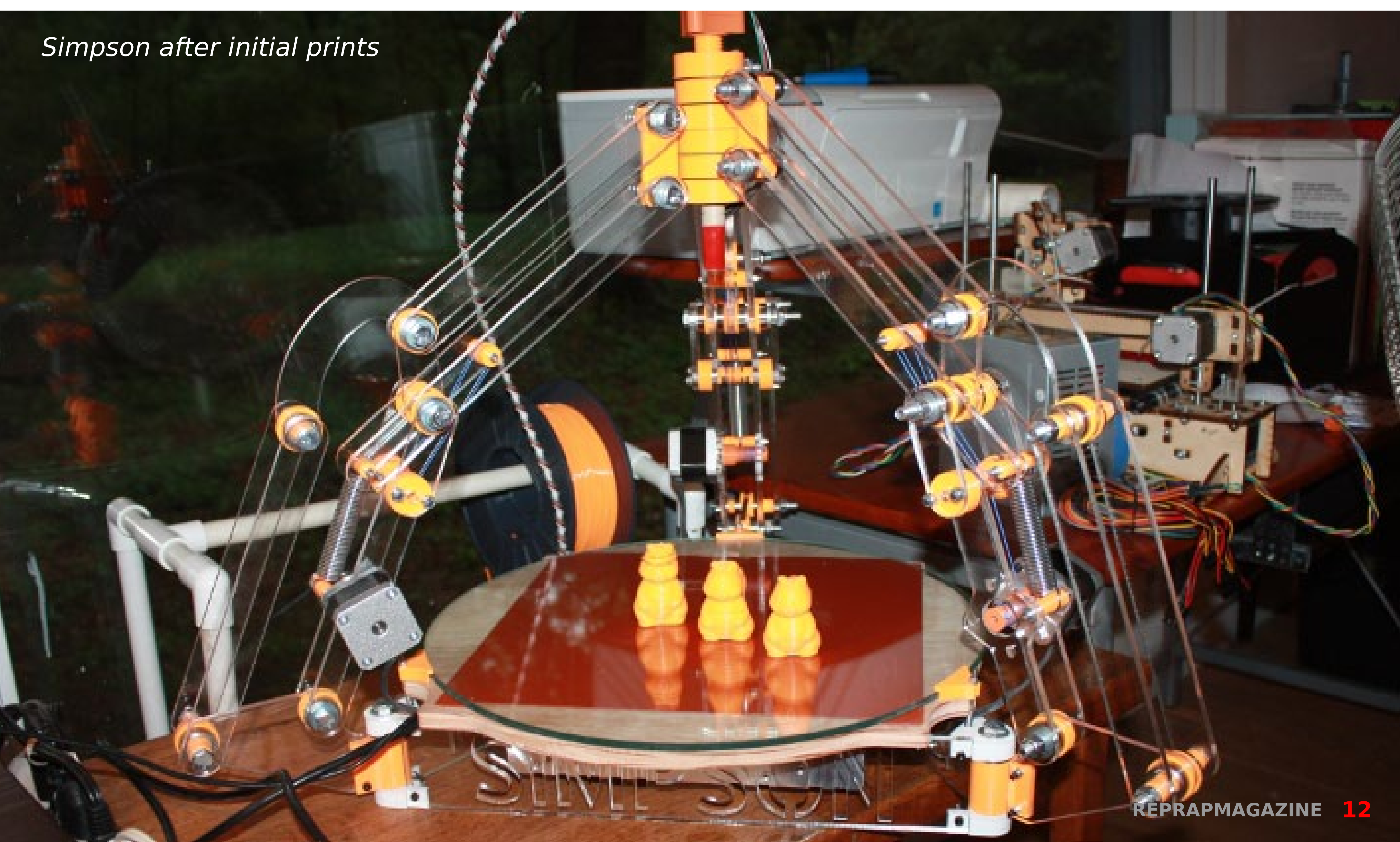
Gary Hodgson

Author

Alias:
garyhodgson
Country:
UK, living in Germany
Website:
http://garyhodgson.com

With a Bachelor of Science in Mechanical Engineering from the University of Arkansas, which is soon to be complemented with a Master of Arts in Physics, Nicholas is no stranger to mechanical design. However the feedback and positive critique via the forums helped define and develop the designs, a fact he happily relates: *"the RepRap community has drastically changed the direction of these projects multiple times. I can not take full responsibility for the Wally or Simpson. They truly belong to the community."*

Nicholas' motivation drew from early experiences with his first printer, an LC Printbot, which he received as a birthday gift from his wife. Whilst admitting that the Printbot is *"great"*, he immediately recognised ways in which he would have designed it differently. Once the machine was running he slowly started tweaking the printer to remedy the various issues he encountered, resulting in a machine quite different to the original. This process, of tackling problems and tailoring the design to meet his own needs, was instrumental in driving him to go on to produce his later work, he says, *"In retrospect, without the initial problems I probably wouldn't have been as motivated to take on all that I have."*



Simpson after initial prints

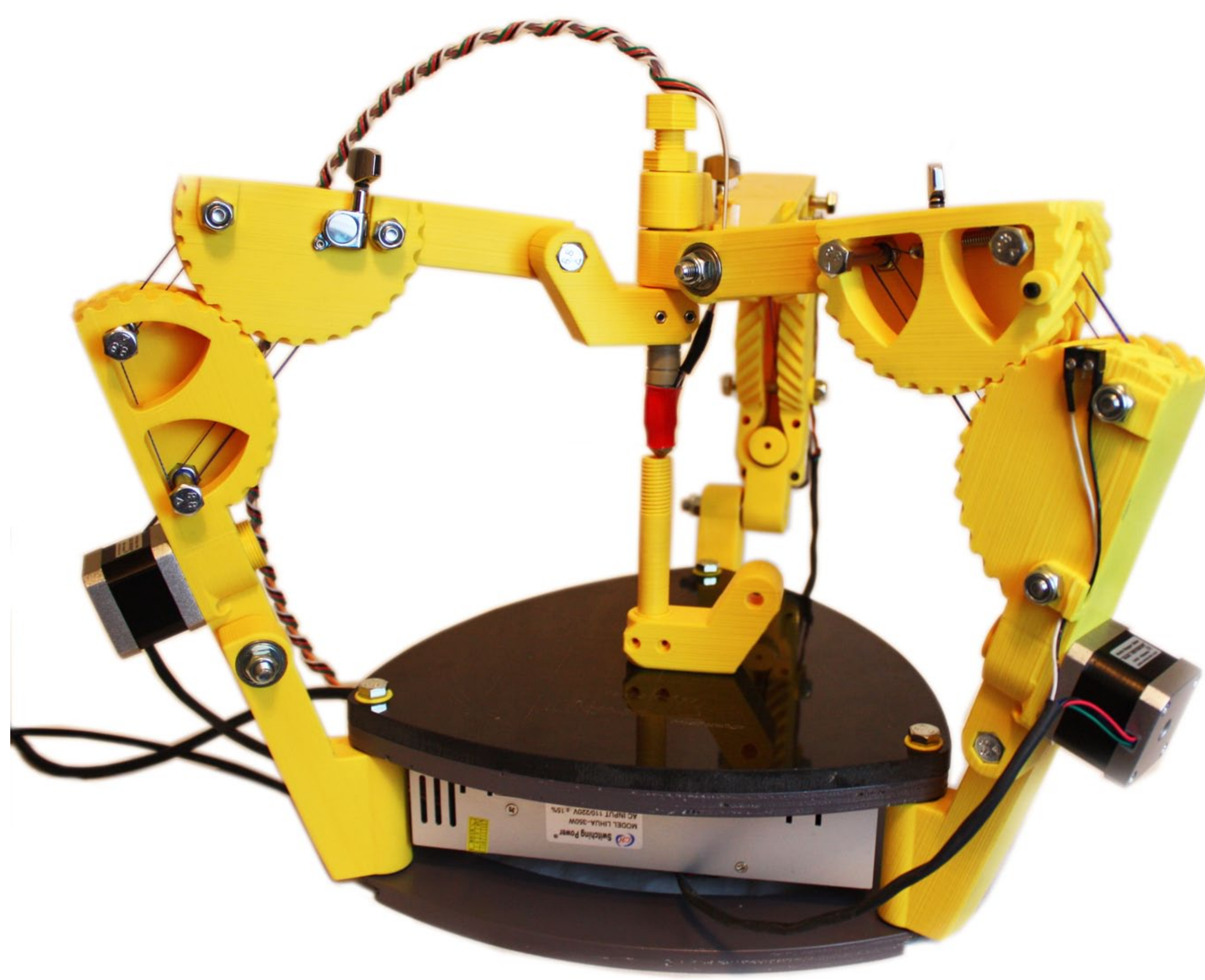
The positive reception of the printer designs led to thoughts about starting a business. Rather than rushing out and creating a Kickstarter campaign straight away, Nicholas decided, quite sensibly, to test the waters by offering 20 beta units of each printer. The creation and delivery of these units is still under way, but the experience has already taught him that any further attempt at printer sales would be a bad business move: *"I could print custom parts for people for three times as much money. I am now targeting a single arm SCARA design that can be completely laser cut. I have it mostly designed in my head."*

He also admits that he *"sucks"* at production and took flak from some in the community after being behind in the beta run and yet still producing a modification to the Simpson design, codenamed LISA.

To alleviate the burden Nicholas introduced discounts for those wishing to receive the beta kit without printed parts, or who would print parts for others in the scheme. reviving a long-held RepRap idea of *"print it forward".* The difficulty and feasibility of small-scale manufacturing is highlighted as this beta production run will actually cause a slight loss for Nicholas. Ultimately the biggest loss is that of his time taken away from working on new designs. His goal now is to honour the commitment so he *"can get back to being a mad scientist"* as he puts it.

The mad scientist persona has resulted in a profusion of derivative designs. Alongside several interesting mechanical variations of the Simpson mechanism, which ultimately led to the GUS Simpson, there has since been a threaded-rod based delta bot (LISA), which followed the incredibly rapid prototyping pattern of the original Simpson, by being turned from idea to reality, and producing it's first print, in only three weeks [1].

Another is the wildly experimental design called the Sextupteron [2], which introduces six degrees of freedom to the hot-End. The key limiting factor to the latter is the electronics, something he hopes to remedy in the near future. Another Simpson derivative is BOB, which stands for "Boltless and Bearingless", an attempt to reduce the vitamin count as much as possible. Nicholas goes on to explain, "he will be a novelty but he will be all plastic except for the hot end, wiring, steppers, string, controller, and possible the bed. I want to explore ways to actually print the bed out of higher temp plastic or print on a surface like a table that the printer sits on. I am viewing this more as a learning experience than designing a serious printer."



Simpson

He also has a *"ton of other printers"* he has yet to design but readily admits that there are other things that have to take priority before they are developed further. One of these is a better filament drive, another is more documentation for the existing designs - the well-known dilemma of wanting to support existing work and yet enjoy the freedom of following new ideas. He also wants to explore alternative means to producing beta runs, which leads to yet another idea...

ConceptFORGE is itself still in the early concept stages, but its goals are far-reaching and go way beyond simply printer designs. As Nicholas explains: *"My ultimate goal with ConceptFORGE is to provide a place for people like me to collaborate on OSHW [Open Source Hardware].".*

The forge would form a distributed manufacturing network, connecting designers and inventors, such as Nicholas, with other individuals or small businesses who offer their services in the manufacture and distribution of their ideas. Manufacturers of any capacity could participate in the network to offer services which help monetise their machines. Designers would have a platform for their products, and people might also be able to commission designs too. *"I want to build up a web enabled toolkit that can make this [collaboration] accessible to all."*

To seed the forge he is considering taking small steps, building up products, kits and services along the way, using his own printer designs alongside others which fit the ConceptFORGE catalogue. Production may come from their own bot-farm or could be contracted out to other providers as necessary. The idea is not limited to only 3D printing but can expand into milling, laser cutting, and more. This correlates with thinking within the maker community, and expressed by some for example at the TCT Live show earlier this year, that 3D printing is one aspect of the much broader landscape which is digital manufacturing. Taking advantage of the increasingly easy means of networking, plus the reduced barriers to entry, so that more people can produce and share projects they are passionate about.

Left: A filament drive problem caused the print failure. Middle: Printed without tweaking the bowden extruder. Right: With bowden modifications.

The digital part is also something Nicholas would like to pursue. He currently teaches computer science at the Arkansas School for Mathematics, Sciences, and the Arts, a position he describes as his dream job. This follows a career of teaching engineering, math and science subjects at high school level. The job not only provides a team of willing assistants, who are currently building the LISA prototype along with other robotic creations [3], but also gives an insight into what tools and techniques are required for taking on such projects, from a variety of backgrounds and experience levels.

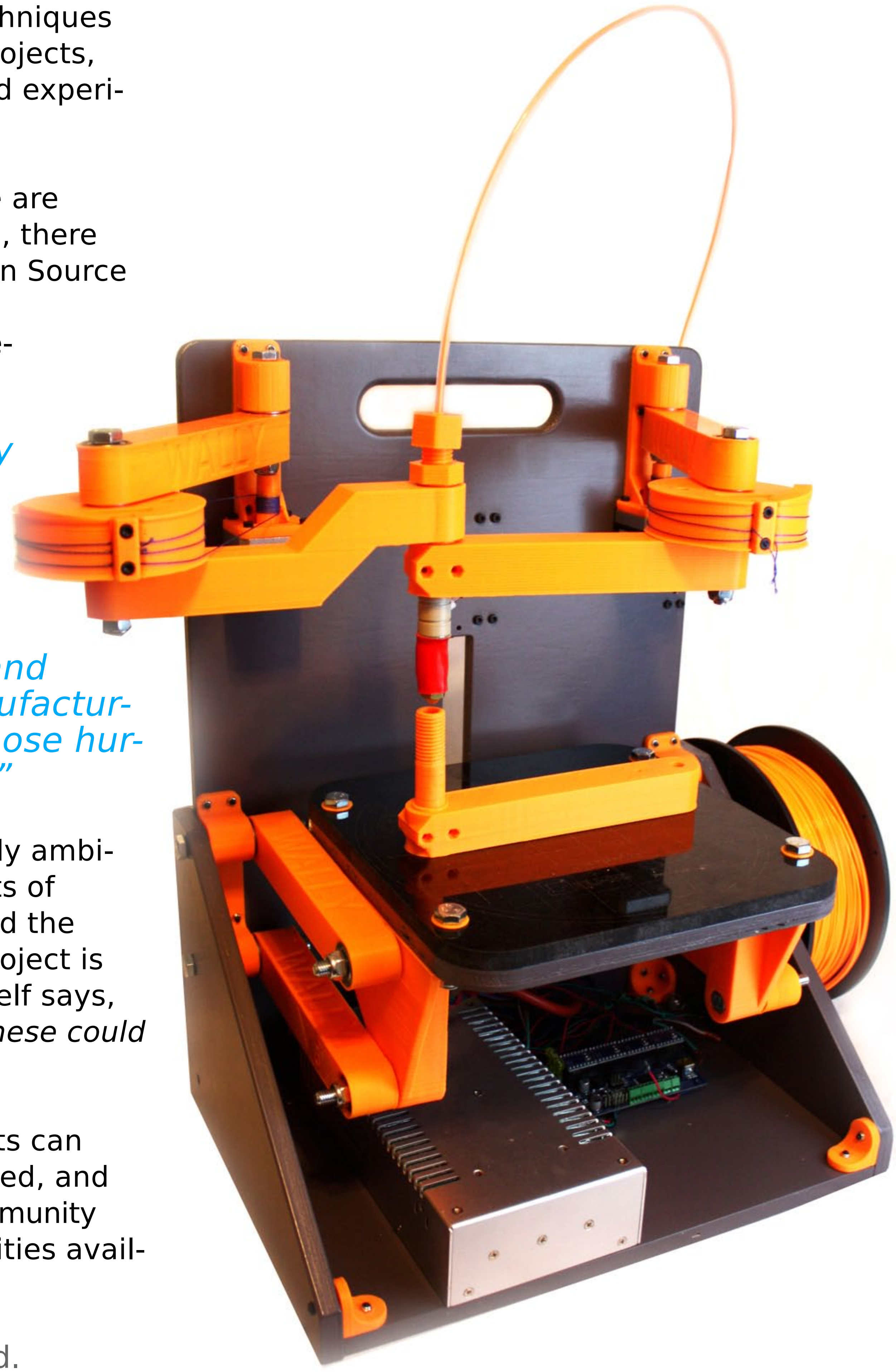
He laments that, whilst there are several free to use CAD programs, there are no viable FOSS (Free and Open Source Software) options, particularly web-based ones, and this is something he would like to tackle.

"The biggest problem in my book is modeling software and that is followed by the availability of tools. If I can provide FOSS web enabled modeling software that can plug into my parts catalog and go with the distributed manufacturing then I remove both of those hurdles to collaborative OSHW."

All of these ideas are certainly ambitious, touching on the many facets of modern digital manufacturing, and the viability of such a far-reaching project is open to debate, as Nicholas himself says, *"who knows what will happen. These could all be pipe dreams."*.

But the fact that such projects can be considered, promoted, discussed, and championed within the maker community hints at the exceptional opportunities available to us.

[0] http://forums.reprap.org/read.php?178,206458,page=1
[1] http://www.youtube.com/watch?v=N7XVxtgHHhY
[2] http://www.youtube.com/watch?v=2kXdsU2bBp0
[3] http://youtu.be/vnXVperYk3o http://youtu.be/0NXDAEupfOA



RepRap Wally

Do you have a cool project to showcase?

A new develpment that works great?

You just went to a RepRap community event and have its review to share?

The RepRap Magazine is open for your suggestions for content that might interest the community.

Its just as simple as sending an email to start the conversation or post on the community forum.

We are waiting for your contributions!

general@reprapmagazine.com

Follow us, and get in touch, at
www.reprapmagazine.com

TCT SHOW 2013

The TCT Show + Personalize 2013 took place in September, and our magazine had the opportunity to be part of it due to our involvement in organizing the RepRap Community Hub.

By Paulo Gonçalves

We have only one word to describe the two days that lasted the TCT Show: Amazing!

When we first started preparing the stand for the show the first thought we had was how can we fill out so much space, but after a couple of months of hard work and a few minutes after the opening of the show we realised we could have used a little bit more space!

The reality is that the RepRap Community Hub was swamped with people during the two days of the event making really hard for everyone on the booth to step out just enough time to grab a cup of coffee, and for that we want to thank to all our readers who visited us during the show.

tct MAG + personalize.

www.prsnlz.me personalize. the hub for the 3D printing and personal manufacturing community

A special thank you to the TCT Show + Personalize for making it possible to do the RepRap Community Hub.

Such success couldn't be achieved without a great team that got involved making the RepRap community booth really interesting and probably one of the booths that printed more stuff during the show.

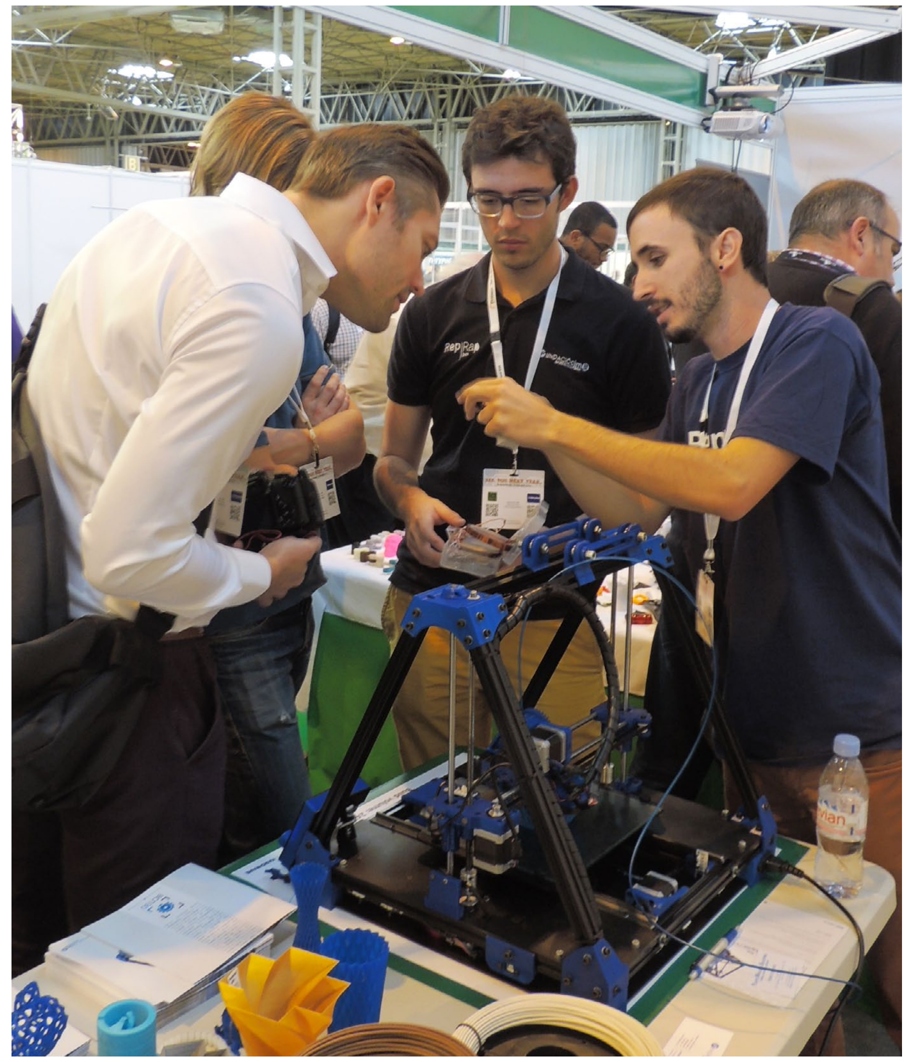
At the date of the TCT Show the magazine was yet to complete its first year of existence, but it was truly inspiring to realise during the conversations we had with our readers that so many of the members of the RepRap community already knew about it.

The view from inside the booth

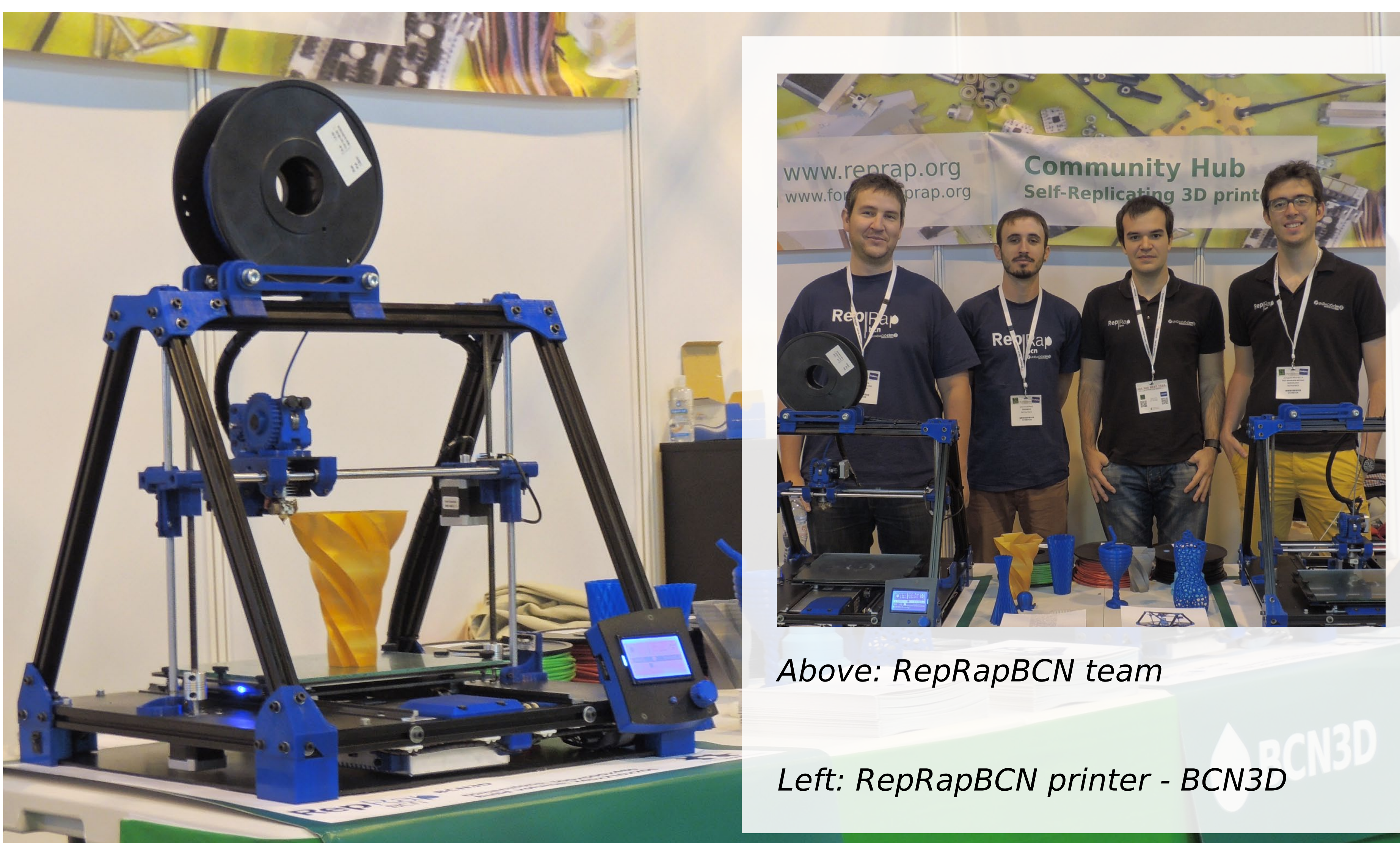
They brought all the way from Spain two very reliable machines and a very good dose of enthusiasm and knowledge.

Their BCN3D printer has a build envelop of 240x210x200mm and performed some really nice and impressive prints during the two days of the show, and its black aluminium profiles give it quite a personality. It features a heated bed and BCNozzle, a full metal hot-End.

www.reprapbcn.com

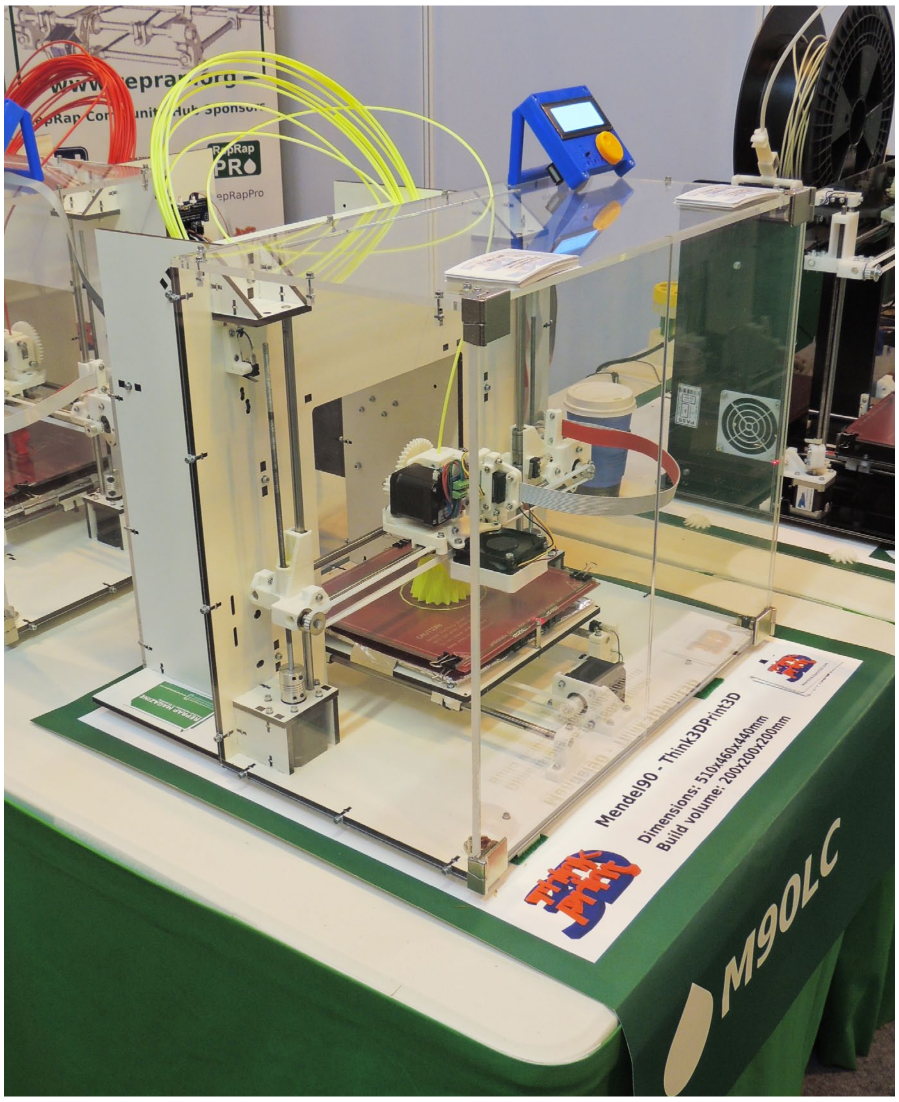


RepRapBCN



Above: RepRapBCN team

Left: RepRapBCN printer - BCN3D



M90LC printer

Tony and Roland brought two of their machines, the M90LC. This machine is a laser cut version of the Mendel90 that features a full encloser that comes really helpfull for those large ABS prints.

I have been following their blog for quite a while and it was really interesting to see their new printers printing live and we can say that a lot of work is put up into the details of this printer.

www.think3dprint3d.com

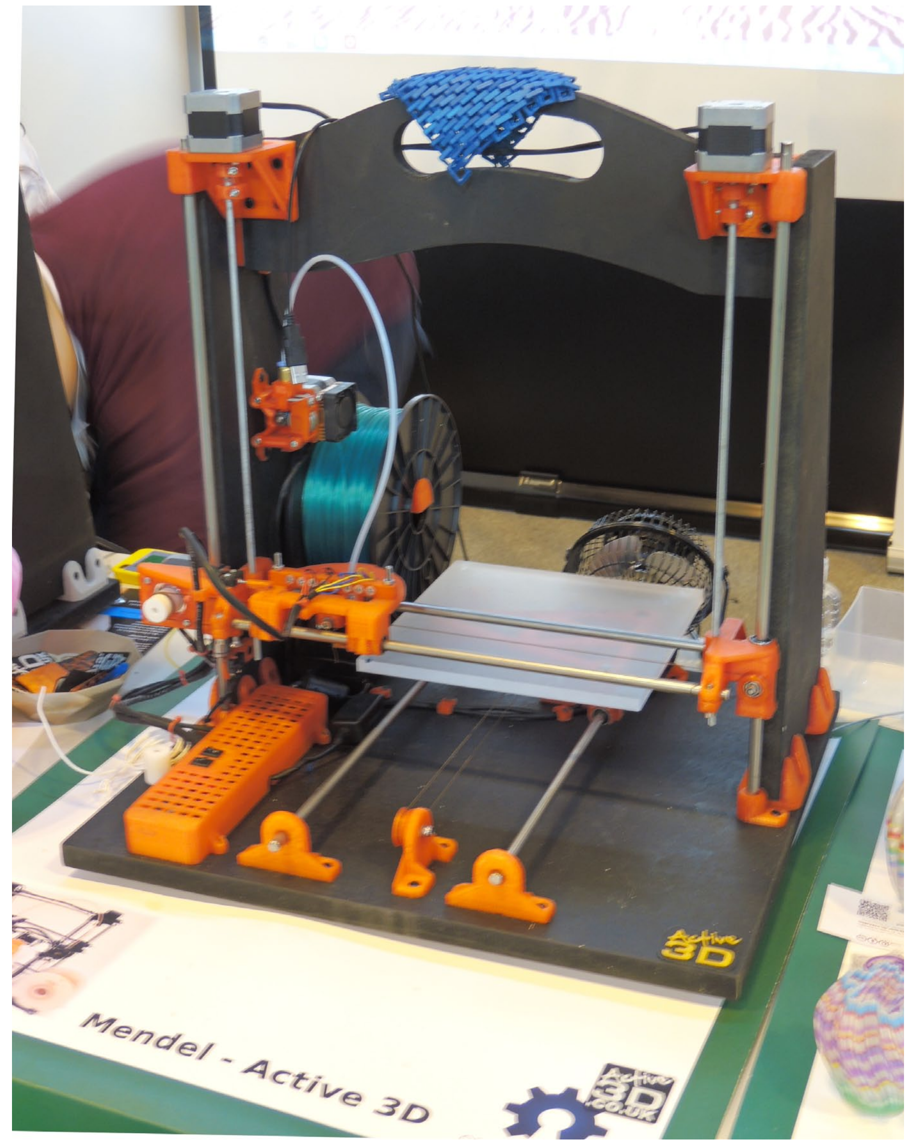
Above: Tony (left) and Roland (right) with their new printer.

Left: Roland talks about the M90LC

I have to admit that the Active3D was one of the very pleasants suprises I had during the show. Personally I did not know anything about their printer before the preparation of the show started and was very curious to see it in action, and once I saw it I have to say it produced really great prints.

Their printer named ARA-X has a very strurdy frame, a Perspex build surface and a build envelop of 270x220x220mm.

www.active3d.co.uk



Active 3D printer - Ara-X

Active 3D print in laywood filament

Active 3D printers on display

faberdashery
.co.uk

It was great to count with Clare and Andrew on the stand. Together they brought along to the booth lots of printed objects made using their top of the line Faberdashery filament.

The quality of their filament is great and their colours are amazingly bright and vivid, and really got a lot of attention.

www.faberdashery.co.uk

Andrew and Clare

Faberdashery display prints

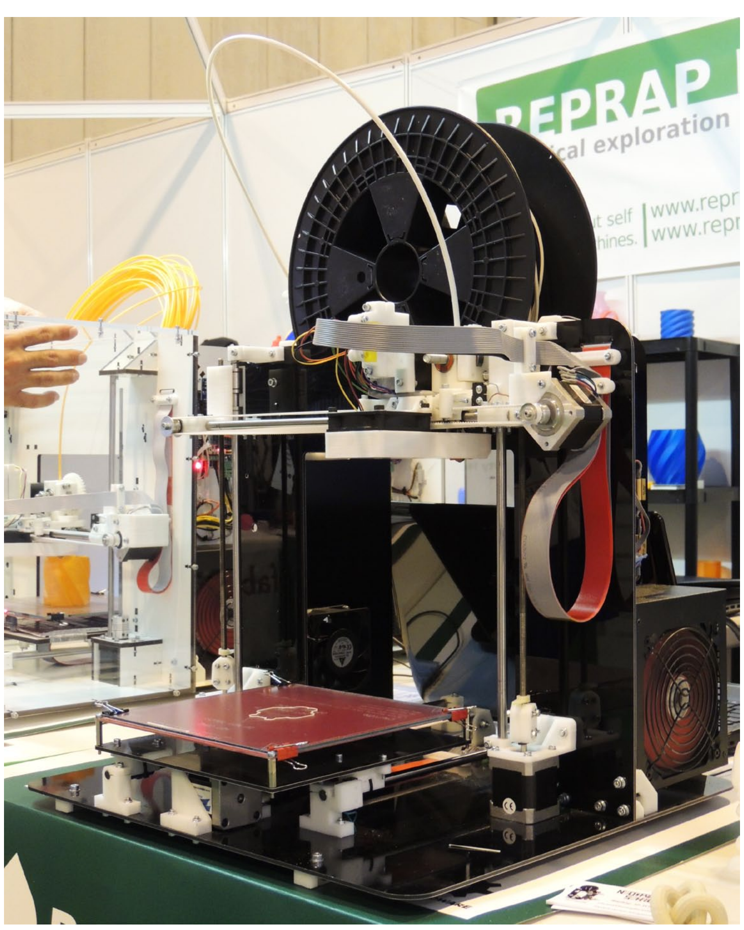
Hammish Mead

Haven't you heard of the Open source Time Machine yet? Wheel Hamisnh is the creative mind behind this cool project.

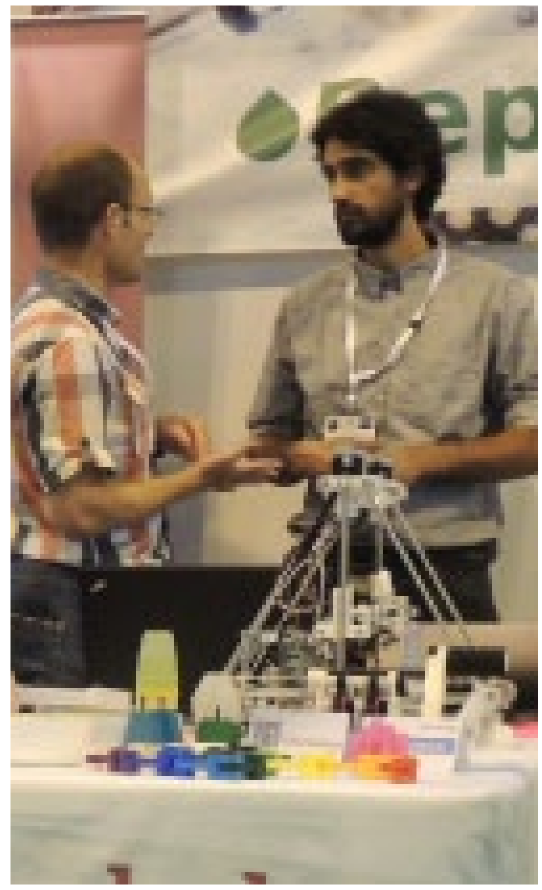
OTM is an open source watch module that has a strong focus on using off-the-shelf components, and it looks great!

github.com/hairykiwi/OTM-02

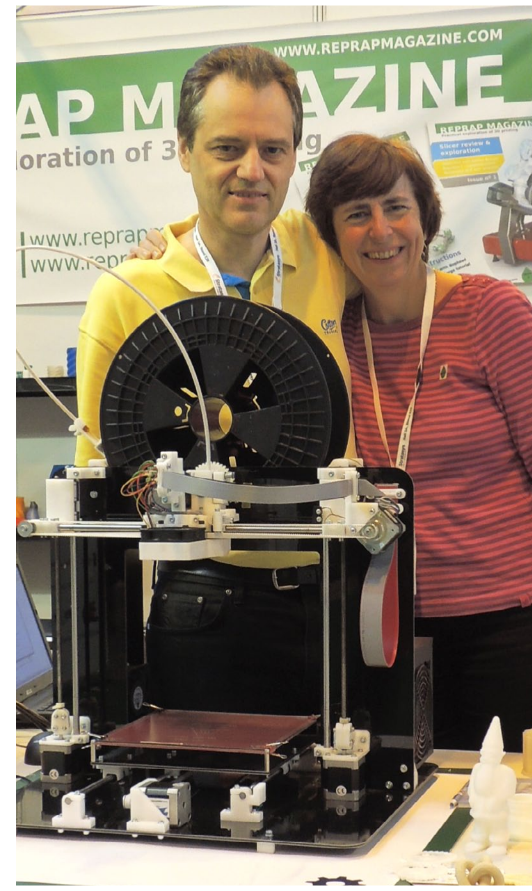
Hammish 3d printable watch (OTM)



NopBotShop Mendel90



Left to right: Hamish and Alessandro



Left to right: Chris, Mary and their Mendel90

Slic3r

We also had the pleasure to be able to have Alessandro present during the two days.

It was very interesting to talk with the man behind one of the most used pieces of RepRap software. He presented some of the features he released on the version 1.0 of his slicer Slic3r, and always had one more advice for the stand visitors.

http://slic3r.org

NopBotShop

Well the name Nopbotshop may be stranger to you but make no mistakes they are a major reference in RepRap developments.

It was a pleasure to have Mary and Chris (Nophead)on the booth. They brought the Mendel90 printer that Chris designed from scratch, and if you check his blog (Hydraraptor) you can see for yourself that there are not that many printers out there so carefully designed and tested from the ground-up.

http://hydraraptor.blogspot.pt

RepRap PRO

They had a stand right next to us where they showed their printers and their range of produts and solutions. Like us their stand was also packed with visitors during the show.

They also had a presence on the Community stand where they demonstrated how to build a Huxley kit from scratch. True be told they spend most of the time multitasking between the Huxley assembly and answering hundreds of questions. It seemed that the visitors did not want to give him enought time to build the printer!

http://www.reprappro.com

Ian building a Huxley printer

Richard Horne was not only in the booth representing the magazine and showing is 3DR printers but was also on the main stage giving a very interesting presentation about his path as a maker involved in the RepRap Community.

Also on the show, and right next to us was the team from RepRapPro with the stand always crowded like the Community Hub which made that back corner the most alive place in the show.

Richard Horne on stage.

http://www.youtube.com/watch?v=KT5frWkqaW8

RepRapPro Team

And for 2014?

A great show is being prepared for the 2014 edition. This year it will be a 3 day show, at NEC Birmingham from Sep 30th - 2nd October.

The 2014 Show Highlights Include:

-200 Exhibitors covering the entire spectrum of 3D printing and additive manufacturing machines in action as well as supporting technologies and software for scanning, digitizing and inspection; and for design and manufacturing.

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-Start-Up Zone -a dedicated area for start-up companies and entrepreneurs looking to showcase their products and services to the growing market.

-RepRap Hub - a dedicated space for the makers and hobbyists out there to showcase recent developments from the community as well as the chance to network.

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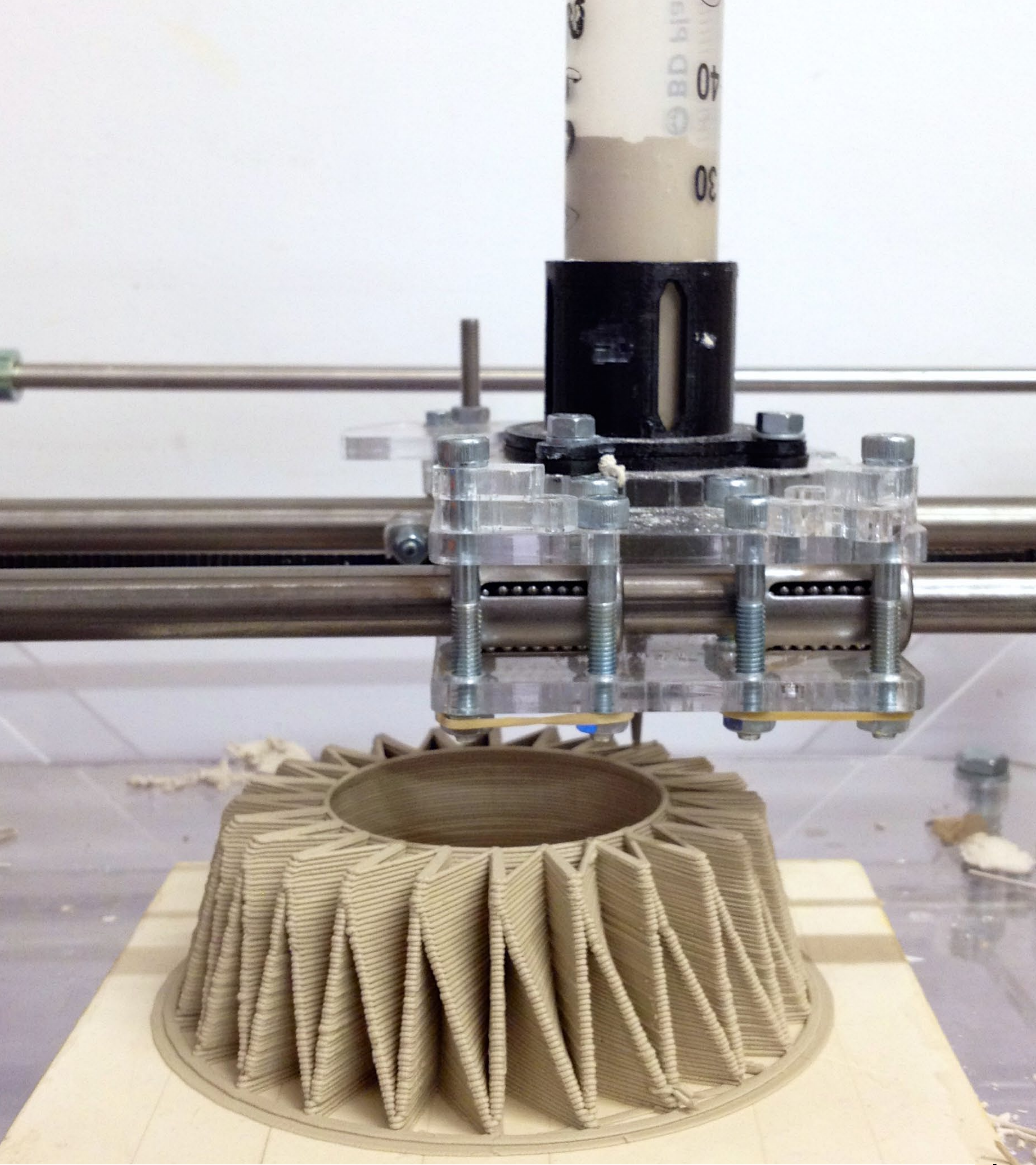

The road to better paste extrusion.

By Dries Verbruggen

photo by Unfold

A paste extruder is a type of extruder that extrudes material in the form of a paste rather than melt a plastic filament. Typically this is a cold process where the printed object solidifies by air-drying. Examples of paste materials include ceramic clay, silicone, resins, play-doh, cookie dough, bio-material, icing sugar, etc. One could even print chocolate or wax with a modestly-heated extruder.

This may sound like it's only useful for hobbyist applications and not for serious use. But have heard about all the research now going into 3D printing biological materials, organs, cells, and tissue? Basically, paste extruders!

Author

Dries Verbruggen

Alias:
Unfold
Country:
Belgium
Website:
www.unfold.be
unfoldfab.blogspot.com

Unfold blog: unfoldfab.blogspot.com
Unfold website: unfold.be

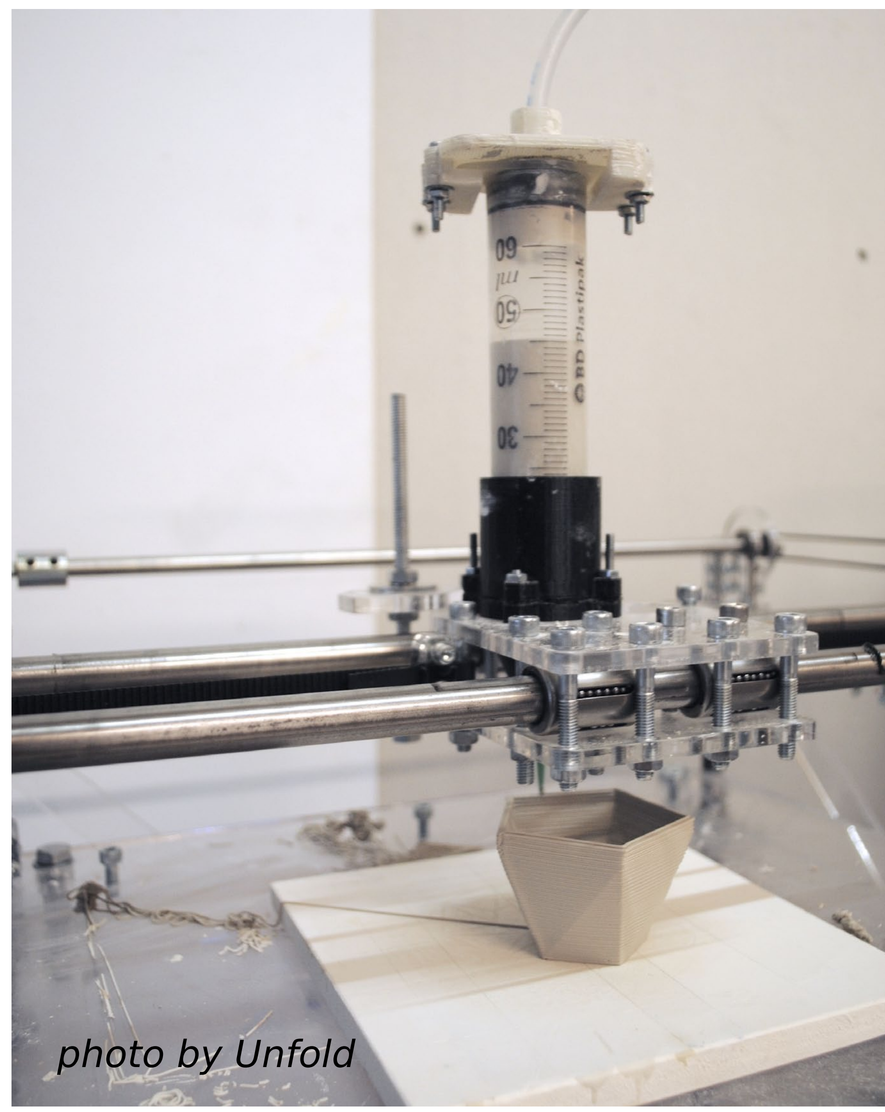

photo by Unfold

I started working on paste extruders at our design studio, Unfold, in late 2009 because we were pursuing the idea of 3D printing ceramics by extruding tiny coils of clay, a process very similar to a traditional craft technique called coiling. It's a form of semi-industrial craft production that projects the past history of traditional techniques into the future. Because of its ability to produce such fine layers, new forms are possible.

photo by Unfold

The Reprap was born with a paste extruder.

When we began we were still firmly in the Darwin age (the first-generation RepRap) and there were barely any commercial RepRap-derived kits available. There was a fair amount of talk in the RepRap wiki and forum on paste extruders, mainly as a method for printing support material, conductive materials for circuits and motors, and hot-end ceramic insulators. One of the goals for RepRap v2 (later born as Mendel) was to have true multi material capabilities


Syringe pump
photo by Adrian Bowyer

sturdy, standardized, easy to use, and maintenance-free.

I was never personally interested in the challenge of developing hardware, and frankly I lack the skills to do so. What excites me is the new “form language” created with the tool and its applications and implications. Out of necessity I’ve continued researching paste extruders on and off, and I’ve learned to enjoy it.

so it could print more of its own parts. (As mentioned, the RepRap project started with a paste extruder before filament extruders took precedence. If you’re interested in the back-story, check out the announcement on the RepRap blog from March 23, 2005. The photo of the original prototype a small syringe pump - is no longer there, but you can find it using the Internet Archive Wayback Machine if you’re deeply curious.)

The general interest in paste extrusion died down quickly in the RepRap community because such exciting progress had been made in Fused Filament Fabrication. FFF proved far superior for producing mechanically-sound parts. Also the need for support material was reduced by designing parts that could be printed without any support. Eventually people lost interest in the development of ‘inferior’ paste extrusion.

The RepRap potential as a serious 3D printer has grown exponentially. Today there are dozens of professional RepRap-derived commercial 3D printers and kits kickstarting the home 3D-printing revolution. This explosion of public interest in 3D printing has had the further effect of diverting effort from Adrian Bowyer original noble goal of a fully self-replicating machine, and towards the (still quite noble) goal of developing professional-grade 3D printers that are more

After a few years of relative neglect, lately I’ve seen a revival of interest in paste extruder development. My sense is that the low-hanging fruit in the development of extruders, frames, and drive mechanisms has been pretty-well picked, so developers have begun to look for new challenging ventures, especially in materials, fabrication processes, and frame design. This is very exciting and hopefully we will soon make large strides in developing RepRap paste extruders. And this is necessary because - as I have experienced by mainly using them in the last three years - the issues are more challenging than they initially seem.

In this article I want to give a state of paste extruder development from the perspective of a non-engineer, go over the main principles with their pro’s and con’s and show examples of various types of extruders.

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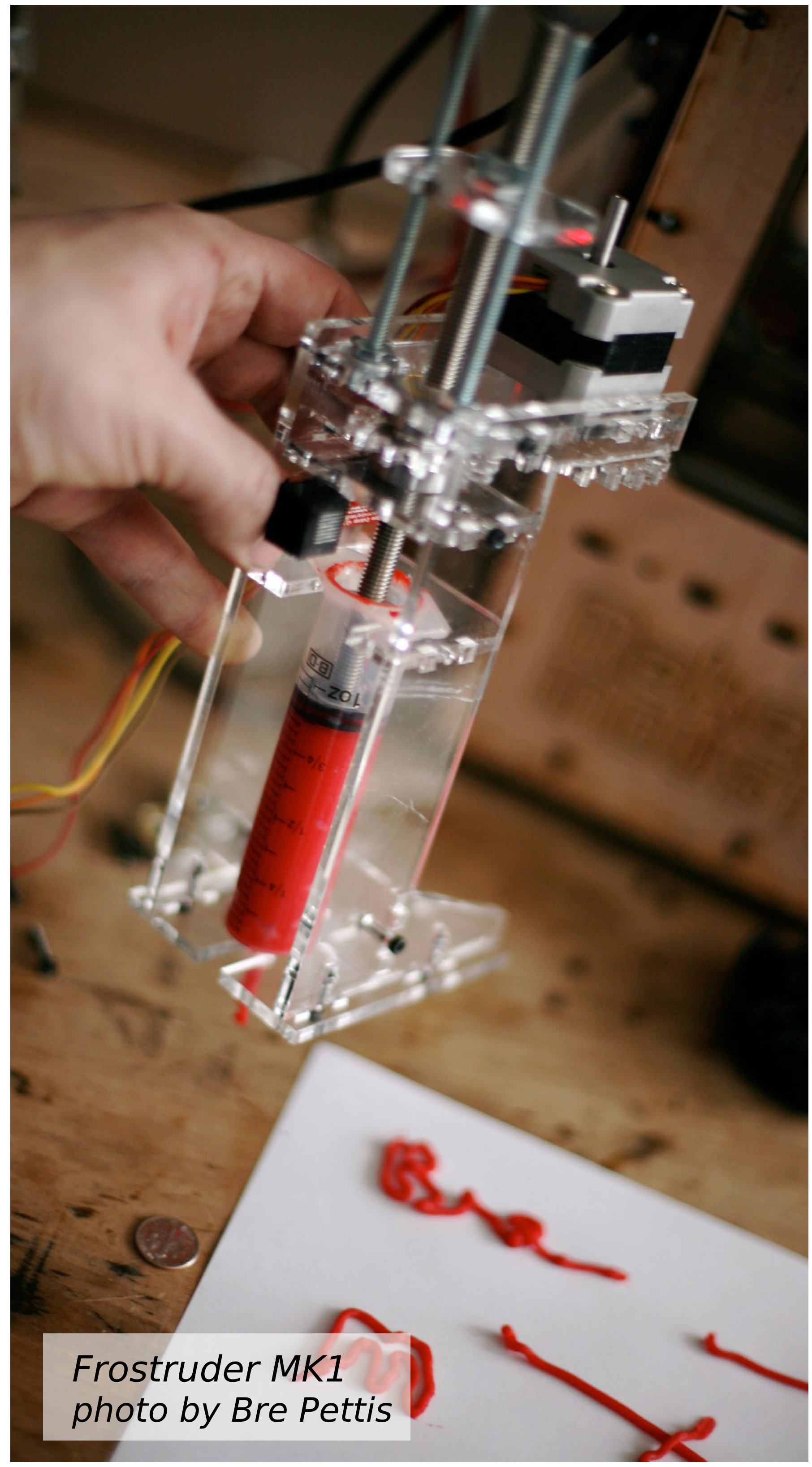
1) Stepper-Driven Syringe Pump

As the name implies, a Stepper-Driven Syringe Pump (SDSP) uses an electric motor to push a plunger down a syringe barrel. This is sometimes called “Direct Drive.” Here we have various options. The “Fab@ Home Model 1 Syringe Tool” uses a pricey linear stepper. Other current models use the more standard rotational stepper with some extra mechanics like a gear train. Early examples of this approach include the Fab@Home Model 2 Syringe Tool, the above mentioned syringe pump by Adrian Bowyer, Zach Hoeken’s Frostruder MK1, and Viktor’s (VMX) Syringe Tool. More recently there’s David’s Paste Extruder and the Universal Paste Extruder by RichRap.

The concept is simple enough! Want to empty a syringe? Just push the plunger down with a motor! This simplicity probably accounts for the popularity of this approach. Brute simplicity has some benefits, but there are some major drawbacks as well. The first drawback of syringe designs is that the extruder becomes very bulky. The total extruder height needs to be at least twice the syringe’s length to make room for the extended plunger, then add even more for the mechanics. A 60cc syringe with the plunger extended is 30cm long. Add in the extra drive bits and the nozzle, and your extruder can easily end up being 40cm high.

Various approaches have been used to slim down the design. For example, RichRap’s Universal Paste Extruder pulls a belt over the plunger with a geared stepper motor. Unfortunately its tiny 10cc syringe is barely enough to print a cookie! BonsaiBrain has produced a 20cc version, but to use his own words: The construction is quite monstrous! It requires so much torque that a fourth gear is needed. But the syringe capacity is an important factor. 60cc is one of the largest standard syringe volumes, but it takes 40cc of ceramic clay just to print a small coffee cup. Anything larger requires a more capacious syringe or multiple syringes, meaning a vastly larger and more complex extruder. One could try swapping out syringes in mid-print or move the syringe out of the extruder by design (something I will discuss), but that’s not the most workable solution.


Frostruder MK1
photo by Bre Pettis

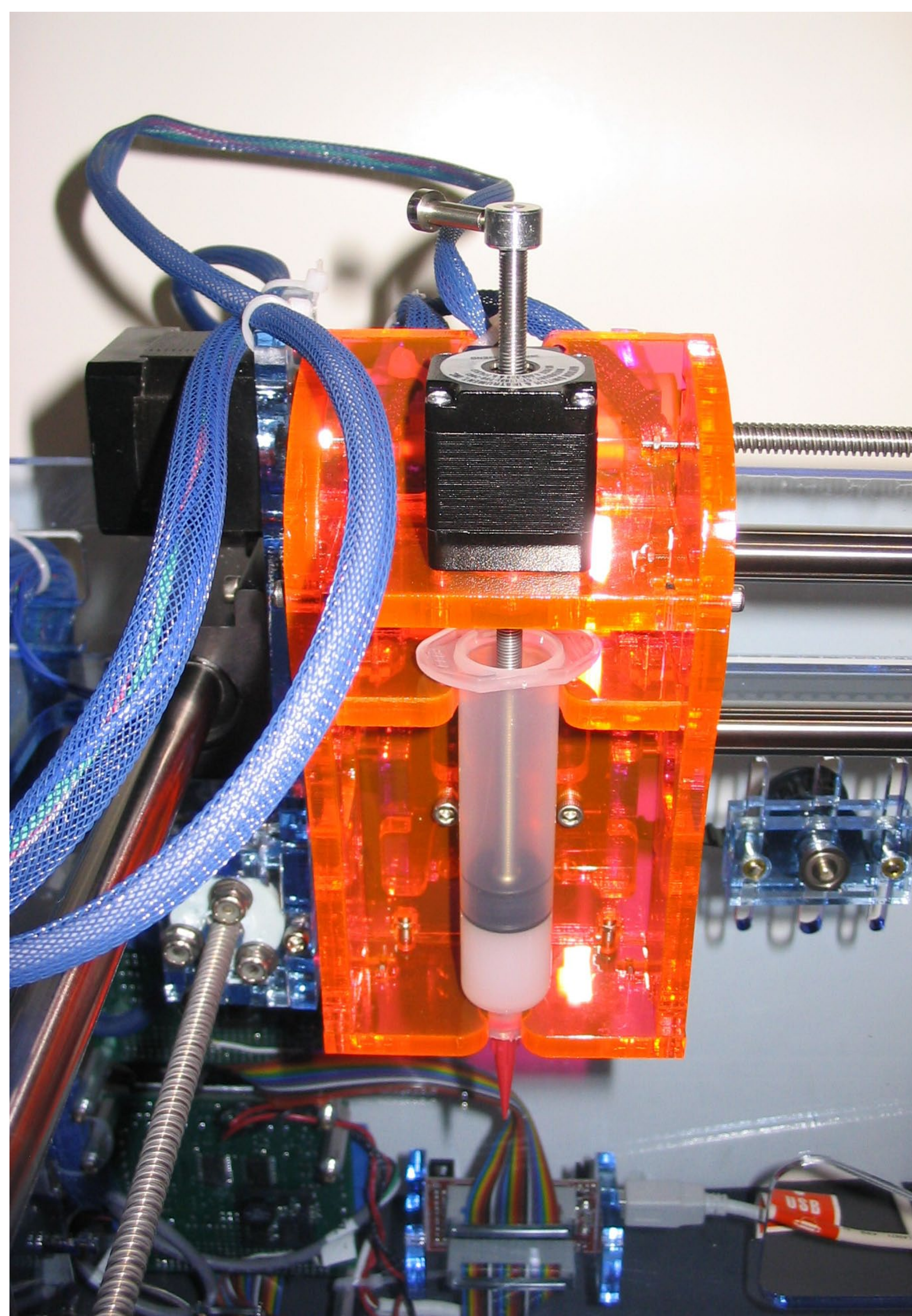
Another vexing problem is that syringe designs vary a lot by manufacturer. Any design that depends on a specific syringe probably won’t work with other sizes or brands.

Some designers have proposed using something like the Bowden approach (first popularized by Ultimaker) in which filament is pushed down a long PTFE tube. Following this approach, paste or clay would be plunged into a tube and fed to the nozzle on the print head. This allows the extruder to be mounted off to the side, reducing the weight and complexity of the nozzle carriage, but it adds some friction and thus requires more torque. Nevertheless, with such an approach it's theoretically possible to use syringes even as large as a 310cc caulking gun cartridge.

Another drawback of the Syringe Pump design is that it's not really a good idea to control your extrusion by pushing your entire volume of material from behind. This approach may work fine in a small 10cc syringe, but it becomes unwieldy when we try to scale up to 100cc and beyond. This is akin to pushing your whole roll of filament from the end of the roll instead of feeding it from the extruder. As we scale up to larger syringes the diameter of the plunger gets larger and it becomes much harder to extrude small amounts with precision.For every millimeter of linear plunger travel, a doubling of the plunger diameter results in a four times the amount of extruded material or a quadratic increase, so any imperfections in the drive mechanism are noticeably multiplied. This also increases the start and stop time, and we see a lot of oozing when scaling past 20cc.

It takes substantial force to push paste through a syringe, and the more viscous the paste the more force it requires. With filament you can use more heat to reduce viscosity, but we can't do this with paste. Paste needs to have sufficient viscosity at room temperature to be stable for a printed object. Since it takes longer to set, it must be able to maintain its shape and not collapse under its own weight. This is especially important in printing taller objects. We experienced frequent mechanical failures while testing RichRap=E2=80=99s Paste Extruder with Precious Metal Clay (an ideal material for the small syringe) and our own 60cc design, which is comparable to the Frostruder MK1. Gears came loose, steppers lost steps, belts broke, and syringe retainers failed under pressure.

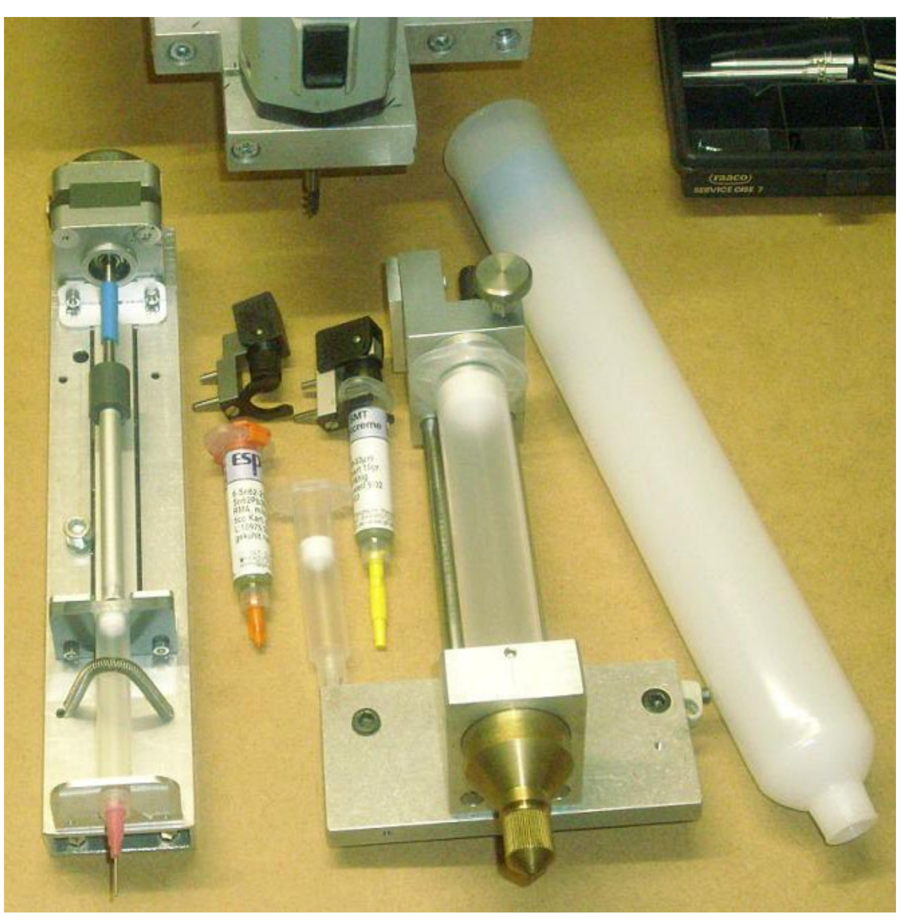
By now you may be wondering if there's anything positive to say about the Stepper Driven Syringe Pump. Actually, yes! Foremost, a syringe pump is perfectly volumetric, a vital characteristic of any paste extruder design.



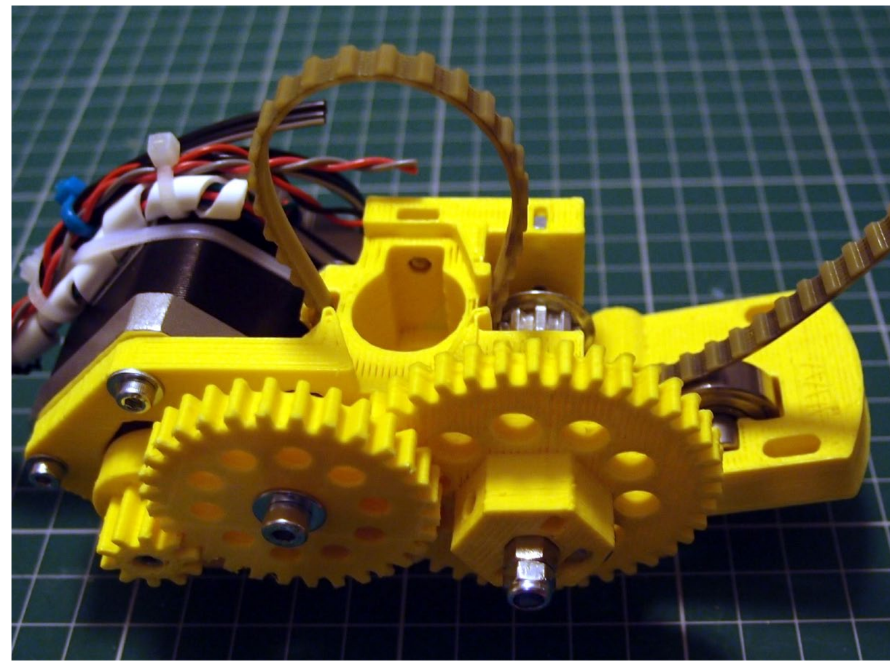
Fab@Home - Model_1.1 SyringeTool-photo by Fab@Home

"Volumetric" means that a specified amount of rotations from the motor leads to a predictable and repeatable amount of extruded material. Just as in a filament extruder, you can easily calculate the amount of material extruded per step and control your extrusion pretty nicely. The use of a stepper in the design means you have full compatibility with existing electronics and software. RichRap Universal Paste Extruder is an excellent way to get started with paste extrusion and do small tests with various materials. But as we've discovered in our testing, for any serious printing of multiple or larger parts, we need to look for a different approach.

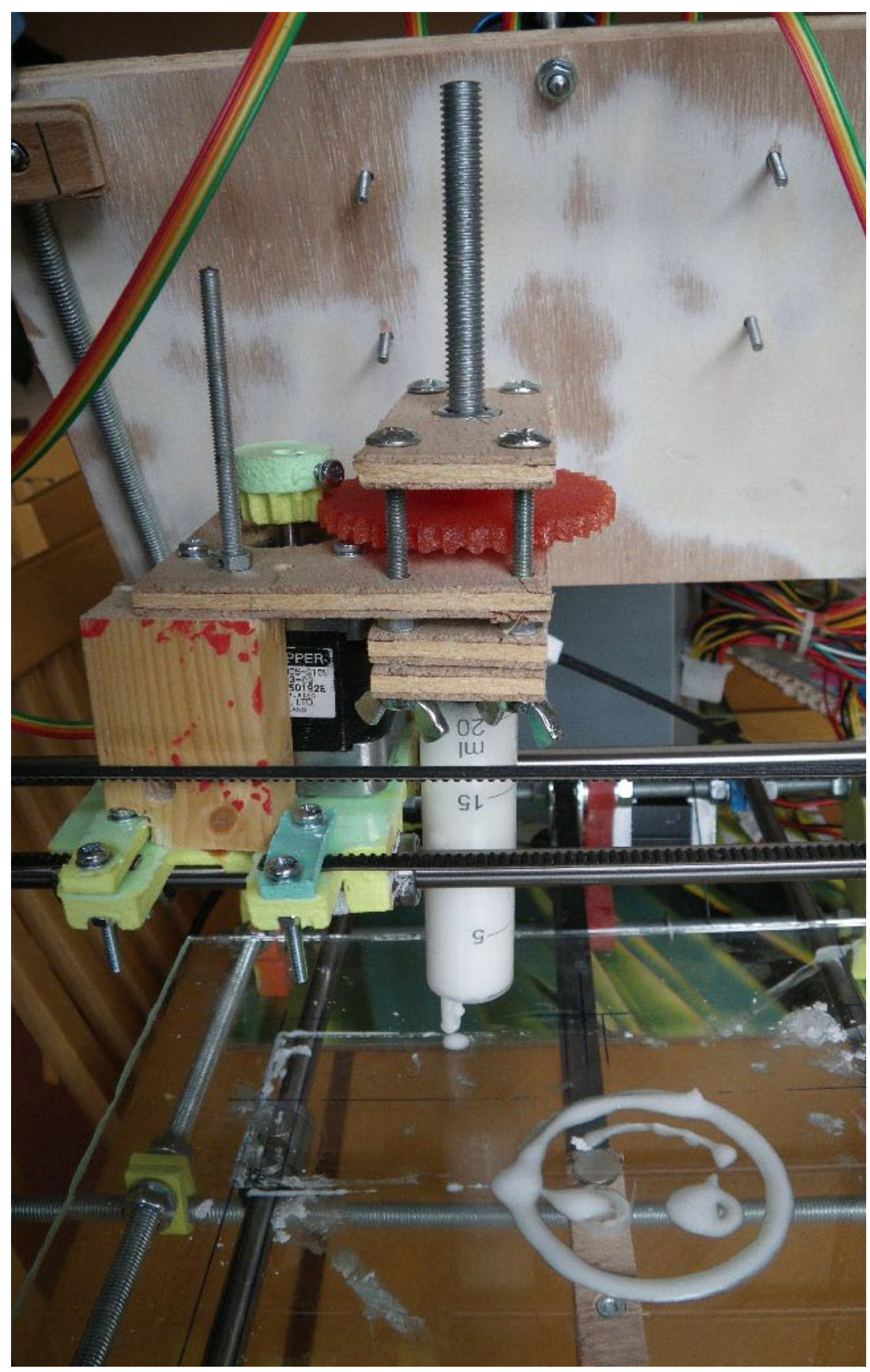
One potential way to improve the Syringe Pump (which no one has implemented as far as we know) is to use a fairly small permanent chamber with a plunger (like a syringe), perhaps 5-10cc in volume, that can be quickly refilled from the side. Once the plunger has pushed all the material out of the chamber, printing pauses, the nozzle moves off the print, the plunger retracts, the chamber is refilled from a large capacity pressurized container, and finally it does a small starter extrusion before resuming.



VDX Paste Dispenser 2
photo by Viktor Dirks



RichRap - Universal Paste Extruder
photo by RichRap



Davids Paste Extruder
photo by David Mckenzie

A valve on the feedline would switch between extrude and refill. With some cleverness and two alternating pistons it could even print continuously. Such an approach could retain the straightforward volumetric principle while keeping the size of the print-head small and the control precision high.

2) Direct Air Pressure Extruder

The Direct Air Pressure Extruder (let's call it DAPE) is almost the exact opposite of the Stepper Driven Syringe Pump. Instead of using a mechanical method to push down a plunger DAPE applies air pressure directly to the material. This extruder design is radically simpler and lighter than the method previously described. The top of the syringe is sealed with a pressure cap which connects via a narrow tube to an air compressor. Air flow is then controlled using a solenoid valve (a fluid or gas valve controlled by an electromagnet) to start and stop the pressure.

Using this method the extrusion can be started and stopped almost instantaneously. While the extruder design is light and simple, it does require a supply of compressed air. Most homes unfortunately are not equipped with central air pressure, so an air compressor needs to sit next to the machine.

This approach was first proposed by Zach Hoeken for Makerbot Frostruder MK2 and in all fairness (and to stick with our digging into RepRap history for traces of paste): Adrian Bowyer designed a very crude paste extruder that uses a balloon filled with material in a PET bottle pressurized with a bicycle pump! You can find this rather amusing 2007 Support Extruder 1.0 on the RepRap wiki. So that's the major benefit, a simple and lean extruder.

At Unfold we still use DAPEs all the time because of their relatively straightforward simplicity. We designed a couple of iterations of the extruder for the Bits from

RepRap Support Extruder 1.0
photo by Adrian Bowyer

Bytes "Rapman" which became very popular with paste extrusion experimenters because its print-bed is limited to Z movement. You can find these designs on Thingiverse; just search for "Claystruder." Mechanically this design is also far easier to scale up. Just extend the syringe or go for a larger syringe and cap.

British ceramicist Jonathan Keep, for example, has shown that a DAPE with a 310cc caulking gun syringe can be installed directly on a DeltaBot XYZ carriage.

As you might expect, DAPEs tend to perform very poorly in the controllability and predictability of the extrusion process, and in their compatibility with RepRap electronics and slicing software. The first problem is that there are so many variables involved in getting a repeatable and predictable flow-rate. The most obvious variables are air pressure and material viscosity, which combine to produce a certain flow rate. Then you must consider plunger friction, the changing material level in the syringe, etc.

Flow rate = 3D Material Viscosity + Air Pressure.

So if your material's viscosity changes only slightly you need to compensate for that by raising or lowering pressure to keep a steady flow. A static input of air pressure gives a wide range of flow rates depending on the material. Compare that to the static speed of your Stepper Driven Extruder which regardless of the type or viscosity of paste gives a predictable and continuous flow rate.

Many ideas are being considered to address this chaotic system. Firmware could be updated to work with the parameters of air pressure systems and compensate for some known effects. But this may require replacing syringes with each successive print because a plunger acts differently in a used syringe, and generally the consistency will never be exactly the same on each print and throughout the entire process. Today we can control for these variables with an industrial setup, but not in RepRap style.

A possible fix is to create a closed control loop with an electronically-regulated pressure valve monitoring flow at the nozzle and adjusting pressure to achieve the desired flow-rate. The components required to do this aren't the cheapest parts available. Alternatively it could adjust the print speed dynamically based on the flow rate within a certain "workable" range, not too fast/slow.


photo by Unfold

Unfortunately, cheap ways to measure the flow-rate of a high viscosity material which don't obstruct flow haven't yet been found. Most of us now actively printing ceramics use the very simple Direct Air Extruder, but since the printer has no way of knowing how much comes out of the nozzle at any given time, we all have to babysit our machines and adjust air pressure as-needed. Our attention to the process makes this more craft than 3D printing.

The incompatibility with exciting new electronics, firmware, and slicers is also an extant issue with DAPEs. There's no stepper to control, only electronic valves, and, potentially, digital pressure valves and flow sensors. But never mind that, because the extruder's physical control to stop and start the air pressure is highly unreliable anyway. Each time the syringe is depressurized and quickly returned to the "same" pressure, the flow rate is likely to be different, so repeatability is low. One solution would be to maintain a constant pressure level and throttle the material flow at the nozzle. There are various industrial valves that do just this, and these could be easy to replicate. F@H's valve tool does this by using an off-the-shelf valve between the syringe and the nozzle. The vintage RepRap Support Extruder 1.0 uses a similar method.

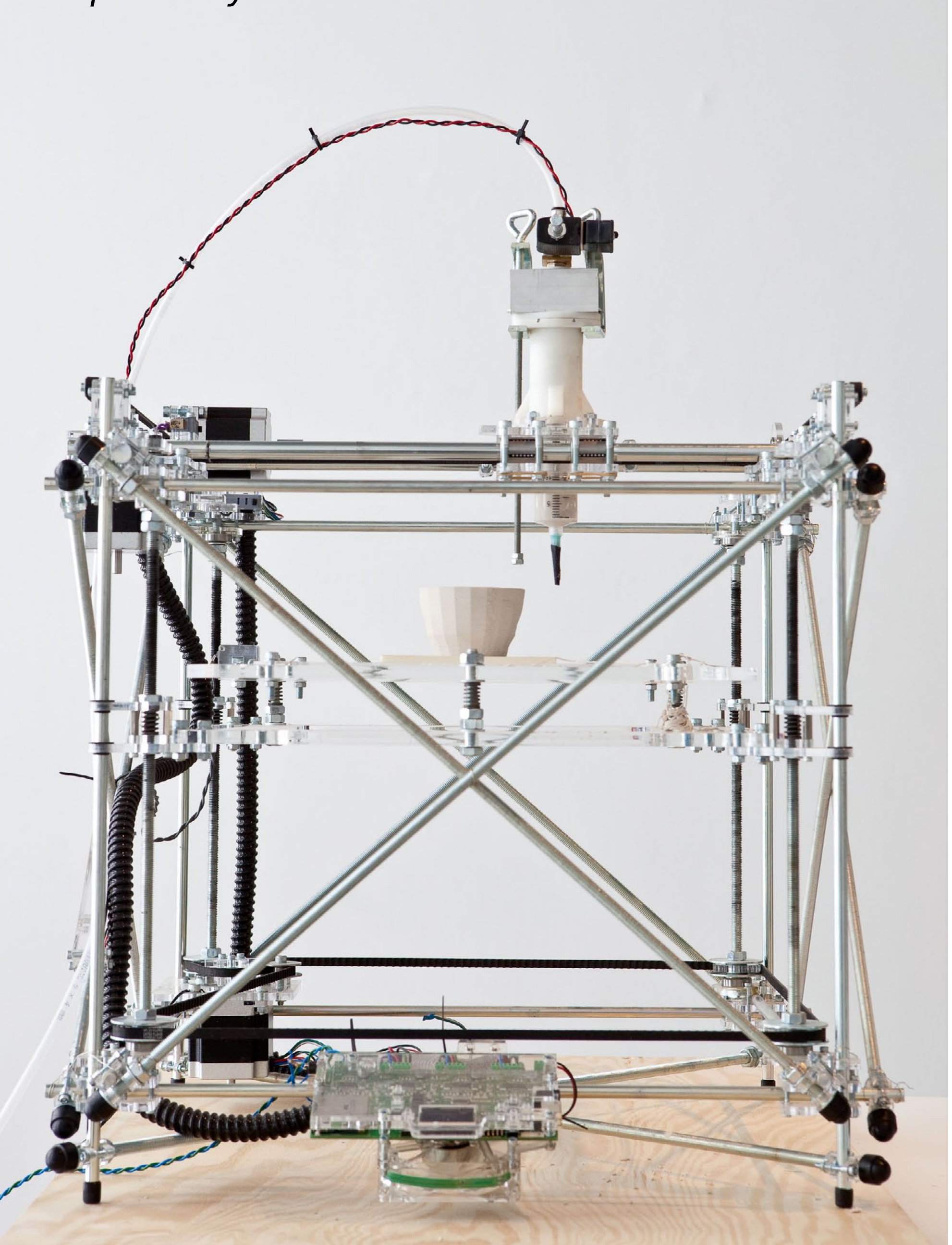


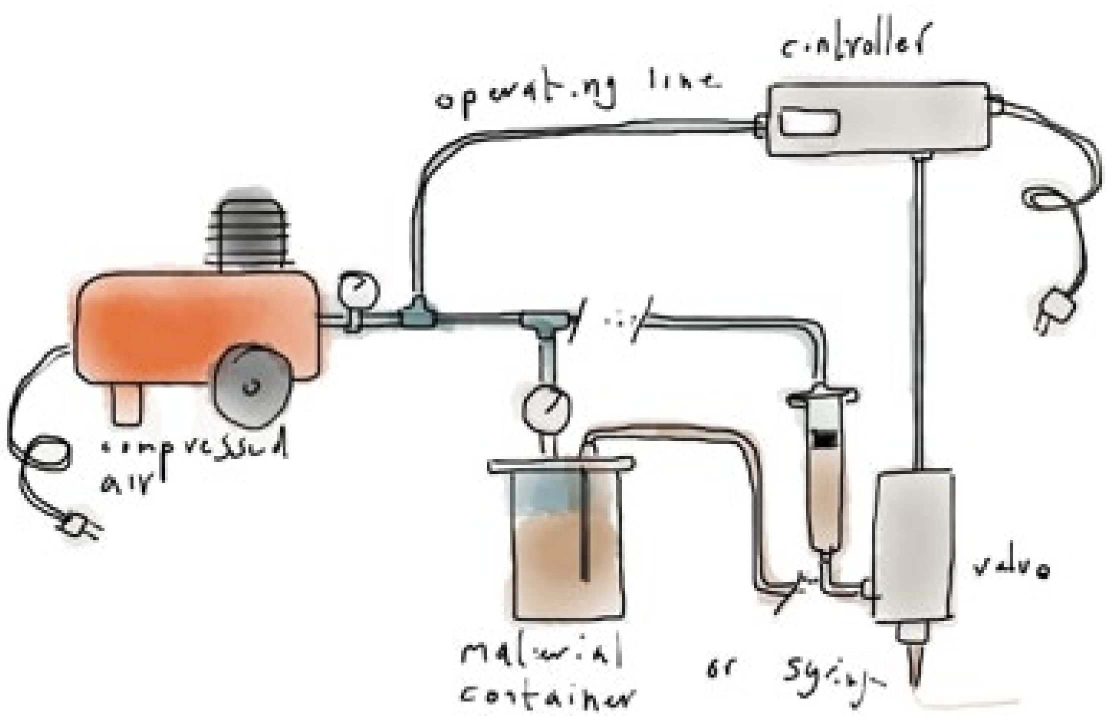
photo by Kristof Vrancken

Honestly, most people using DAPEs (mainly for ceramics) have stopped using electronic valves altogether and designed around the problem by creating objects that can be printed in one continuous action without the need for the extruder to jump from one place to another. Pressure is plugged in at the start of the print and released at the end, again a very hands-on approach. As with the Stepper Driven Syringe Pump, If you don't mind manually controlling the extrusion process, DAPEs are a great way to start exploring paste extrusion, especially for printing ceramics and other large volume materials.

3) Positive Displacement Extruders

So we want the best of both worlds don't we? We want to move the syringe out of the extruder, and a stepper motor would be lovely for compatibility, we want a pure volumetric or metered system and we don't want to control the extrusion by pushing all our paste material back and forth but rather control the flow close to the nozzle.

Enter the volumetric or positive displacement pump. Frustrated by the first two principles as a starting point for an extruder worthy to sit next to your high quality filament extruder I started to look at the various ways in which industry, and more specifically the dispensing industry, tackled this problem and started digging through countless websites and books.



From wikipedia: A positive displacement pump makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe.

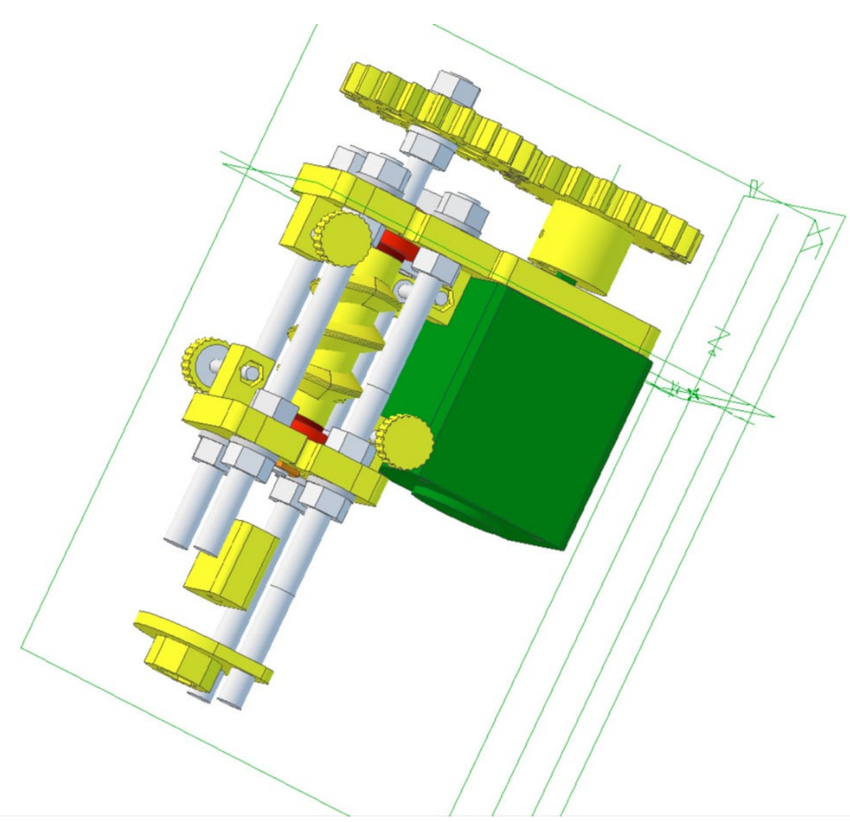
So the key here in the definition is the ‘trapping a fixed amount’ part. Each rotation of the pump mechanism traps a specific volume of material and sends it to the exit of the pump, the nozzle. If a stepper motor drives this, we have a system in which we know that X amount of motor steps results in Y amount of extruded volume. You place this pump as close as possible to the nozzle and let it ‘pull in’ the material from a feed line in exactly the same way your filament extruder pulls in the filament right before the nozzle.

The only difference is that we don’t have a nice roll of filament but a messy blob of paste in a reservoir. So there is the need for an external reservoir. In case of a runny fluid like a molten chocolate one could use a gravity feed system (the material flows in the pump by gravity when the reservoir is above the extruder) but more often than not we will need to pressurize the reservoir. The easiest way is by air pressure. Yes, that uncontrollable thing we rejected above. In this case we apply more than enough pressure to get the material to feed into the extruder, which will take over from there and control the flow rate.

Let’s look at a couple of positive displacement pump principles that are often suggested for a paste extruder.

The peristaltic pump is a type of pump where the pumped medium travels through a tube and never comes into contact with the pump mechanism. The pump consists of a set of rollers that squeeze the tube and push the medium forward. It shows a lot of pulsation in the output at each contact point between roller and tube. This can be solved by having multiple tubes with alternating wheels. Ioan Festeu designed a very elegant, compact peristaltic extruder design with dual channel feed lines.

Unfortunately neither Ioan or me managed to get it to work with thicker pastes and literature will tell you that the peristaltic pump is only suitable for low viscosity fluids and there are several other issues with it too.



Ioan Festeu Peristaltic Paste Extruder 2
photo by Ioan Festeu

Another system is the gear pump, commonly found as an oil pump. Two locking gears rotate in a sealed housing and the fluid is pumped on the outside of the gears. While this could work fine for certain self lubricating materials (like oil but may be chocolate too?) it's terrible when trying to dispense a ceramic clay which is filled with abrasive particles that easily get in between the large contact areas between the static and moving parts and grind the pump down.

One of the systems that caught my eye during research was the auger pump, an Archimedes screw extruder, often used for dispensing small shots of solder paste in PCB assembly lines. It's billed as capable of dispensing high viscosity, abrasive, particle filled materials with ultra precise control.

Auger pumps works like this: The material is fed from a continuously pressurized external reservoir into the top of the pump. The pump consists of an auger screw fitting perfectly in a cylindrical housing which at the bottom ends in the nozzle. The pressure on the syringe is just enough to feed the material in the pump where it will hit the top of the auger and stops there because of the increased friction caused by the narrower size of the fluid path along the screw thread and ultimately at the even narrower nozzle end. The screw is actuated by a motor and this rotation forces the material down the screw thread, creating a pressure difference and the material flows out of the nozzle. The flow rate is controlled by the RPM of the motor.

I designed a first extruder using this principle nicknamed the Claystruder 2, Auger Paste Extruder which was based on a small 25€ disposable plastic auger extruder from an industrial dispensing system. The first tests with clay were fantastic, this was exactly what was needed. It behaved very much like your standard plastic filament extruder. Turning the stepper on resulted (after priming) in an immediate flow of clay proportional to the speed. Stopping the stepper resulted in an immediate stop and no material passed the auger form the continuously pressurized syringe.

We did some initial test with clay, chocolate and potato mash and those looked all promising. But after some further extensive testing with porcelain clay the system became less and less reliable and odd symptoms started to occur: flow rate became unreliable during a print and adjustment was needed, material leaked past the auger when the motor was not turning. Closer inspection of the auger confirmed a suspicion, that the delrin plastic augers were being worn down by the ceramic material and this happened already after a few minutes. For 125€ one can get a steel version of the auger but even with that the housing degrades quickly.

Claystruder Auger
photo by Unfold

With even more budget one could buy a complete stainless steel ‘disposable’ package or even a ceramic one but those go at the averages selling price of a Mendel kit. Plus they all look geared towards dispensing small volumes of material and not continuous extrusion in the amounts we need, they are under dimensioned and therefore pushed beyond their limits. There was another observation that was against what one needs in a reliable predictable paste extruder.

I did a couple of tests to see what happens when you change the air pressure on the syringe that feeds the material into the auger and, obviously, below a certain point the pressure would drop too low to feed the auger but above that point the output of a fixed speed turning auger would vary in relation to the input pressure. Definitely not as much as when you would use a Direct Air Pressure extruder but still more than enough.

What this means is that a change in material viscosity would still result in a changing flow rate at the nozzle. In spring 2013 an engineering student camped a couple of months at Unfold to work on his master thesis on paste extruders, and he wanted to look again into the auger. While I was skeptical, there were two reasons for him to pursue: the auger is the most commonly used extrusion system in the industry and his professor made him do so. The main goal was to over dimension the augers for the purpose so that wear and tear would be kept at a minimum even with plastic printed parts. The augers were factors larger than the disposable ones and could turn at much lower speeds.

He started with using drill bits as a first test, something a team from Bauhaus University Weimar also tested some time ago but both without much success. The thread of a drill bit is to steep for an extruder, material flows through it by air pressure alone. We build around two dozen prototypes with many different variables and bench top testing them all to map out the relation between RPM, inlet pressure and outlet flowrate. We measured this by running the extruder for one minute and weighing the resulting amount of extruded material with a precision scale.

After two months of researching and painstakingly testing we managed to improve the auger but never had metered operation. There was always a relation between material viscosity, inlet pressure and the resulting flowrate in the charts.

Another issue observed and maybe specific to clay (which is a suspension) was that the flowrate decreased in a very consistent manner over time. When taking apart the extruder an almost dried out lump of clay could be found at the end of the auger clogging the nozzle. This happened time after time and the final conclusion is that this is due to backflow of water that is being pushed out of the clay flowing back up the sides of the auger. While the auger pump sounds simple, its main operating mechanism is pressure difference build up and that is a challenging thing to work with.

We found quotes in books that stated that while auger extruders are successfully used in industry, various aspects of it are not yet fully understood. The conclusion was that one could probably build a working paste extruder based on the auger but that you would need to carefully tune all the parameters for each different material. Not a one size fits all (or most) approach. This apparently works fine in a controlled single purpose industrial setups and indeed I’ve seen research labs 3D printing successfully with 3000€ auger dispensers, but as basis for a versatile DIY RepRap extruder, not so sure.

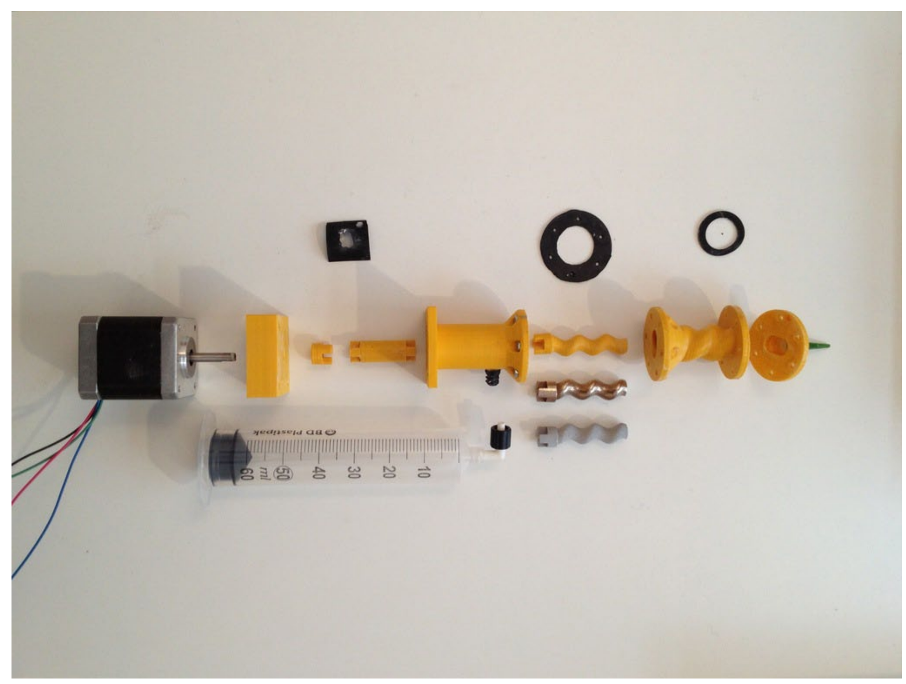
Before this renewed effort in experimenting with augers I found this quote which still holds:*"Positive displacement implies that a specific volume of material is displaced within a specific mechanical actuation. Positive displacement is not influenced by changes in temperature or viscosity. The Archimedes screw pump is very consistent, but this consistency depends on the viscosity and flow characteristics of the material. Archimedes screws have been marketed as positive displacement pumps, but viscosity metering pumps is a better definition."*

True positive displacement pumps should produce the same flow at any given speed no matter the discharge pressure. And this is where the last system comes into view, the Moineau pump. From the surface this pumps looks pretty much the same as an auger pump but the geometry of the auger (the rotor) and housing (the stator) are a bit more complicated. In a Moineau there is no continued path down the rotor but several sealed cavities between rotor and stator which progress down when the rotor is turned, hence it's other common name: progressing cavity pump. Every cavity has a known volume so with each rotation a specific volume is being discharged from one or more cavities. The intricate geometry ensures that the cavities alternate to avoid pulsations in the extrusion.

The only influence the input pressure has, is that it needs to be high enough to feed the material in the pump but not to high that it would leak past the rotor-stator seal and this is often a wide range. Other beneficial characteristics is that the Moineau is very well suited for pastes and particle filled slurries. So it's designed for extreme applications like in the oil drilling industry but also very well suited for less demanding applications.

I never thought it would be possible (at least not for me) to design a printable Moineau pump but early 2012 Tomi Salo posted a Moineau stepper extruder on

Tomi Salo Moineau
photo by Tomi Salo



Unfold Moineau
photo by Unfold

Thingiverse designed in OpenSCAD and based on the basic parametric rotor and stator geometry by Emmett Lalish. Tomi's design is a gravity feed design and not suitable for working with materials under pressure. I made a quick and dirty update to seal all the parts and stepper shaft and tested the updated extruder with clay. In the initial test, which you can find on YouTube, the extruder performed very consistent with instant start and stop and responsive ramping.

The extruder's drive mechanism and shafts failed rather quickly though because of the substantial torque needed to pump a viscous clay slurry. Months later, again as part of the engineering thesis and after the disappointing work on the auger,we picked up again on the Moineau design, which is my favorite. The length and parameters of the rotor changed based on the analysis of an industrial Moineau pump in order to get a better seal. This is crucial because normally the rotor is stainless steel and the stator a very durable rubber and so the two seal very well. This makes that it dispenses low viscosity material like water with the same ease as a thick clay. In a plastic 3d printed version you will never archive this type of sealing but we also don't need the low viscosity capabilities, you'll use high viscosity pastes. Making the rotor longer creates more cavities and seals.

Various other improvements taken from literature were sketched out to reduce possible pulsation. The same one minute bench top extrusion tests were done with this 2nd update of the Moineau and the results were vastly more consistent versus the auger based design. At this point the Moineau still needs a lot of improvement but that is mostly on the mechanical part of the design, the working principle itself seems capable to offer what we need.

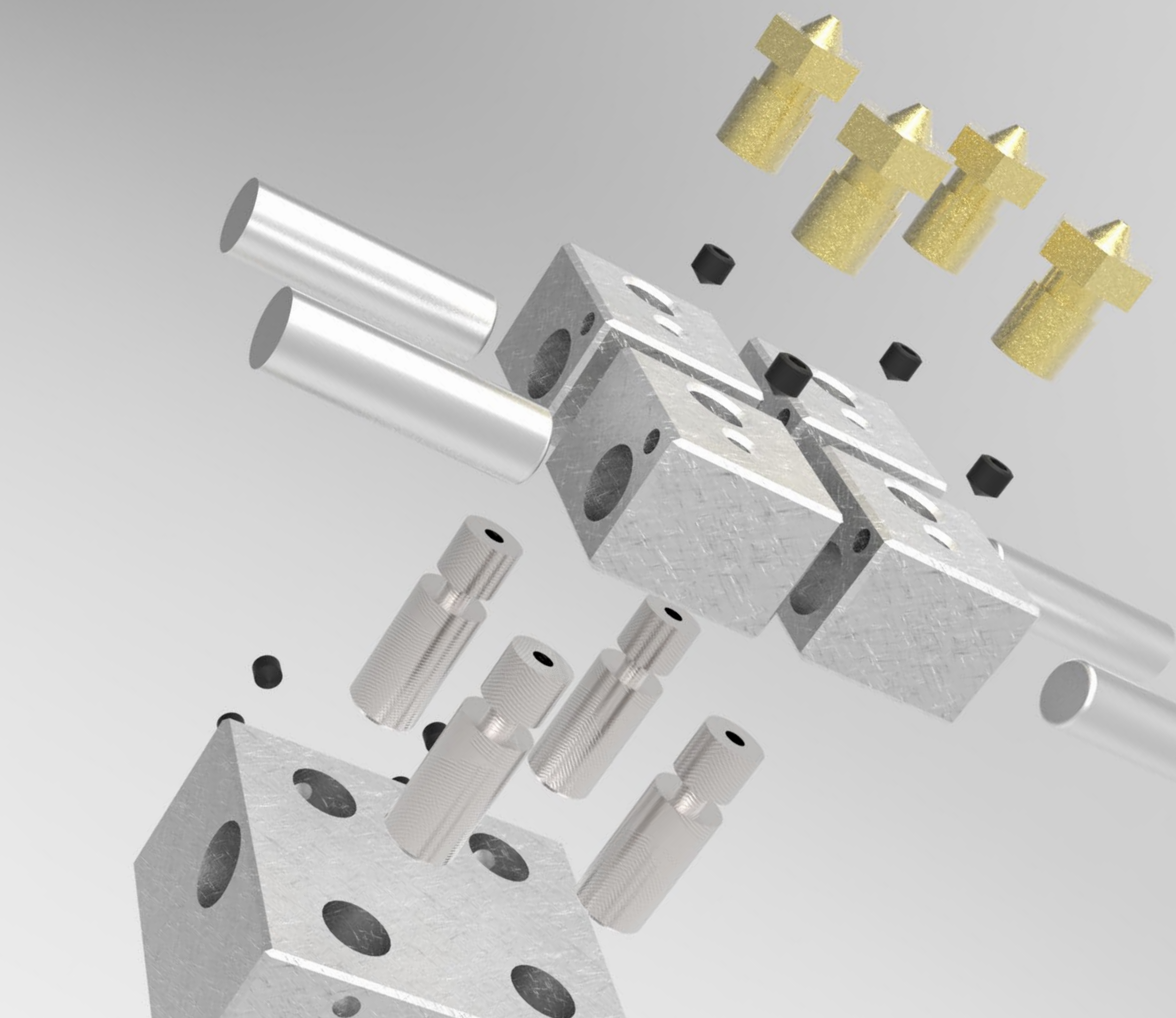
What needs to be improved is the mechanical strength of the coupling between the rotor and stepper. Because the rotor moves in an eccentric manner, there needs to be a flexible coupling shaft and this shaft ploughs through the material in the inlet chamber. This is now a very basic three prong coupling that has the tendency to wobble up and down and frequently breaks because the torque is too high. Also related to the torque, a standard nema 17 coupled directly to the shaft is really on the edge. Sometimes it works sometimes it doesn't and your stepper will skip a lot. Either a size up stepper like the nema 23 needs to be incorporated or a geared stepper. So basically the whole extruder needs to be hardened for high torque operation, that's work that still needs to be done.

As indicated in the first section of this article, the Stepper Driven Syringe Pump and Direct Air Pressure Extruder both have their merits but don't have the potential for growing into a multifunctional software driven and volumetric extruder that operates in a similar manner as our filament extruders.

Because of its excellent volumetric continuous mode of operation, the Moineau Progressing Cavity pump principle is by far the best design to focus development on today and a lot of the initial community work is already there to start with. Lets hope you join in!


photo by Unfold

Unfold works
photo by Kristof Vrancken



Render based on Kraken 3D model by Mike K2lly: https://grabcad.com/library/e3d-kraken-quad-extruder-1

Feature

2013, the year of the hot-end.

For the last year I have been using and experimenting with as many different hot-ends I could get my hands on. 2013 was a strong year for Hot-end and nozzle development. As we move away from building hot-ends out of plastic materials that can melt to ones that can offer extremely higher temperatures, more interesting materials will be tried in RepRap 3D printers.

By Richard Horne

Giraffe - Voronoi Style, model by roman_hegglin - Voronoi models are great for testing the ability of a hot end to print fine structures without ooze.

I decided to make this a general overview of the different hot-ends and give you some feedback from my real-world use of these. Because I have used them to print real parts on a lot of different machines and over a period of a year, so many things have also changed, even the hot-ends themselves, based on user feedback have been further tweaked and refined by the developers.

I also had different filament sized, both 1.75 and 3mm and a wide range of nozzles, so I'll make the specification clear in the below and in a future article these differences will also be compared.

Richard Horne

Author

Alias:
RichRap
Country:
UK
Website:
http://richrap.blogspot

So for this overview if seemed fair to provide general feedback and observations rather than going into exact scientific measurements for this article. But now that things are starting to settle down with lots of these newer designs, with a few of the top performers I do plan to test different aspects like force to extrude, maximum flow and ooze characteristics at various temperatures, in a more controlled and repeatable way.

Some general tests you can perform on any hot-end - It almost goes without saying, but be careful these things get extremly hot and molten plastic is not something you want to get on your skin.

The two finger extrusion test (2finger)

You need to do this one 'hot' (at material temperature) and after auto-calibration (M303) has been completed and settings added to firmware.

I always like to see how well a filament can be extruded by only using two fingers to push the filament directly down into the hot-end manually. This can tell you a lot about the hot-ends ability to melt material and the pressure required to extrude. It's worth doing this test at various temperatures going up in 5 degree steps, both with and without cooling fans. I find this especially useful for 3mm hot-ends, depending on how the nozzle has been drilled and the taper, gaps and seals etc. this simple test can give yo a lot of indication how well it will perform and what sort of drive system you are going to require on the extruder motor.

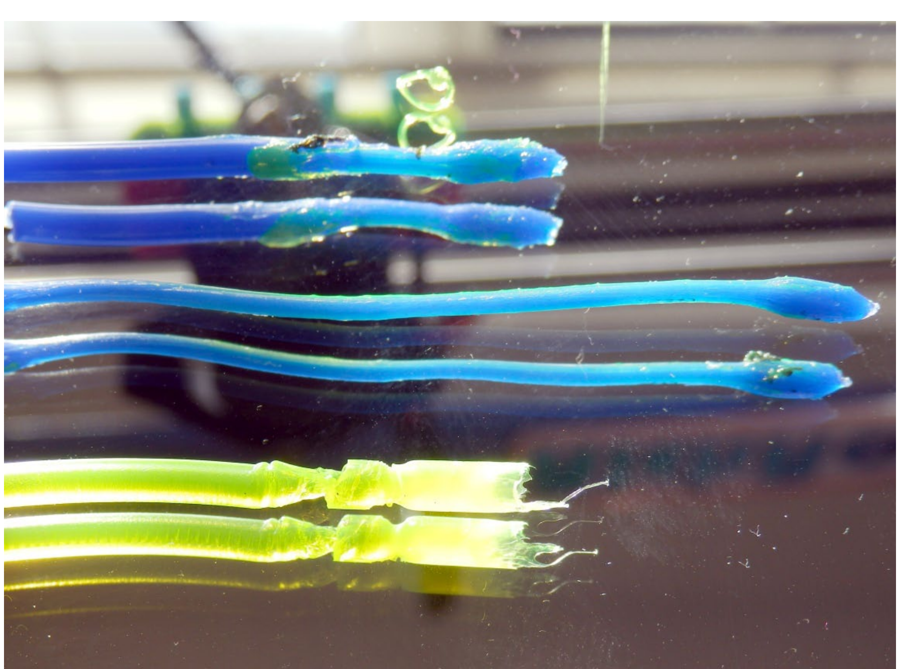
The force required can of course be exactly and carefully measured for hot-ends and nozzle sizes, but it's good to feel how much pressure different nozzles take, you will find that some are almost impossible to push by hand and others flow and extrude quickly with only gentle down pressure. Much also depends on the material and temperature, so perform like-for-like tests.

Plug test (Plug)

The plug test is another manual test to perform while the hot-end is at temperature, I usually use PLA and allow it to heat to 190 Degrees C.

Perform the 2finger test above, but after 3 seconds of pressure pull the filament as fast and safely as possible out of the hot-end. allow to cool an take a look at the melted Plug of filament. This can help you see how much of the filament is melting (melt-zone) and if any steps in diameter size are visible due to parts not sealing flush or double tapers that can cause swelling, increase torque and potentially cause jamming.

Some hot-end side walls will grip onto the filament and it will stretch as it's being removed, but you usually still end up with a plug of some description at the end. The stretching point, length and plug can all give interesting indicators to how the hot-end has been constructed and how well it will process material.



Pico PLA plugs

Manual Ooze test (Ooze)

This is simply a test to see how well the filament relaxes and self oozes after pressure is applied.

It's well worth trying this test at various temperatures, just 5 Degrees C lower can often make a big difference to reduce the amount of oozing out of a nozzle.

I draw a line on the filament around 60mm from the end (with a sharpie) then perform the 2finger test above, and after 3 seconds of constant pressure release the filament and observe both the marked line on the filament and the material extruding out of the hot-end nozzle.

Some hot-ends will allow the filament to decompress and the line will rise quickly, others will grip the filament and only slowly rise or not move at all.

Pico manual ooze test

A long melt-zone can show up as both a lot of spring (compression) in the melted filament and also increased ooze from the nozzle end.

In my use of different nozzles it seems better to have a shorter melt-zone and so less spring /compression in the filament and minimal side-wall grip so when pressure is released oozing is minimized. You can't just have a bigger barrel size as this usually produces a plug at the thermal transition zone actually causing oozing and other problems when trying to retract the filament during printing.

Materials

Wherever possible I have tried to use similar materials and batches for testing, I use PLA mostly, then Nylon, PET and lastly ABS. Not all materials are the same, so as they say 'your mileage may vary'

Wood/chalk/mineral filled filaments, conductive and soft materials all bring their own challenges and will be covered in a future article.

Nozzle Heating - a word of caution.

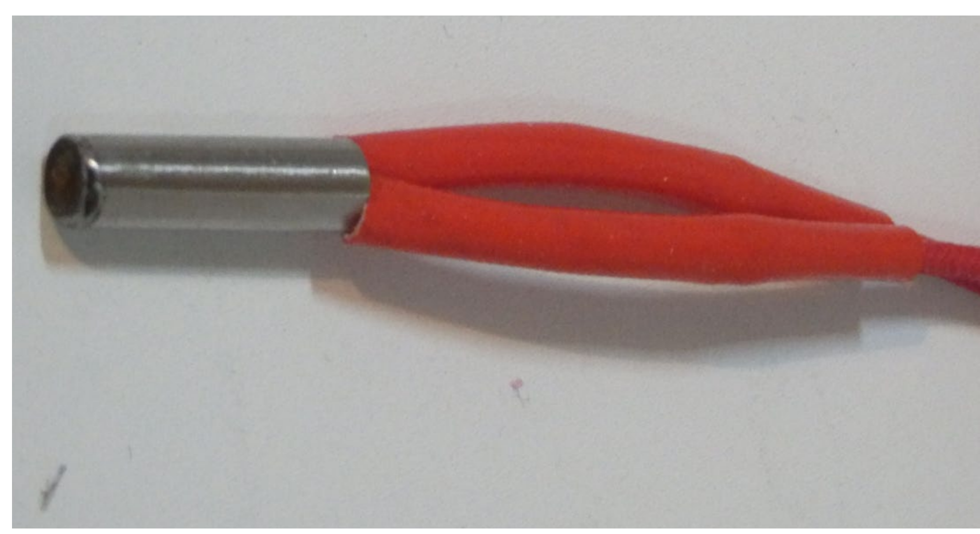
Many nozzles not come with a cartridge heater, these heating elements are usually well over powered for use in a 3D printing hot-end. The standard types mostly available are usually rated 12V at 40W. This is a lot of power and can get your nozzle temperature well in excess of 400 Degrees C.

Be aware that if uncontrolled full power (usually +12V) is applied to a hot-end it's going to get really, really hot indeed. A 12V 40W cartridge heater running at full power for just 15 minutes in free-air will glow orange then white hot, expand the metal case and start to break-down the fibreglass insulation. It'll melt almost anything it touches and make things catch on fire.

Back in the early days of RepRap is was common to fit nichrome wire or use a vitreous enamel resistor as a heating element. Both of these have issues too, but they were usually less powerful than most of the cartridge heaters being fitted now.

I have always limited the power available to the hot-end in firmware. While this does not take away the risk of a shorted Mosfet applying full power, it will at least limit the energy going into the hot-end when in normal operation. It may take slightly longer to get to temperature, but this can also have benefits for the temperature control algorithm (PID loop) that is aiming to reach a target temperature without too much over-shoot.

If you do adjust the maximum power to your hot-end do make sure you re-run the M303 Auto-tune again and enter the new values. You can get 24V 40W heaters, running these at 12V is another option to lower the power. Ideally we need a ~12W 12V Cartridge heater for most general 3D printing requirements.



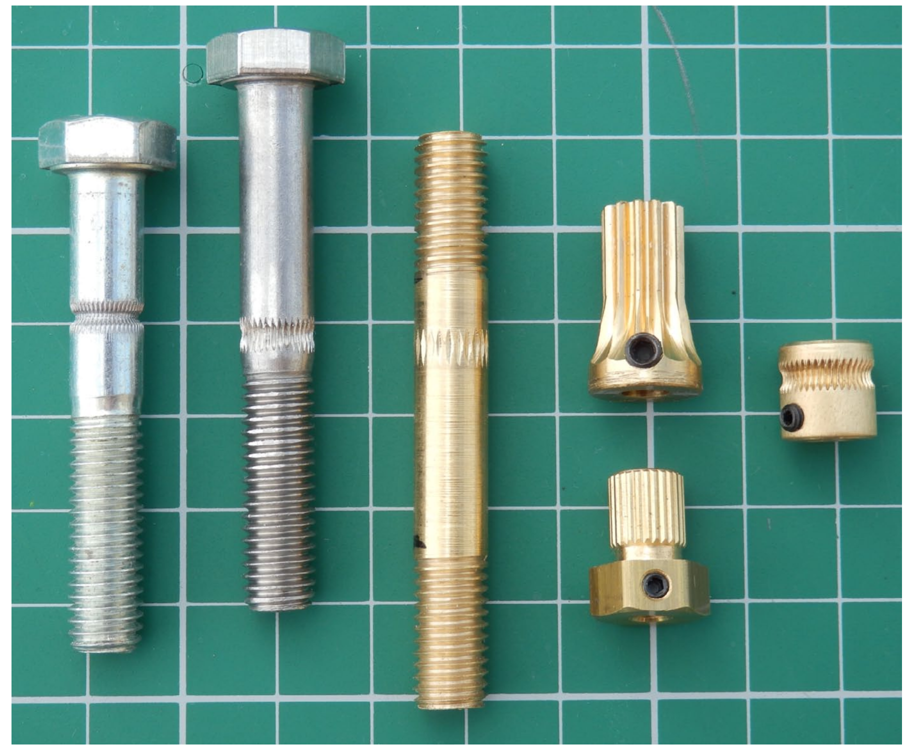
Cartridge heater

Running a cartridge heater at 12v, this is current limited 2.7A by my power supply, still glowing red-hot and burning the insulation.

Extruder Drives

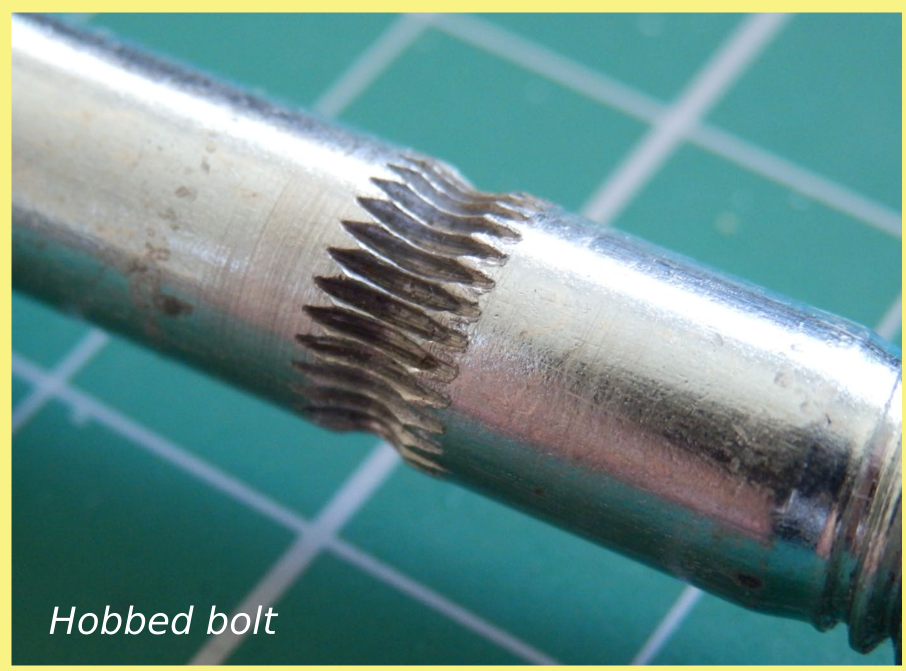
You have so many options for driving filament down into a hot-end and that itself would really require a separate article. At the end of this I sum up the results but I have always found a geared extruder to be the most suitable for most of the printing I have done over the years.

I just wanted to state here that I have tested lots of different types, and made many of my own, both direct drive and geared in one way or another over the last few years.



Many different drive systems are in use for extruders.

After testing and using every different type I could get my hands on, I come back to the standard hobbed M8 bolt and a V groove 608ZZ bearing for the idler as my drive method of choice in most machines.



Hobbed bolt

Example Direct drive extruder systems, very simple to assemble and service, but do tend to have limited torque to drive the filament and depending on the pinch system can be more prone to jamming or skipping lesser quality filament.

Almost all apart from the Kraken testing used a geared drive extruder. for the Kraken you can use gearing but I found a standard Nema 17 with a direct pinch-wheel worked perfectly even at fast extruding speed.

Direct drive extruder gears

J-Head

The J-head has been my default hot-end for almost all my RepRap adventures, I have a lot of experience with it in almost all it's revisions and I still use them today in various models and adaptions.

Recently we have seen an explosion of J-head like designs, some are built to the same or similar standard as the original design (hot-Ends.com) and others fall way short of being even slightly usable.

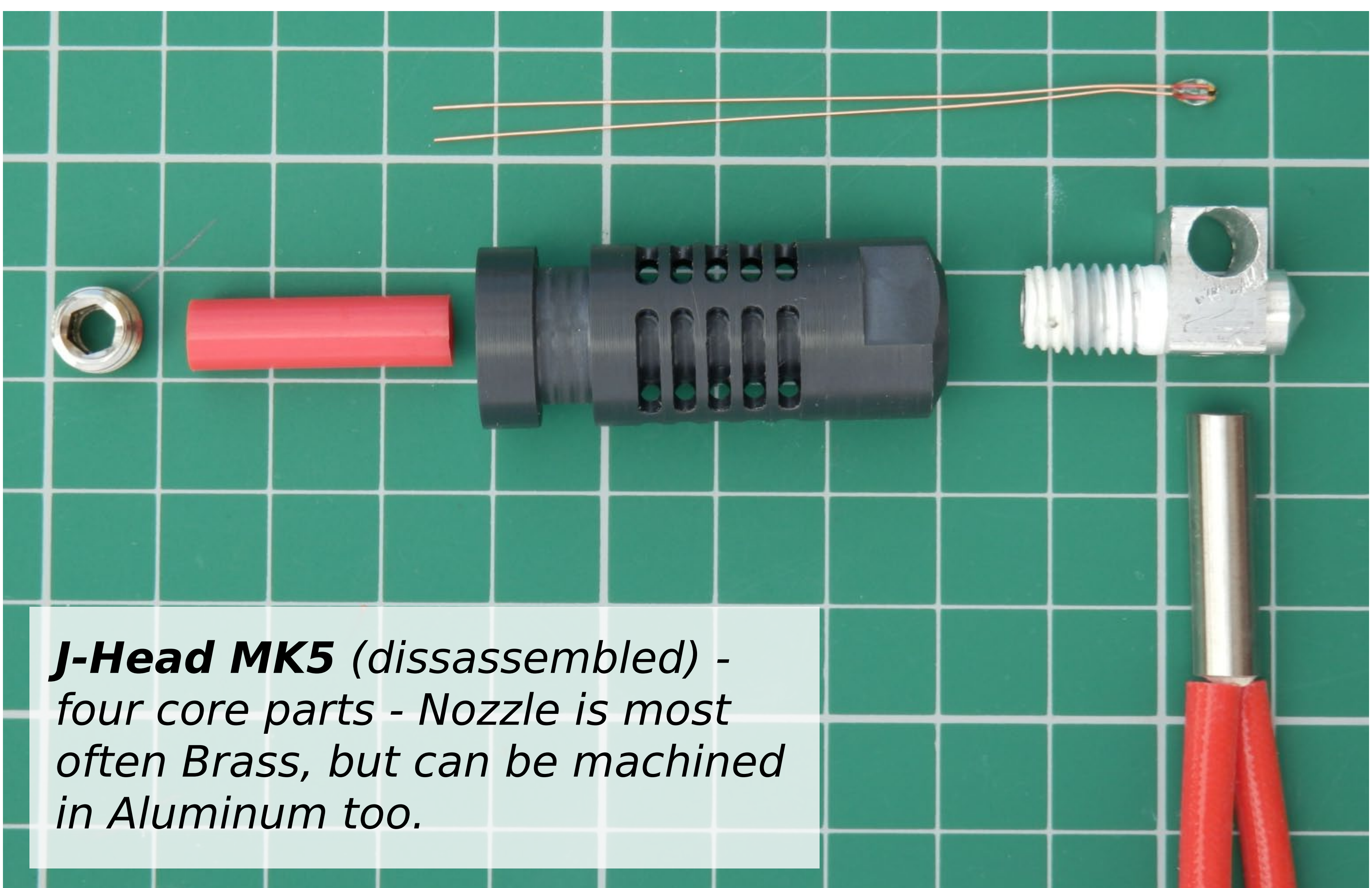
J-heads do use multiple materials and tend to have more parts than other stainless or minimal designed hot-ends, but a well made and built J-head can run for years and process tens of Kg of material without any significant issues.

They do have some limits and unfortunately people do tend to melt them more often than you would expect (see above warning about cartridge heaters).

J-Head MK2 - Still a good and solid design, I have a stock of them that only run ABS, no external cooling required, extrusion speed is limited to around 40mm/sec, but they run ABS well at 245 Degrees C

J-Head MK4 - Longer and heavier than the MK5 with similar printing performance.

J-Head MK5 - Compact and very light weight, great for Bowden extruders running PLA, needs to be fan cooled for best results.



***J-Head MK5** (dissassembled) - four core parts - Nozzle is most often Brass, but can be machined in Aluminum too.*

One thing that I have never been able to explain is that in all my printing with Nylon the J-head always seems to give better print results than any other nozzle I have used to-date. I do not know if it's linked with the level of moisture in Nylon, or how the PTFE sleeve transports the material, or the level of compression, oozing or melt-zone. I have a feeling it's a combination of all these. So for Nylon I do prefer to use a J-head MK4/5 over anything else at the moment.

Do watch out for cloned or badly manufactured J-head nozzles, I have had some during the year with various issues. Some requiring a massive amount of force to extrude, due to an incorrect machined nozzle hole length and others with sealing issues, incorrect use of materials and poor cooling capability giving a lot of oozing.

Another interesting read for J-head background information is Brian's J-head and 'clone' overview here.

J-Head MK5

Overall opinion and general recommendations

1. Best for Nylon Printing (245 Degrees C @ 30-80mm/Sec) (1.75mm recommended)

2. Good for general PLA printing (190-220 @ 10-80mm/sec) - Exceptional performance and print results at very low PLA temperatures down to 155 Degrees C. - needs active cooling of the PEEK

3. Do not overheat or the PEEK & PTFE can fail - Keep to under 250 Degrees, insulate the heater block.

4. 'Industry standard' Groove mount.

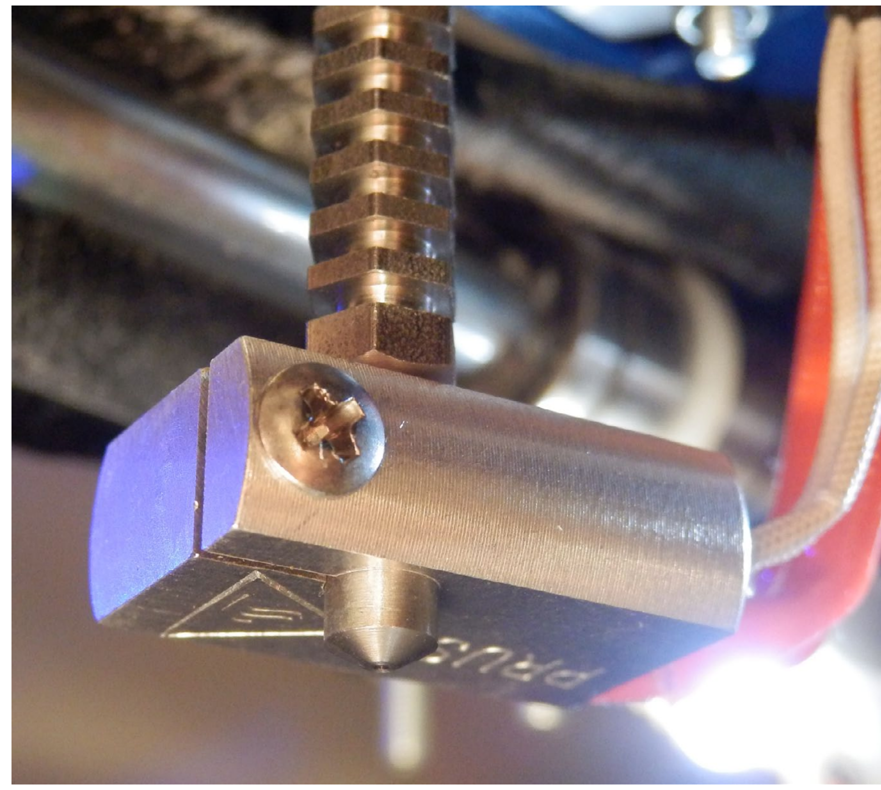
Review

Prusa Nozzle V1

One of the first single piece stainless steel nozzles - The original V1 nozzle was right on the edge of thermal design. without exactly the right amount of barrel cooling I found even the slightest insulation around the heater block could cause problems with flow when extruding PLA, leading to stalls or jamming. With too much cooling a similar issue could happen where material, especially when being retracted could cool too fast and jam in the barrel.

The V1 design could also be driven at vastly higher temperatures (+280 Degrees C) to extrude PLA at amazing speed, I eventually ran out of extruder performance to go much higher than around 180mm/Sec print speed, but the nozzle was still capable of faster speeds.

When it’s setup well, this nozzle could extrude at the fastest rate (0.6mm nozzle / 3mm filament) using the 2finger test, and with minimal pressure applied.



Prusa v1 mounted

Overall opinion and general recommendations:

1. No longer available.
2. Use the V2 nozzle.

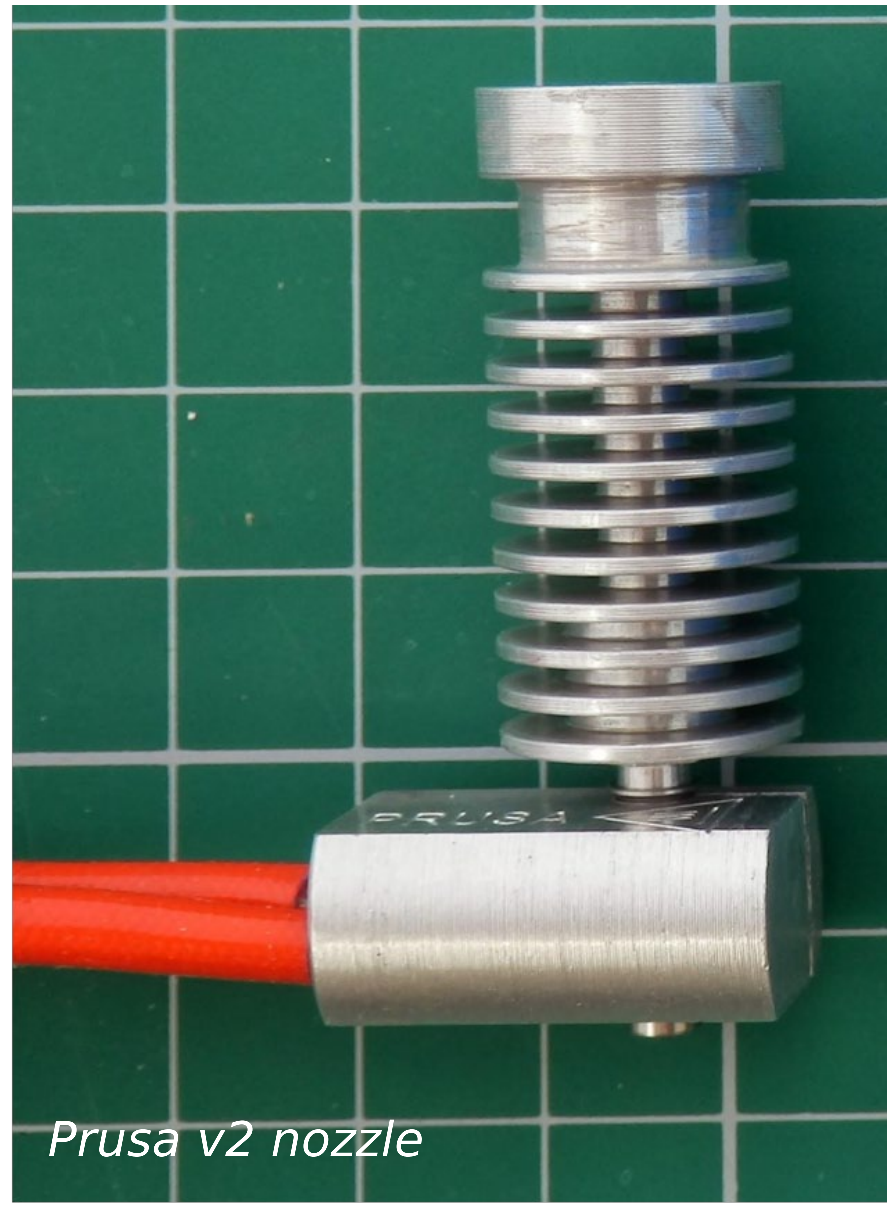
Prusa v1 nozzle

Prusa Nozzle V2

With revision 2 came stability and still great results. The single piece stainless steel nozzle is retained and a heat-sink was added to the barrel. With some level of active cooling (25/30mm Fan) this hot-end performs in a much more controlled way. You don't need very high temperatures, (192 Degrees C is adequate for PLA) and it's still capable of fast speed printing (70mm/sec)

This is a great nozzle for ABS printing. I had the best results with PET material, very clear prints can be retained even at higher speeds (+60mm/sec)

* Because it's light weight it would make an ideal Bowden, but it's only available in 3mm versions at the moment, this makes it great for most RepRap style machines, but anything that is using a Bowden feed like most Delta printers will usually benefit from using 1.75mm material. So I have not been able to implement it on a delta yet.



Prusa v2 nozzle

Overall opinion and general recommendations

Review

1. Best print results and performance with PET materials (220 to 235 Degrees C)

2. Great for ABS, even at high speeds,

3. Good for printing PLA fast (longer melt-zone), but more ooze than some other nozzles at low speed PLA.

4. 'Industry standard' Groove mount.
Using a lower temperature and a little more extruder retraction (I used 1.6mm) than normal really helps with the V2 nozzle, for me that resolved almost all issues I had with ooze and fine angel-hair strings on slow-printed intricate models using PLA.

E3D Nozzle V4/ 4.1 and V5

E3D's Nozzle consists of a Stainless Steel tube (thermal break), Aluminium heat-sink and heater block with a Brass nozzle.

V4 had only minor machining issues when first released, these were quickly rectified in V4.1. This nozzle has become loved, trusted and used by many in the 3D printing community.

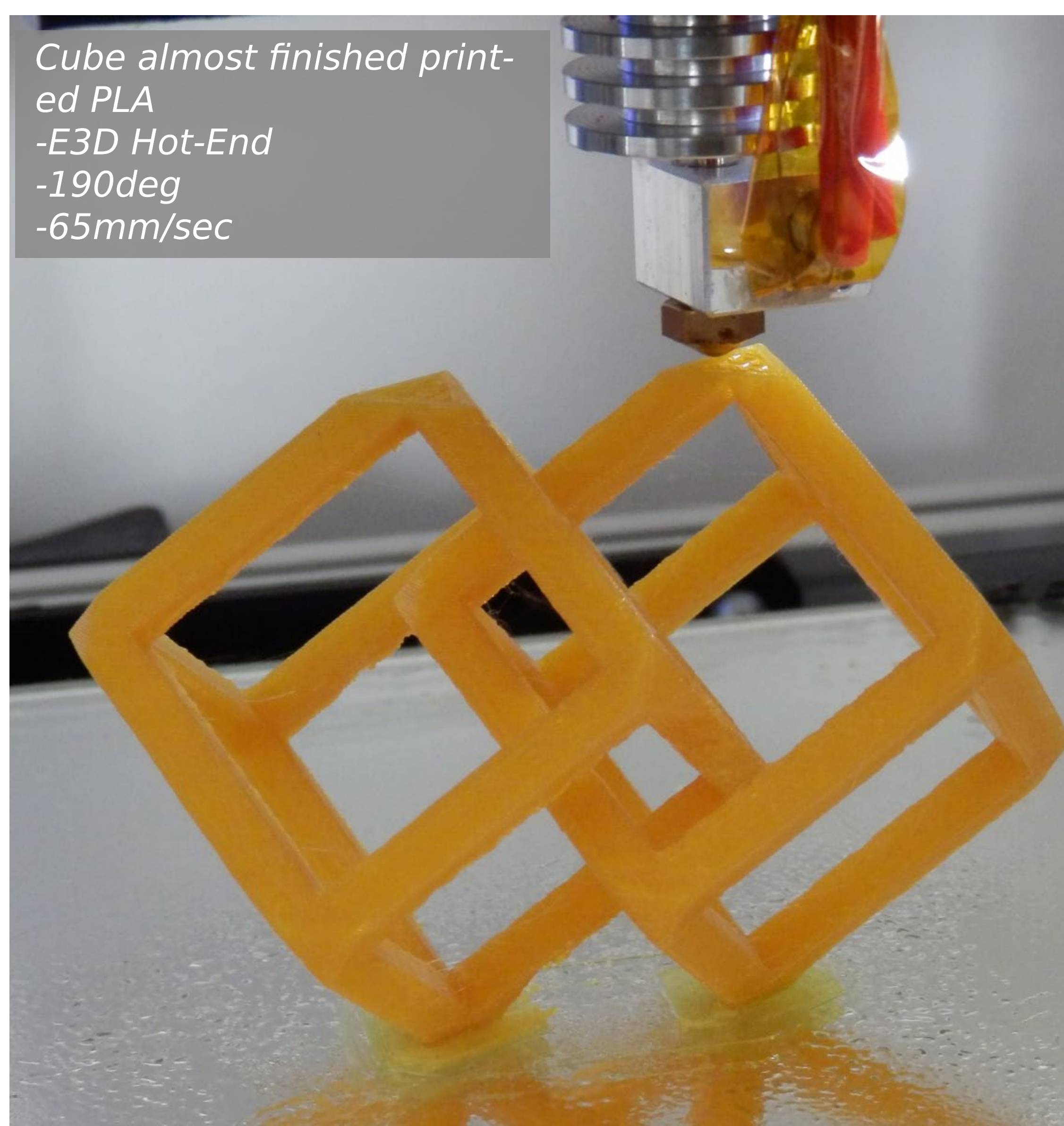
The E3D nozzle is quite heavy due to the size of the heatsink, it requires fan cooling for best performance and is ideal for most materials printing slowly (it has very little ooze and a short thermal transition zone) to moderately fast, for me the 3mm version maxes out at around 140mm/Sec (@218 Dec C PLA) but with more extruder torque it could go faster still.

Having a brass nozzle is a big bonus, you can easily clean and change nozzle sizes. Worked very well with ColorFabb Woodfill material (0.6 and 0.8mm nozzles). My Hot-end of choice for PLA printing.

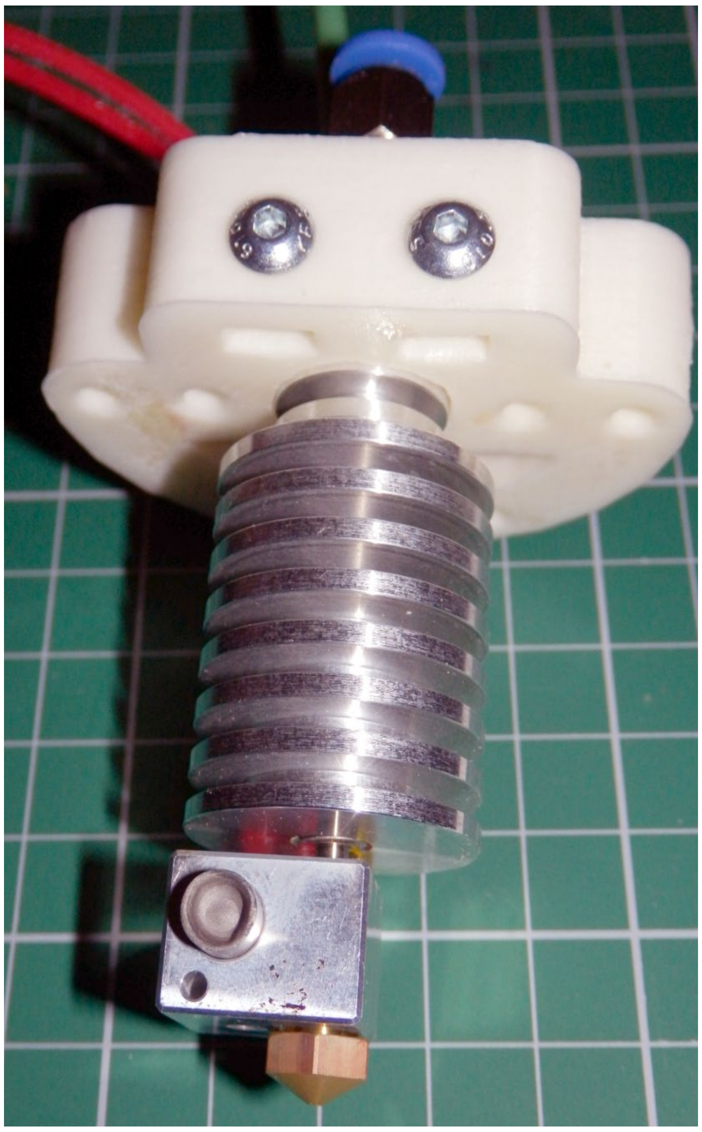
E3D do make a dedicated Bowden hot-end, this has a lightweight plastic pneumatic fitting directly in the aluminum heatsink, or you can fit a Bowden adapter like the one shown above.

Great for traditional geared and direct drive extruder systems, Reduced weight E3D hot-ends are planned, these will then be ideal for Bowden and Delta based printers.

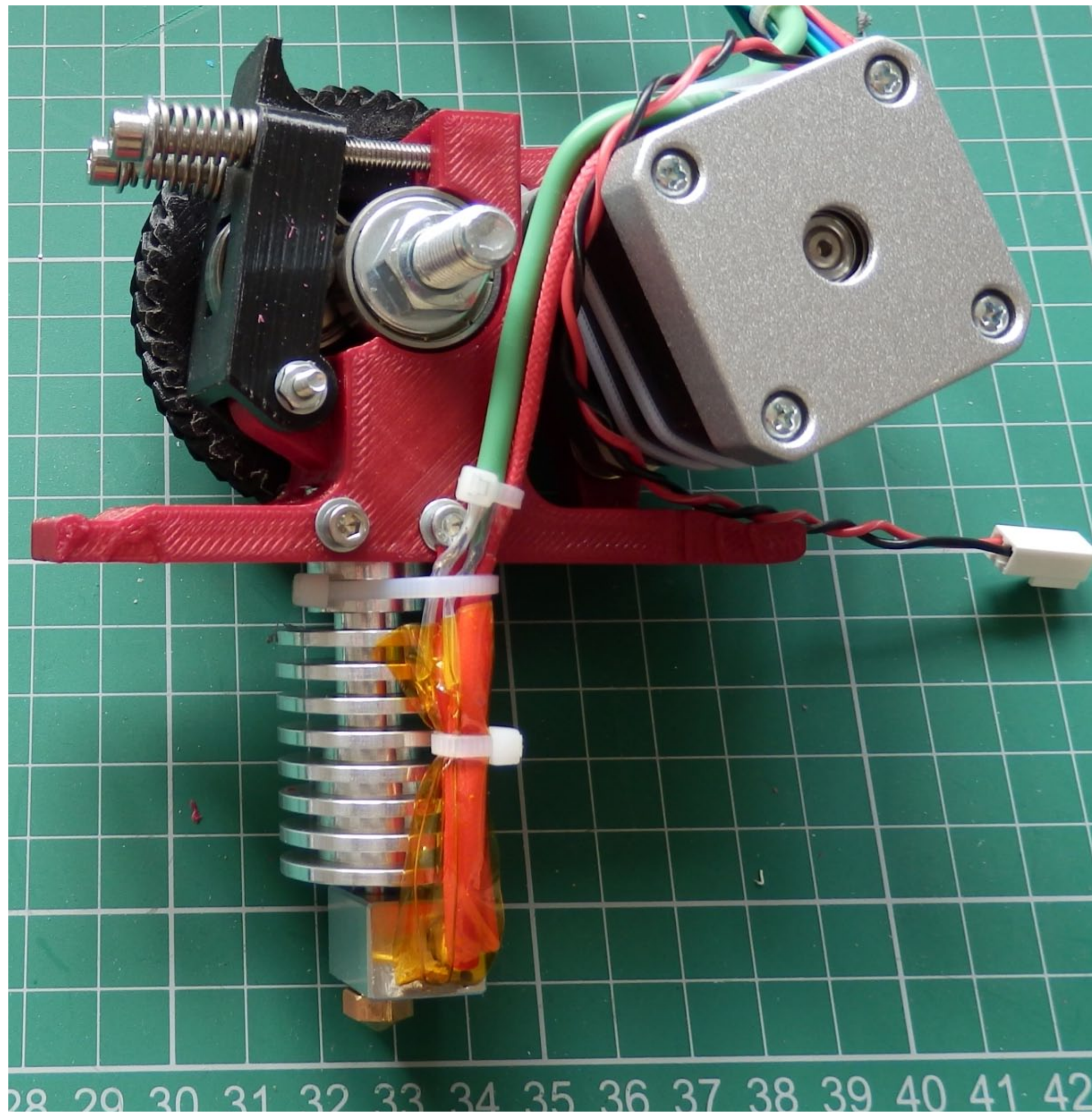
E3D hot-End



Cube almost finished printed PLA
-E3D Hot-End
-190deg
-65mm/sec



E3D hot-End for bowden setup



E3D hot-End assembled on a Gregs Geared extruder

Overall opinion and general recommendations

1.Best all-round for PLA precision printing, very well controlled output even at higher speeds.

2.Great for more tricky materials like wood, mineral filled, bendy and also higher temperature (PC, PC-ABS)

3.Good for ABS, Nylon and PET, (I never managed to get as clear results with PET as a J-Head).

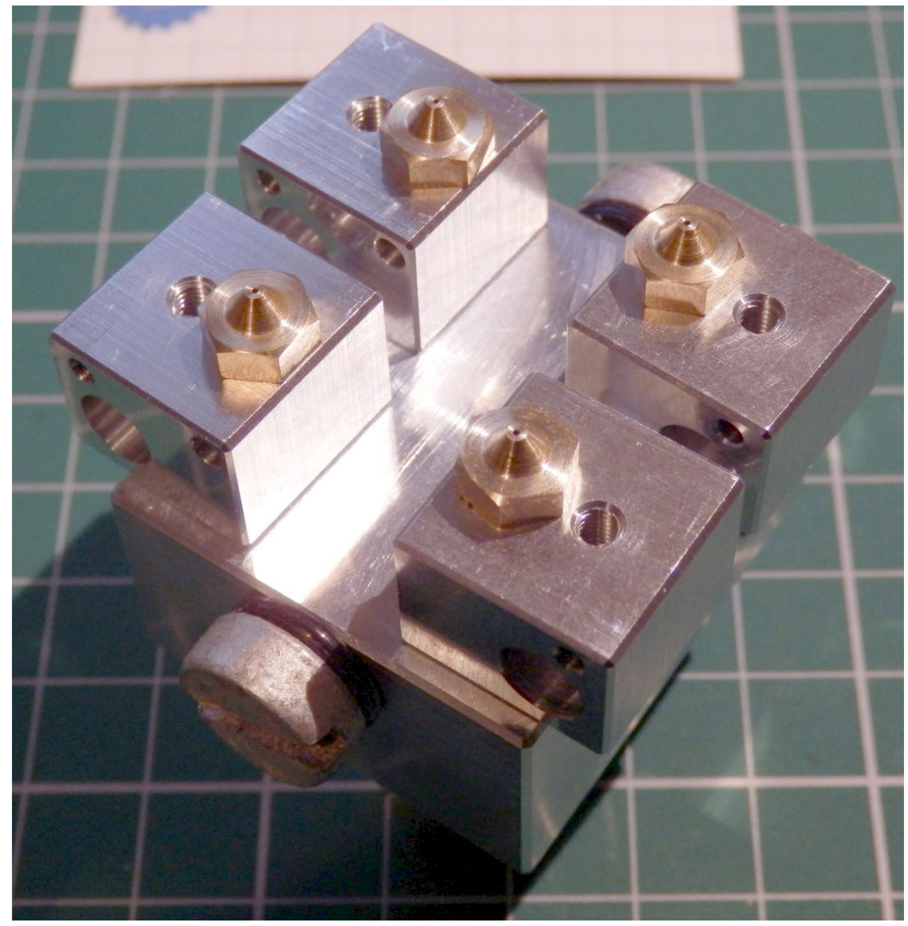
4.‘Industry standard’ Groove mount.

Review

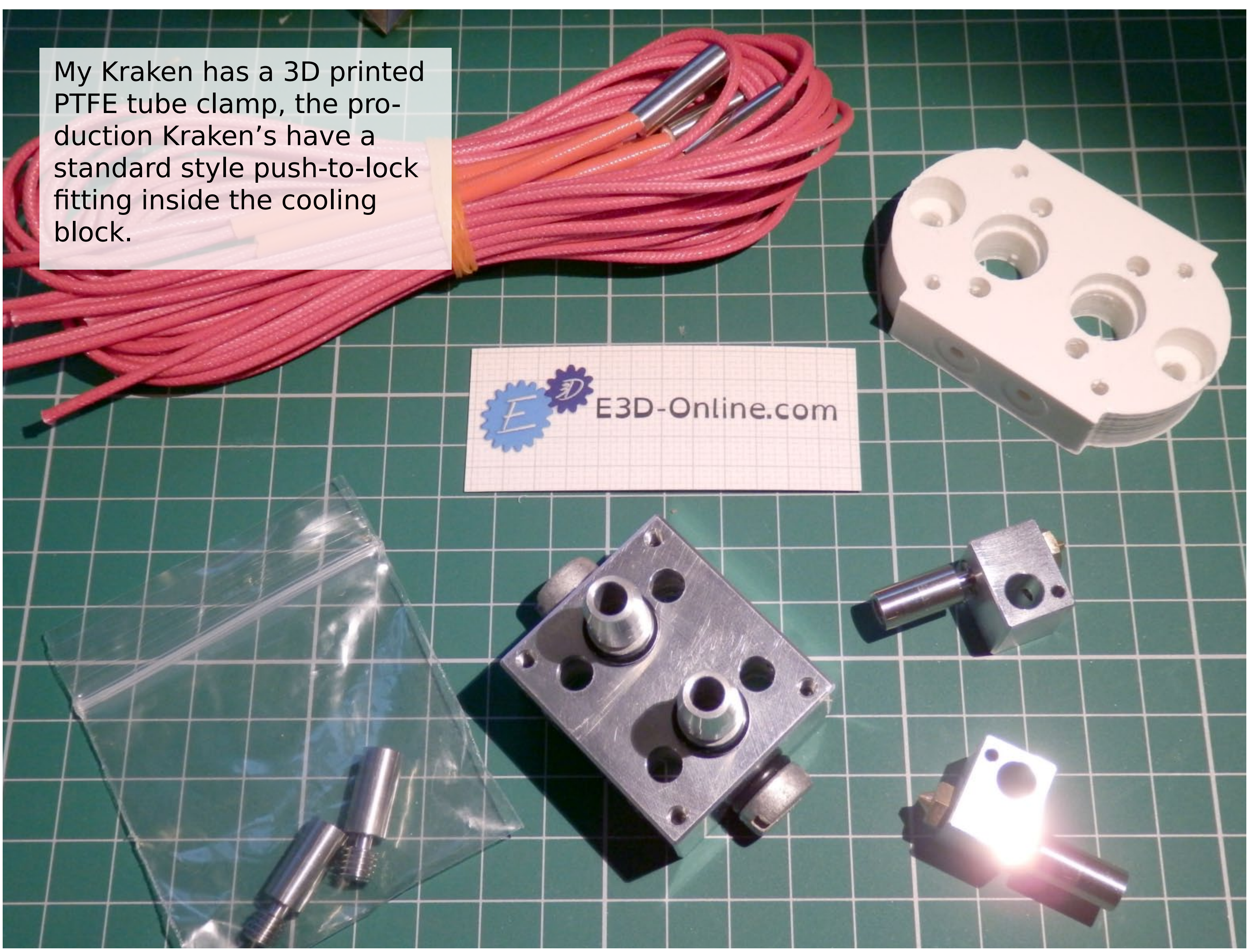
E3D Kraken - V0 (prototype)

For the size and weight the Kraken is amazing! - it’s a one to four Bowden fed nozzle hot-end with a water cooling system. Each nozzle is independent, so this is ideally suited to multiple materials, separate support material printing and printing multiple colour objects.

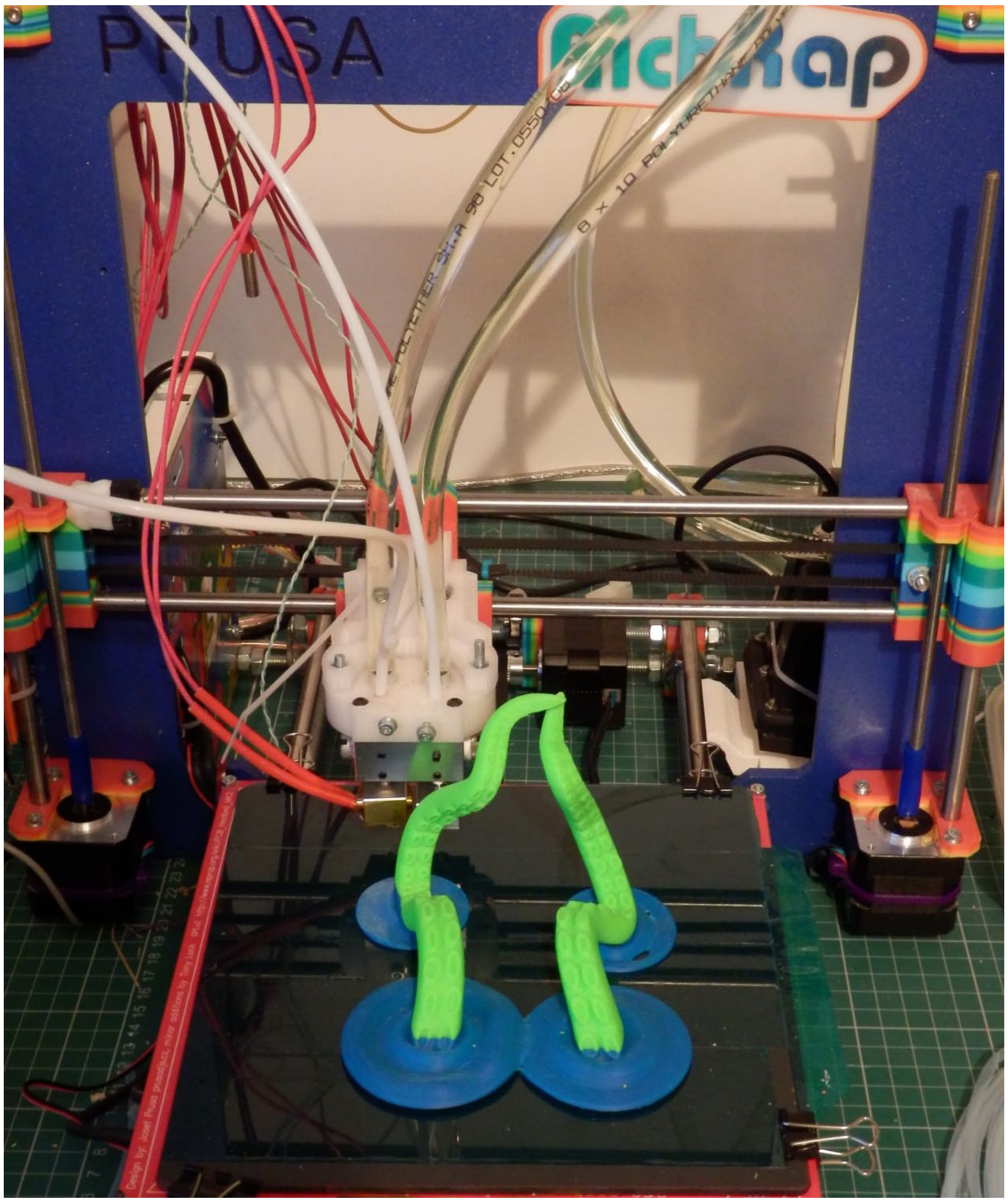
This is the best multi-nozzle setups I have ever used, and I have painstakingly calibrated quite a few over the years for people. All the nozzles can be aligned flat, together and tightened with just an Alan key.



Kraken assembled nozzles



My Kraken has a 3D printed PTFE tube clamp, the production Kraken’s have a standard style push-to-lock fitting inside the cooling block.



Kraken assembled on Prusa I3

Water cooling does make for a quiet machine but at the cost of fitting extra tubes and a cooling system.

Even if you want only a single or dual head machine, I would still recommend the Kraken if you want to experiment, for fitting it to a machine like the Prusa i3 it's easy and everything can be made neat.

I ran the Kraken at full temperature for 4 days printing constantly, it never once caused a single print issue or skipped a step.

Overall opinion and general recommendations

1. It's experimental! Great for PLA printing. (1.75mm Bowden)

2. Great for multi colour prints and material experiments.

3. Quiet and compact.

4. Has it's own mounting system - printed mounts will usually be required to fit to most printers.
models using PLA.

Review

Pico Nozzle V1

I was an early Pico tester before the recent and successful Kickstarter campaign.

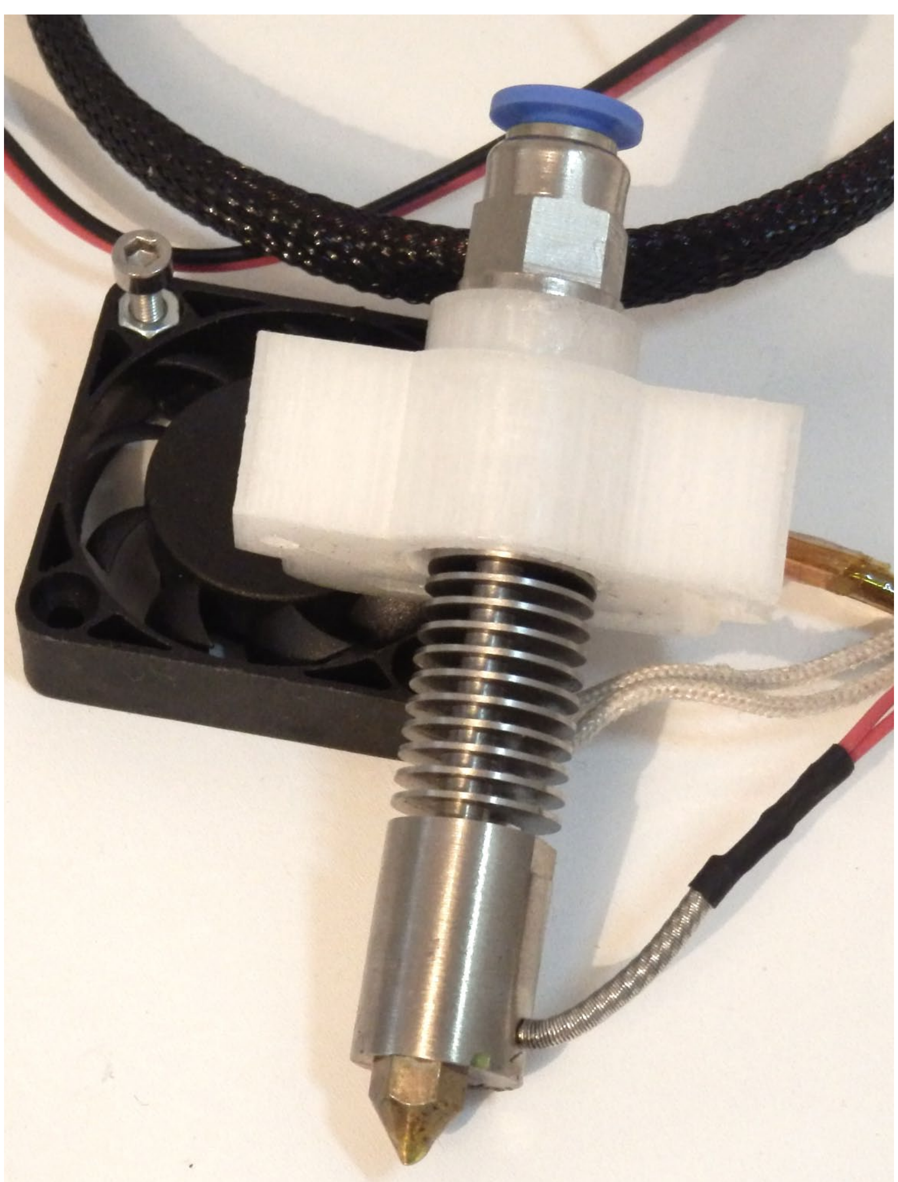
It's a very interesting nozzle, almost a work of art in it's production. It shares similarities with both the E3D having a removable Brass nozzle, and the Prusa V2 with having a complete Stainless steel path for the filament.

It's quite different in operation to many other nozzles and takes time to get the best from it.

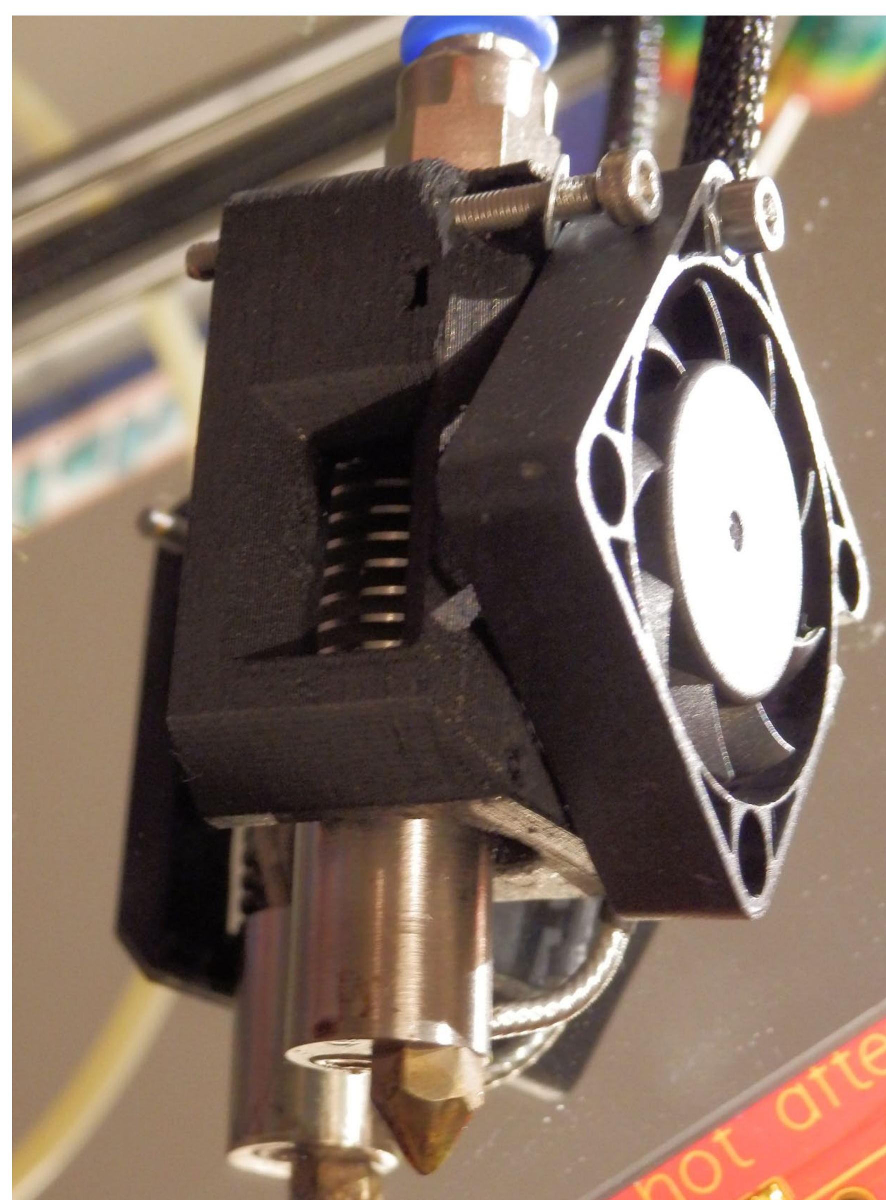
After using the Prusa V1 nozzle I was concerned about the use of an all stainless design, I know from experience over-cooling of the stainless, combined with a non-specific thermal break can cause all sorts of potential issues.

As normal I started the testing with PLA, and had some issues with the 2finger test, requiring a higher force to manually extrude. The Plug test also showed up a long melt zone. I have to say this is the longest melt zone I have ever seen on a hot-end, and I do not believe it's to a benefit for the user.

Perfect and exact cooling of the stainless steel barrel was required for PLA operation, after quite a lot of testing and tuning of fan position and power I had a solution that I could get working for PLA, but I have not managed to get high speed printing. For reliable prints without barrel jams I have fixed it at under 30mm/sec for PLA printing. This is not at all what I expected as with a longer melt zone you really want to be printing fast to minimize issues with oozing and retraction based angel-hair stringing etc.



Pico bowden setup



Pico on J-Head mount with cooling fan

Another issue with PLA was manifesting as extruder skipping but this seemed to be during the first layer printing. Increased back-pressure from the PLA really seems to cause printing issues with first layer prints, where you are squashing the filament into the bed and also on solid fill or with many filled layers.

I spent a very long time using the Pico, trying to understand how best to use it for many different materials and was never really comfortable using it with any type of PLA.

Wood filled materials did not extrude well at all, too much force required even with a bigger 0.6mm nozzle fitted. I did not have a single successful print.

I only had one attempt at using PET material and that constantly jammed during the first layer (3mm Colorfabb_XT) but I expect Taulman T-glase would be the same.

For ABS, it's a different story, I have managed faster and good quality print results, I found running at a slightly lower temperature of 240 Degrees C and a 2mm retraction provided good results.

Bear printed in ABS with the Pico on a Prusa i3 using a Bowden fed geared extruder.

ABS is a material I do not work with all that often so the Pico is of limited use because I could not get as good results with other materials.

Overall opinion and general recommendations

1. Good for ABS printing (3mm material).

2. Not recommended for Bowden based printing (due to ooze and high extruder pressure)

3. Long melt zone but I only managed low speed with PLA.

4. Has it's own mounting system - Standard groove-mount aluminium adapter is available.

Review

Undefined PTFE/Brass Nozzle

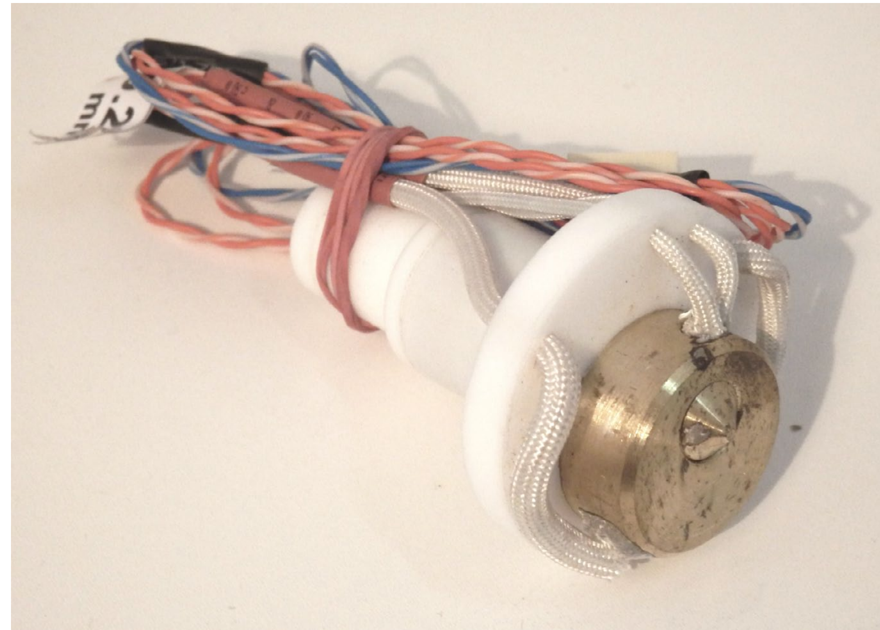
I'm not going to say all that much about this type of Hot-end apart from being wary about trying to use it.

I did not have high hopes because it's using PTFE for the thermal break and also as mechanical support.

The main issue with any nozzle that uses PTFE as a mechanical element is the fact that it changes dimensions as it heats up. This nozzle is 0.2mm so a very accurate distance from the bed is required to get the first layer down well. If that distance changes due to temperature you will have no end of problems trying to calibrate it.

The nozzle does come with metal studding, but because the studs are also fitted to a PTFE disc this does not stop the thermal expansion issues causing a variable distance for the nozzle. That alone makes it not worth the effort of trying to use this type of nozzle.

What can I say, not recommended for use in a 3D printer...



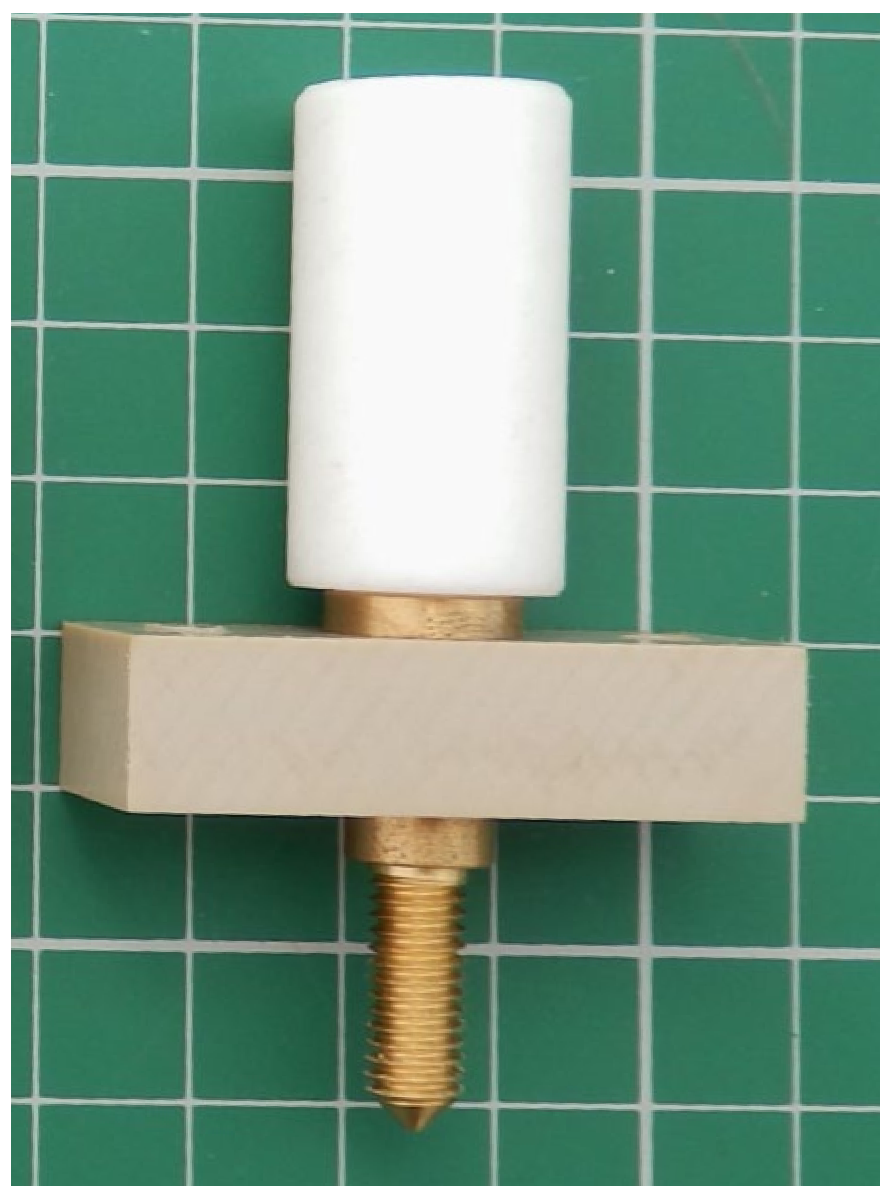
I bought this fully assembled. It has been made very well, but with materials that cause issues for Hot-ends.

Future hot-ends and nozzles

We are going to see a lot more experimental mixing nozzles, lighter all metal designs and higher temperature materials, driving all sorts of new nozzle designs.

And remember you can still make your own, it's not that hard to do and good results can be achieved with basic tools and a drill press.

I would be great to see some standards for 6mm brass nozzles agreed, at the moment we have a lot of 'compatible' looking M6 threaded brass nozzles, but they all have different sealing flats or pressure sealing angles and fitting the wrong type or length can cause.



Older style RepRap hot-ends had similar issues with PTFE and PEEK expansion, long melt zones and melting.

Similar but different - Left is a PICO nozzle, E3D in the middle and QUBD on the Right, all M6 thread, but different sealing configurations.

Having a standard length and fitting dimensions would help with greater compatibility with more printer designs and cooling / mounting options.

I would really like to see some lightweight hot-ends specifically designed for Bowden-driven and fast moving head printers.

Do we have to use 3mm and 1.75mm filament sizes? - that's a question I posed to a few materials manufacturers. It's very possible to make bigger or smaller filaments, bigger machines with wider nozzles and faster extruding systems may benefit from an increased filament size. Smaller machines with tiny low-powered nozzles/ extruders and more tightly wrapped coils of filament, may benefit from a smaller diameter filament.

I plan to do some testing of different filament sizes later on this year.

If only...

Delta printers were on my mind a lot last year (and continue to be); many of the nozzles had one issue or another stopping them being ideal for Bowden / Delta or fast moving-head machines.

If the Prusa V2 nozzle was available in 1.75mm I would be using a lot more of them, especially on Delta's in a Bowden configuration.

If the E3D V4/5 was lighter weight, it would be great for Delta's and fast moving-head machines. It may require a bigger melt chamber to get to really fast extruding speeds. I'm looking forward to what the next generation of design offers.

If the Pico allowed faster PLA printing and had a shorter melt zone (and required less torque to extrude) it may also be good for Delta systems although it too is quite a heavy nozzle being all stainless.

The J-head manages to tick quite a few boxes for Delta and Bowden based printers, but it's not designed for higher temperature materials and can't always achieve as fast printing as some of the Stainless steel extruders.

But...

One nozzle does not do everything, so for one I'm delighted that we have such a range of different designs and capabilities, it may also not be feasible to make a design that does everything quite yet, so when selecting a nozzle, think about what machine it's being fitted too, what size and type of materials you will want to run. And if you need/want different sized nozzles, along with faster extrusion or slow-but-fine ooze-free prints.

Final thoughts

Most of my printers I use every day are fitted with either an E3D V4/5 or J-head. This is because I use both 3mm, but a lot more 1.75mm material and more of my machines are now Delta based or fast-moving-head designs.

For Taulman T-glase and Colorfabb-XT based PET materials, the Prusa V2 is great, and I really like the clear, fast and well bonded results.

For PLA in both 3mm and 1.75 for a Cartesian based printer the E3D V4.1/V5 is without doubt my go-to hot-end of choice.

If I did more ABS printing I would use the Prusa V2 Nozzle because it's light-weight and requires slightly less extruder reversal and less extruder pressure than the Pico.

For Nylon I still prefer to use the J-head MK5 in 1.75mm (ideally with an Aluminum head seems to work the best for me)

For Bowden-fed and/or fitted to a Delta printer again due to the light-weight design I would go for a J-head MK5

For a feeling of adventure and any experimentation with multi-nozzle (colour/material/support), printing do take a close look at the Kraken, it's a great design, easy to setup and smooth, fast printing results.

One thing this year of different hot-end testing has strengthened, is that I still find the most reliable drive mechanism uses gearing (like a Wade/Greg's Design) rather than a direct-drive from the motor-shaft approach. The only reliable and long-print success I have had with Direct drive extruders has been with the Kraken, indicating it's low force to extrude.

Bangles

Shauki Bagdadi

Author

Alias:
shauki
Country:
Germany
Website:
G+ ShaukiBagdadi

The ultra simple and affordable RepStrap in any dimensions.

When I decided to build myself a RepRap early in 2013 I wanted to purchase just the electronics and bearings from the internet, while sourcing all other parts from local stores. 3D-printed RepRap components don't belong to this category and I wanted to avoid the experience of purchasing parts with poor quality. Eventually I came up with a design that had me wondering if printing parts for a RepRap is ever interesting, except maybe to help someone who needs spare parts for his existing 3D printer.

QuadRap requires only the following skills to construct: cutting with a saw and drilling! This opens up the potential for many more people to get into 3D printing and learn to solve problems they've never encountered. Schools can raise the level of education as students start dealing with the electronics, firmware, and using 3D design software.

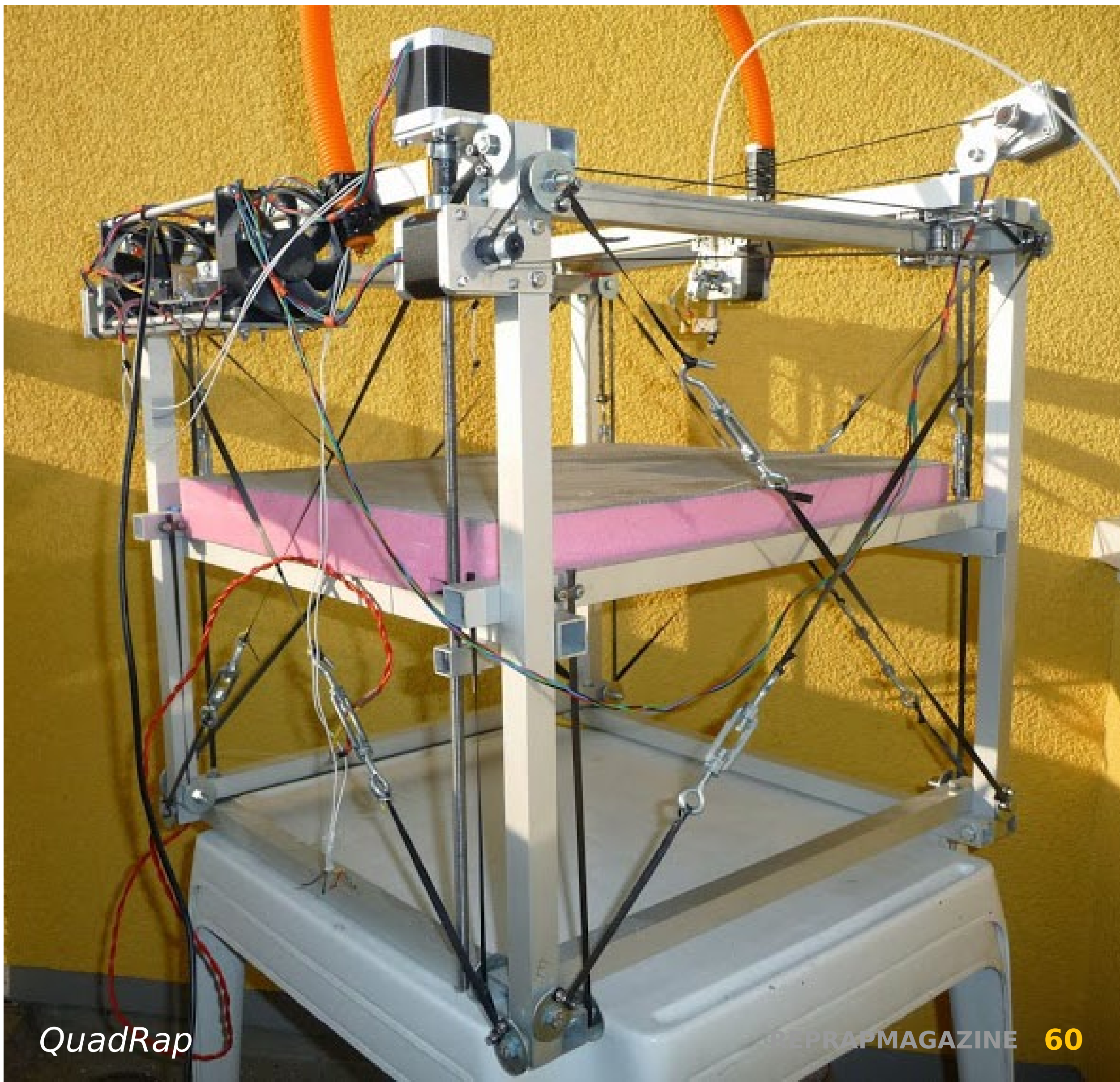
A QuadRap with a printable area of 32x32cm can be built today for about 250€ (US$340). Let us see how the QuadRap accomplishes its simplicity and reliability.

You can find a detailed history of QuadRap's evolution at quadrap-3d-printer.blogspot.de

The Frame

The frame is made from standard aluminium square tubes. This is where the "Quad" part of the name comes from. These tubes are sold in various lengths, and their length is the only limit to the size of printer you can build. Most aluminum tubes are one meter long. In my testing, I found the 20x20mm size sufficiently rigid for this length.

For a portable printer that can fit through a door it's most economical to make it a half meter in each dimension. For a desktop version, 33cm in each direction is most economical.



QuadRap

Of course it doesn't need to be perfectly cubical, either. The QuadRap design makes it easy to customize to your needs.

The dimensions you choose won't affect any other parts, except the length of belts and the Z drive-rod.

The tubes have to be drilled at their ends to accept Ø6mm bolts. Once you've align the edges of the tubes and tensioned these bolts you'll have a perfectly aligned frame, presuming the cut lengths are all the same.

The frame acts as both the supporting and the directing structure for the movable components. Not only that, but it plays the role of a heat sink for the stepper motors, so long as they are connected with aluminum plates to the frame!

In six months of regular use I have no worn out parts yet, but if the aluminum tube in the X-Y gantry should wear out from use, it can be replaced quite easily. In fact, since the frame tubes have the same construction as the gantry, you can just swap the gantry tube with any of the frame tubes, and if the frame has a cube shape, you can do this up to 5 times!

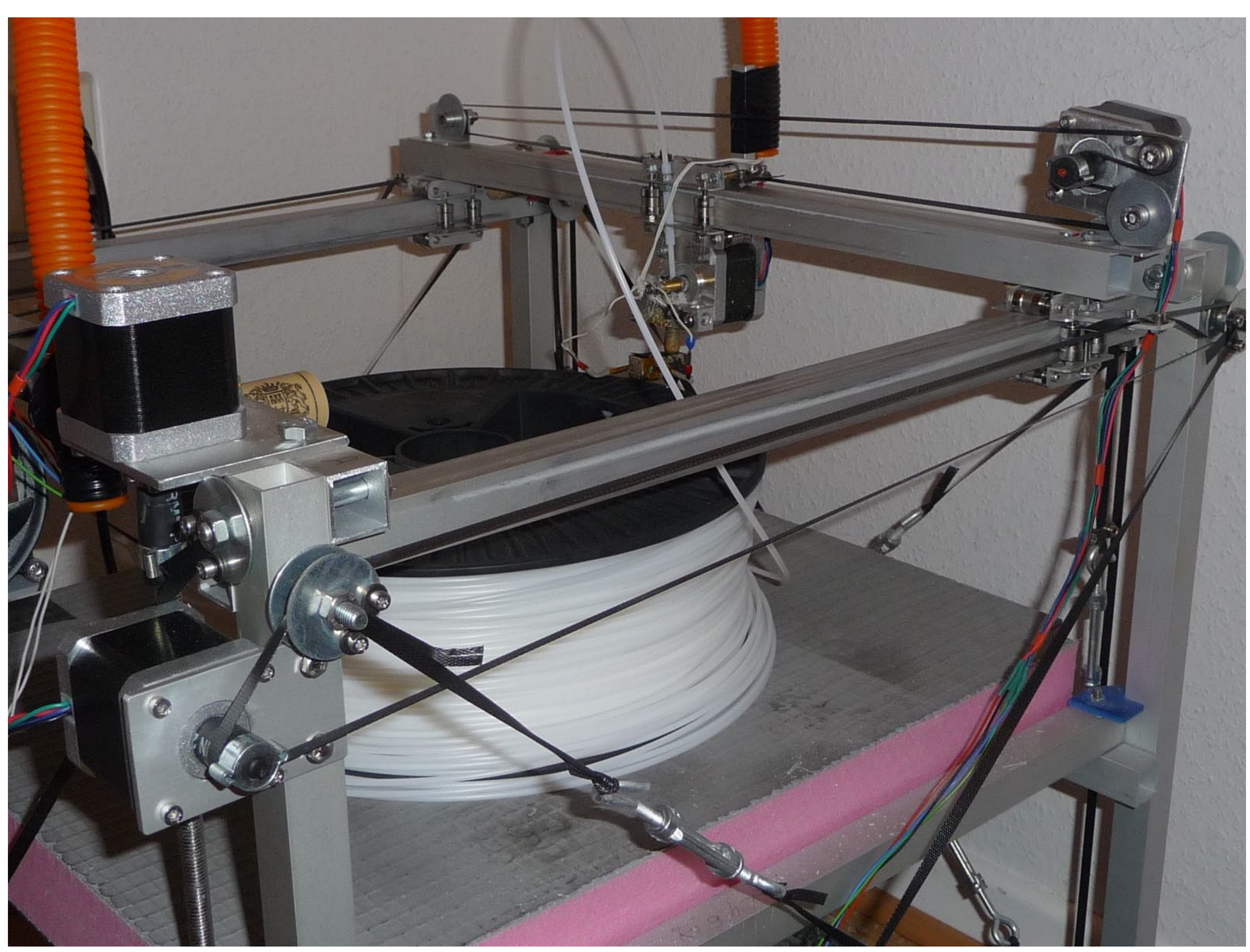
For frames over a half meter in length, it is helpful to add diagonals made of twine or packing tape. The packing tape can be nicely connected with an extra washer and links of bicycle chain.

The Drives

The stepper motors are connected to the frame with an aluminum plate that sinks the heat to the frame, and instead of using toothed gears on the motor shaft, we use a piece of rubber hose from an air compresser. This small rubber drum drives a belt made with reinforced packing strap.

The friction between these hoses and straps seems to be completely sufficient to perform movements with high accelerations up to 900mm/s^2! Even when you try to hold the moving part with your hand, the stepper will lose steps before the strapping will slip.

The absence of friction means there's no wear to the hoses or straps, and because packing straps are designed to remain tight for a long time, the strap doesn't lose its pre-tensioning. Since there are no teeth, its movements are more precise, and the small diameter of the rubber drum reduces the torque required on the motors.



QuadRap detail

Both components have practically zero material cost. Packing strap can be found for less than 4 Euro (US$5) per 100 meters, and rubber hoses can be aquired for very little cost. The straps are connected to the carriages with links of bicycle chain. So don't throw away old bike chains; they're extremely useful for QuadRaps!

The Carriages

The friction of sliding carriages will always be several times higher than rolling carriages, no matter what high-tech sliding bearings you use. Sliding bearings are also very sensitive to asymmetric application of forces, so you'll often see people in RepRap forums lamenting lost motor steps due to belt misalignment or insufficient lubrication.

For the QuadRap I chose to go with mini-rollers which cost about half a Euro (US70¢) each. They can be adjusted from all four angles to get the most ideal alignment.

These carriages roll gapless and without resistance regardless of the force applied to them, and haven't yet caused any noticeable wear on the aluminum tubes, and when they do I can just swap the bars up to 5 times.

The Z Platform

The printing platform in QuadRap moves in the vertical direction. This maximizes the usable area of the printer and reduces printing problems associated with accelerating the printed object.

The vertical movement is achieved with only a single threaded rod at one corner. The other three corners are suspended on fully-tensioned packing straps connected via pulleys from the driven corner. The straps are connected to the platform with bike chain links.

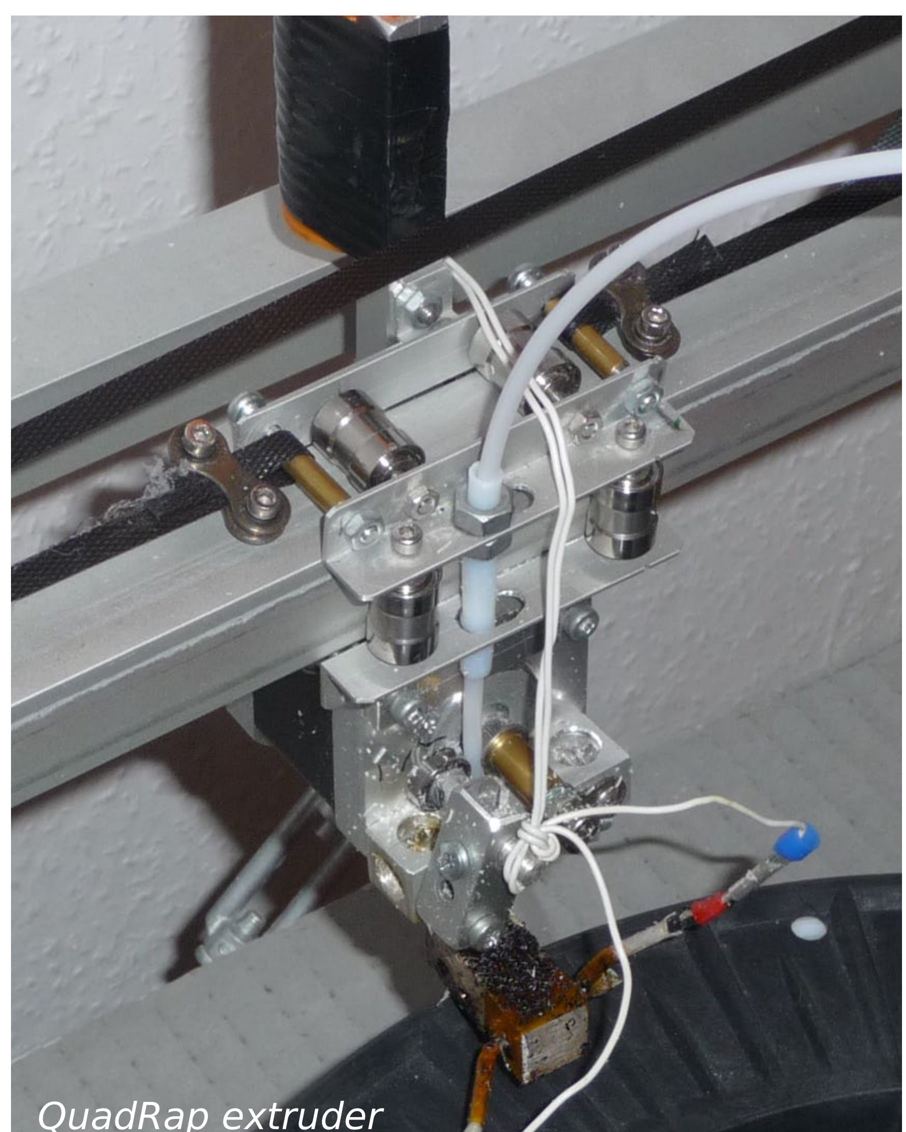
The elevation of the printing platform is adjusted with screws at its corners. Adjustable plastic plates at the corners prevent the platform from moving in the horizontal direction due to imperfections in the threads.

The threaded rod is suspended on the stepper shaft using the same rubber tubing as the belt drives so no exotic coupling from CNC shops is needed.

No Endstops

Pick up some wine bottle corks and connect them with a rubber band as bumpers and alignment guides. Nothing will get broken when the carriages hit the limit positions.

Of course, if you want to embellish your QuadRap, feel free to use any endstops you like. I'm doing fine without being near the printer when it starts or finishes, and checking the GCode to remove the "home axis" commands.



QuadRap extruder

Once the printer "knows" where the print head is positioned, homing will just work, and you should seldom need to adjust it.

Even if the nozzle should collide with the print bed, the rubber hose connecting the threaded rod will slip and the extruder will be protected.

Endstops are a good safety backup but newbies may find their installation frustrating. You want to print as soon as possible and do less wiring work! QuadRap will let you do that with minimum risk.

The Extruder

Flint Wheel: The flint wheel of a used cigarette lighter appears to be the perfect candidate for pushing filament of any diameter. It has an internal diameter compatible with the 5mm stepper shaft, provides great friction, and has a small diameter reducing the required torque. You only need a small bearing to press the filament against the flint wheel, and here also a bike chain link is perfect for the task.

Balanced Thermal Design: By experimenting with different hot end sizes I found that the temperature does not rise over a specific level, and this varies depending on the size of the hot end. Using the same resistor type for extruding PLA requires a longer hot end than ABS, and I have successfully printed non-stop for up to 7 hours without any temperature control.

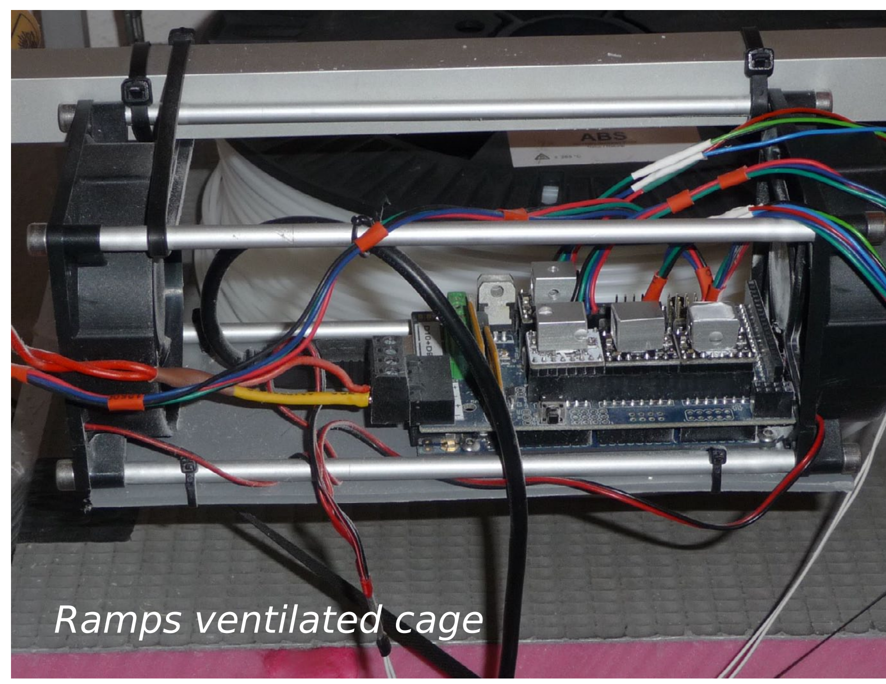
So, by excluding the need for temperature control, QuadRap gives the newbie a greater opportunity to start printing earlier, with no need to purchase thermistors, fans, and wiring, and no need to deal with calibration.

The QuadRap doesn't prevent you from installing other types of extruders and/or doing digital temperature control, but it allows you to save on this part and get started earlier.

The hot end is connected to the cold end with a 35mm x Ø8mm PEEK tube. I desperately wanted to avoid including any exotic materials, but it appears to be just a great, amazing material.

The complete extruder implemented very simply, and is very compact and light. It weighs only 320 grams (11 ounces).

RAMPS Ventilated Cage



Ramps ventilated cage

Installing the RAMPS between two ventilators is a very simple design that provides so much directed cooling that the heat sinks for the Pololu A4988 can be eliminated, even the homemade heatsinks I experimented with on the QuadRap blog. This also saves the cost of the thermal glue required to attach the heatsinks.

Firmware Settings

I've been successfully using Repetier and Marlin firmware and love the Repetier host.

Neither Marlin nor Repetier firmware includes settings directly applicable to the QuadRap (but this may soon change!). The QuadRap uses two stepper motors for the X direction and one stepper motor for the Z direction, whereas most RepRap printers use two Z motors and a single X motor, so RAMPS and other boards conveniently include two stepper motor connectors on the Z stepper. To address this, you can connect the X motors to the stepper labeled “Z”, and the Z motor to the stepper labeled “X”, then modify the firmware source code and swap the pin assignments for the “X” and “Z” directions. (In Marlin, you’ll need to modify the pins.h file.)

Additionally, you should turn off hardware endstops and temperature control from the firmware until you decide to install endstops and a fan.

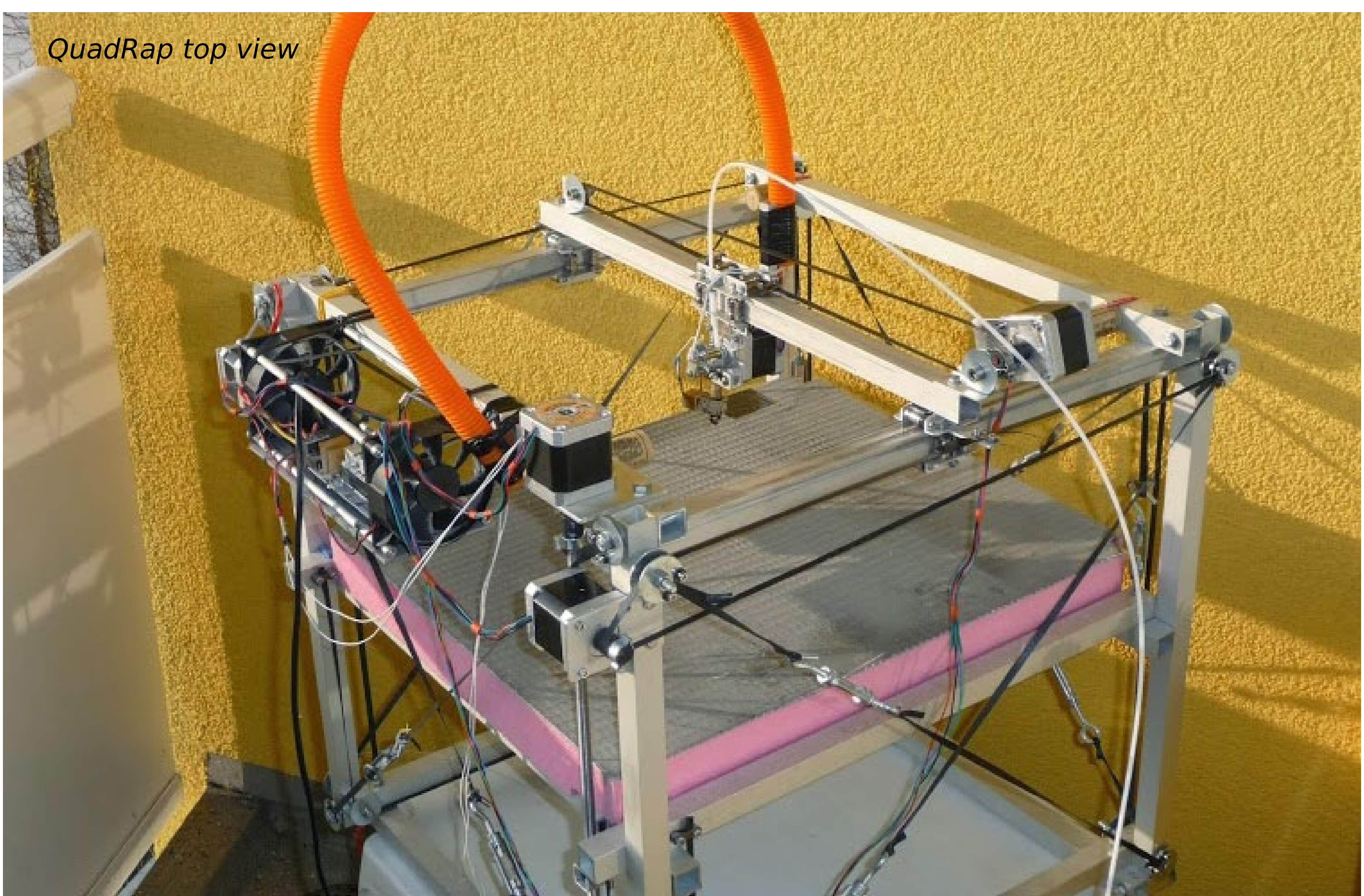
GCode Precautions

The software endstops in the firmware provide sufficient safety for the QuadRap. You can give the firmware the maximum printable volume, manually move the XY carriage to the desired starting position, lift the table by rotating the threaded rod, or moving the Z axis in your print host, and disconnect/reconnect the host software before starting the job. So far for me, it has never happened that the extruder left the theoretical printable zone.

If you happen to go further and disable the software endstops as well, you’ll need to check the ending GCode in your slicer settings to replace the “home axis” command with something like G91 followed by G1 X30, which tells it to use relative coordinates and move some distance away to move the nozzle away from where it can ooze onto the printed part.

Future Plans

- 300 gram quad color extruder
- Street Painter Bot on omni wheels based on RAMPS 1.4



QuadRap top view

Morgan visual instructions

Author
Paulo Gonçalves

Alias:
pdesigns
Country:
Portugal
Website:
http://reprapstyle.blogspot.pt

In this issue we will help some off our readers to assemble the RepRap Morgan, winner of the Gada Prize.

A special thank you to Quentin Harley for his assistance on the making of this article, and for his detailed instructions.

As Quentin Harley, designer of Morgan, mentions in his blog this printer is bourne of **"A dream to make it easy for anyone in South Africa, or anywhere else in the world to build a 3D printer without needing exceedingly expensive materials, hard to find components, stuff that has to be shipped at sometimes more than the cost of the components, requiring advanced tools."**

In the true spirit of a RepRap printer it is named after a biologist, and is this case is Thomas Hunt Morgan:

Biologist and geneticist known for his extensive research on the drosophila melanogaster (common fruit fly).

He found that two very average looking flies could, through propagation of latent genes, spawn many unusually looking offspring.

This is exactly what Morgan aspires to be. The unusually looking offspring of the RepRAPs before it, drawing from the best of what is currently available, but presenting it in a fresh efficient way.

You can find the wiki page here, and the author website here.

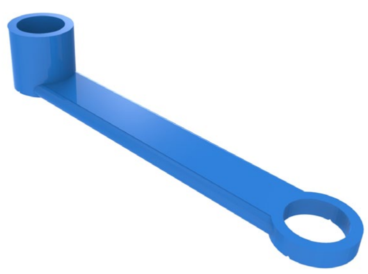
Morgan visual instructions

BOM (Bill of materials)

	Part	Qty
Printed Parts		
	PVC pipe support a (Ported)	4
	PVC pipe support b (Non Ported	4
	Z mount bottom	1
	Z mount top	1
	Motor mount short	1
	Motor mount tall	1
	Drivewheel ro	1
	Drivewheel tube	1
	22mm 6805 bearing adaptor	1
	Bed arm left	1
	Bed arm right	1
	Bed Z mount bracket	1
	Bed rear mountclips	2
	Bed front mountclips	2
	Hall endstop holder	3
	Leadscrew shaft motor mount	1
	Morgan arm PSI a	1
	Morgan arm PSI b	1
	Morgan arm Theta a	1
	Morgan Arm Theta b	1
	Morgan toolhead	1
	Leadscrew nut Alpen8mmSDS	2
	Extruder bowden adaptor	1
	Cap	2
	Eckstruder big gear herringbone	1
	Eckstruder block for Prusa	1
	Eckstruder idler for Prusa	1
	Eckstruder small gear herringbone	1
	Thumb knob M4 extruder	1
	Tightening cone	2
VItamins		
	M8 nut	12
	M8 washer	6
	M8 spring washer	10
	M8 washer 28mm	6
	M4 nut	9
	M4 bolt 40mm	8
	M4 bolt 80mm	1
	M8 nylock nut	6
	M8 bolt 40mm	3
	M8 bolt 100mm	1

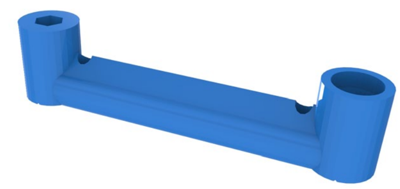
Part	Qty
M8 bolt 60mm	1
PVC pipe OD 32mm - 459mm	2
PVC pipe OD 32mm - 452mm	2
2mm self tapping coach screws, 40mm	2
15mm brass pipe - 440mm	1
15mm brass pipe - 200mm	2
22mm brass pipe - 460mm	1
8mm threaded rod - 650mm	1
8mm smooth rod - 440mm	2
608z	5
F608z	4
6805Z	2
Hard spring (idler compression) 7mm	1
8mm soft spring (lead screw)	1
Cabinet coach screws, 5mm	10
LM8uu bearing	4
Lead screw 330mm, Alpen8mmSDS	1
M3 nut	3
M3 grub screw 6mm	3
Timing pulley T2.5	2
Timing belt	1
Eletronics	
Hall efect endstop sensors	3
Arduino Mega	1
Ramps 1.4 board	1
Pololu low current 1/16th	2
Pololu high current 1/32th	2
Step motor 200step (1.8deg)	2
Step motor 400step (0.9deg)	2
Power supply ATX 400w	1
Ethernet cable, multistrand flexible	5m
High current cable	1m
Lasercut	
Morgan lasercut platforms	1
Universal build plate	1
Aluminium/glass build surface Mk2a heatbed	1
Hot-End	
PTFE tube 6mm - 600mm	1
J.-Head Mk-VB hot-End	1
Kapton tape	1

Printed Parts:

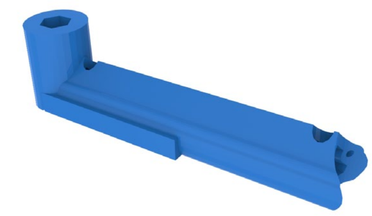


Arm Theta a

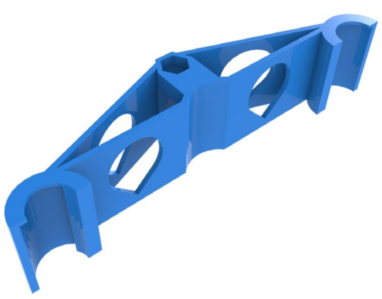
Arm Theta_b



Arm PSI a



Arm PSI b



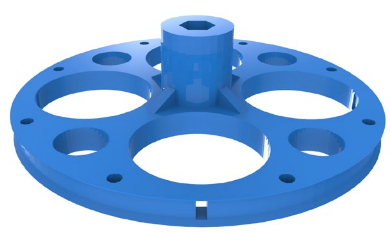
Bed Z bracket

Bed arm left

Bed arm right

Motor mount tall

Motor mount small



Drive wheel rod

Drive wheel tube

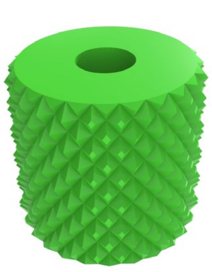
PVC pipe nonported

PVC pipe ported

Tightening cone

Bowden adaptor

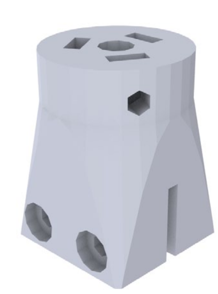
Tool head



Cap

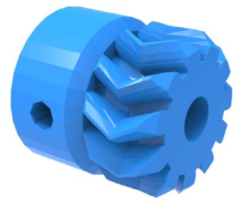
Z mount top

Z mount bottom

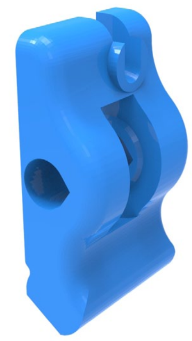


Leadscrew shaft motor mount

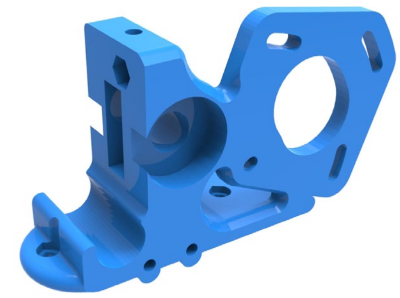
Hall endstop holder



Eckstruder small



Eckstruder idler



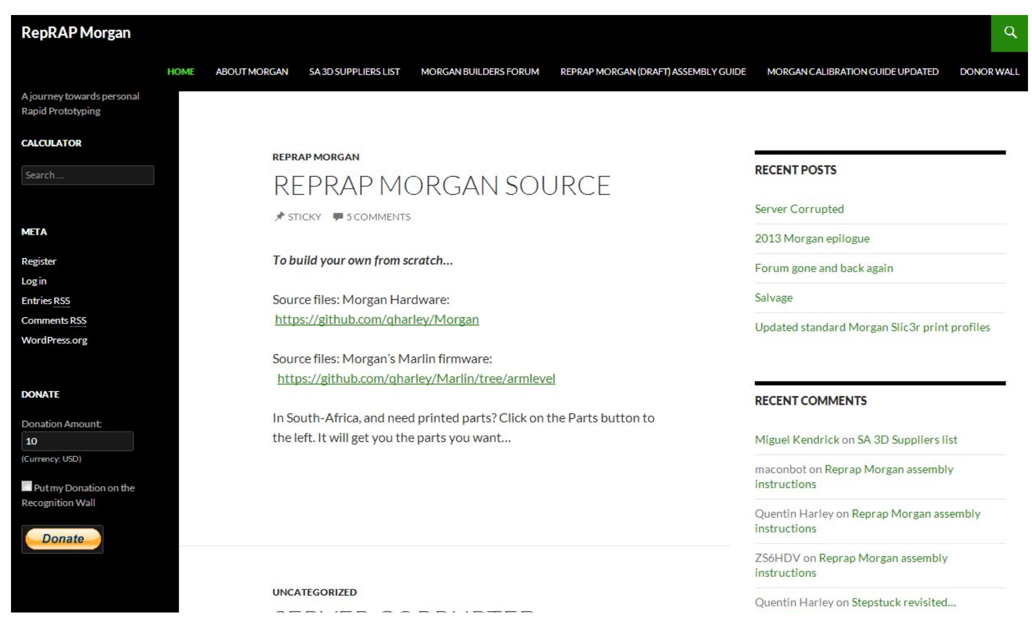
Eckstruder block

Eckstruder big gear

Main links to what out:

Quentin Harley(author) website

Here you can find the main info about the project like calibration guides, a webshop or a forum. It is also where the official assembly guide and BOM are published.

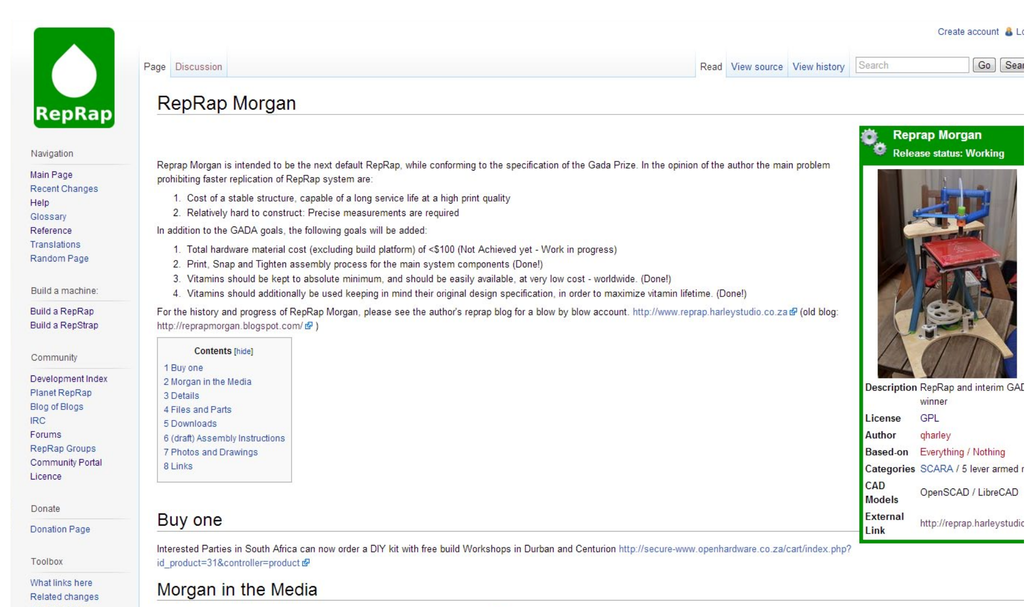


Github page

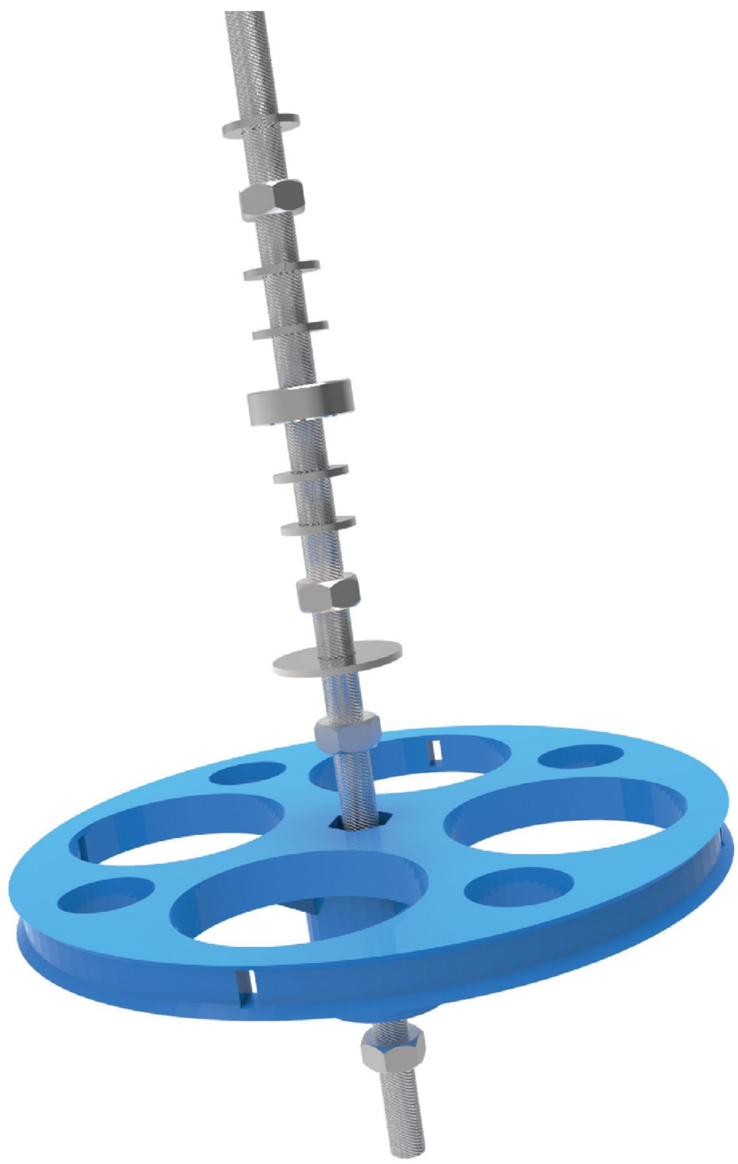
In the Morgan Github page you can find all the files you need to build your printer if you decide to do one from scratch, and you will also find the adapted version of the firmware Marlin.

RepRap page

Where you is the description of the printer, common questions and very useful links. It also contains the assembly instructions and some links to what the Media says about this great printer.



1



Parts:

Threaded M8x650 - 1
608 bearing - 1
M8 nut - 4
M8 washer - 2
M8 spring washer - 3
M8 washer 28mm - 1
Drive Wheel Rod-mount -1

Start by grabbing your threaded rod and then insert in order the following parts loosely:

M8 spring washer
M8 nut
M8 spring washer
M8 washer
608 bearing
M8 spring washer
M8 nut
M8 washer 28mm
M8 nut (insert it in the printed part)
Drive wheel rod-mount
M8 nut (insert it in the printed part)

2

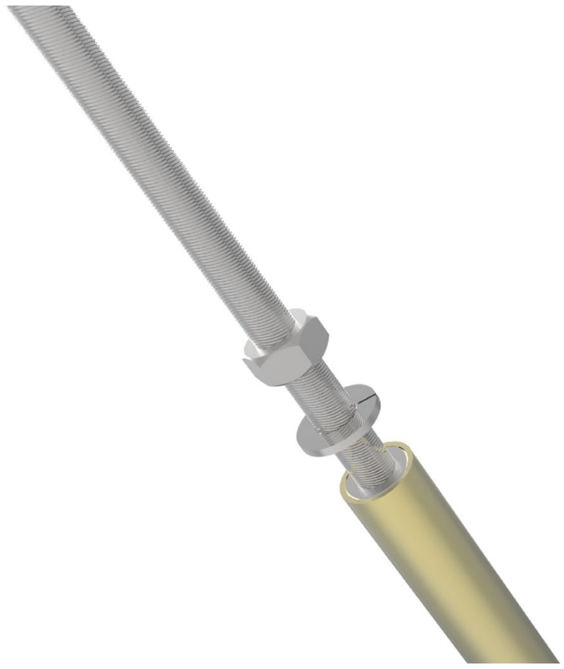
Parts:

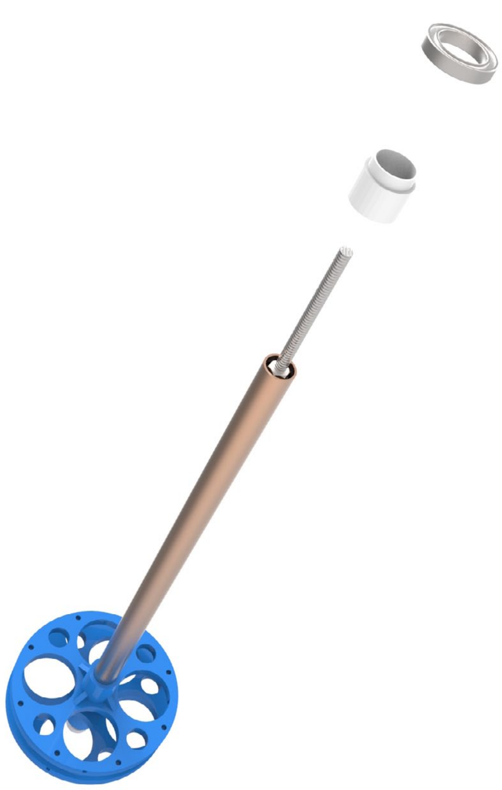
M8 washer 28mm - 1
M8 spring washer -1
M8 washer - 2
M8 nut - 1
M8 nylon lock nut - 1
608 bearing -1

On the bottom part insert also by order the following components Loosely.

M8 washer 28mm
M8 spring washer
M8 nut
M8 washer
608 bearing
M8 nut
M8 nylon lock nut

Tighten all the components on the rod towards the Nylock nut on the end. Turn PTFE plumbers tape around the threaded rod at the bearing sites to ensure they sit tight and centred on the rod.





3

Parts:

15mm OD copper plumbing pipe - 440mm
M8 nut - 3
M8 spring washer - 1

First thing we need to do is to insert two M8 nuts into the pipe 15mm copper pipe. To do this just follow Quentin method:

1 - Take a M8 bolt, and turn a M8 nylock nut onto it so that the lock part sits flush on the tip of the nut

2 - Support the pipe on a block of soft wood, and using a small hammer, gently tap the nut into the pipe until it is 80% in.

3 - Carefully pull the bolt and nut out of the pipe, and repeat on the other side. This creates a nut trap in the pipe.

4 - Supporting the pipe of the wood again, knock a standard M8 nut into each end until flush. Tap the edges of the pipe gently with the hammer to ensure a good hold onto the nut. At this point you can also solder the bolts to the pipe. To ensure good flow, insert plumbers flux paste into the pipes before the nuts.

Now that you have the nuts inside the pipe insert the pipe into the threaded rod and make sure you tight it until the spring washer is completely flat. It is recommended to apply a drop of thread lock on each nut before tightening.

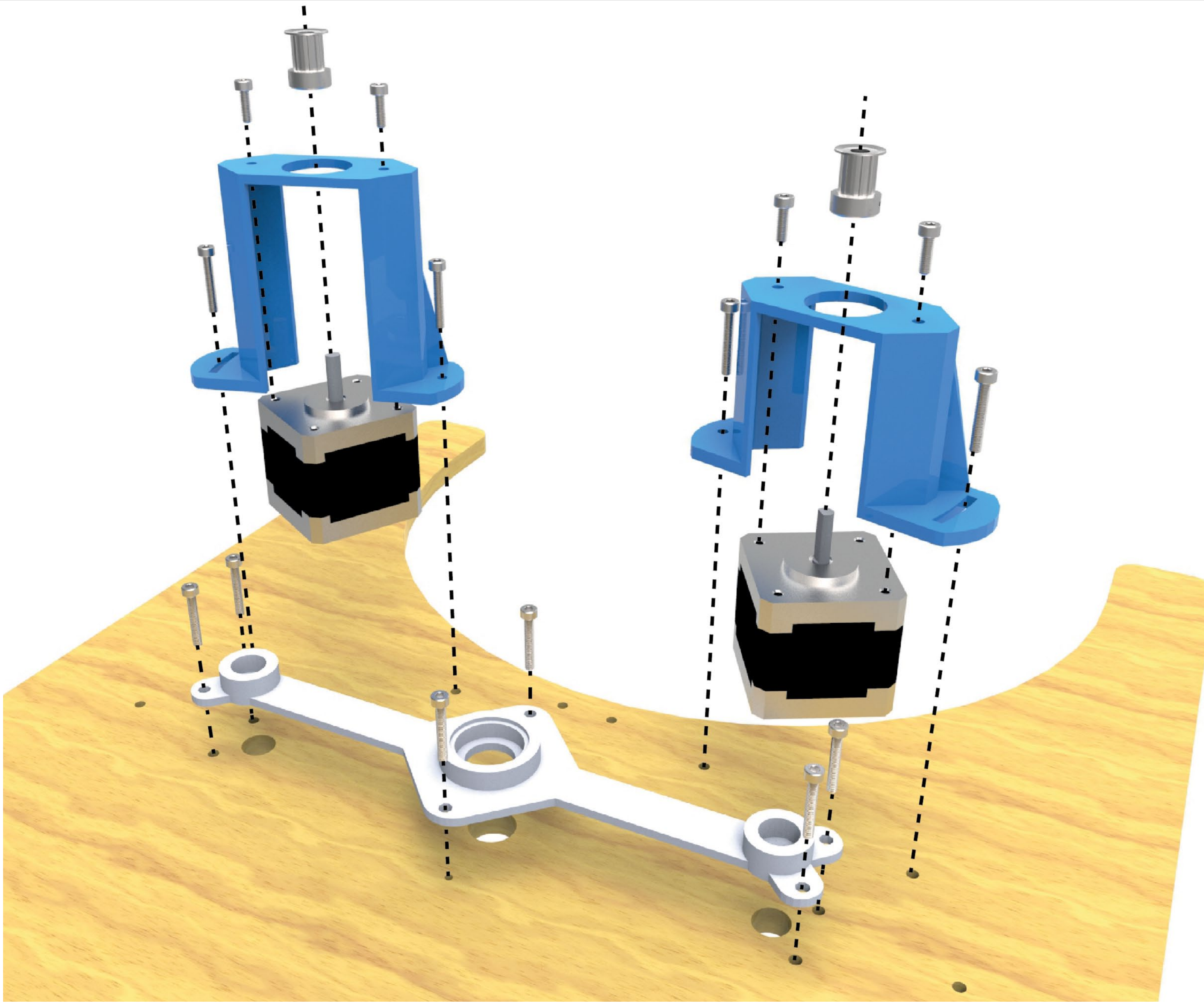
Secure the pipe into place with a M8 spring washer and a M8 nut also with thread lock. It is vital that the rod and pipe assembly act as a single drive shaft.

Next you need to insert the 22mm pipe into the Tube-mount drive wheel, with the flat side of the wheel to the bottom. In the image 5 you can see that the pipe is not yet insert into the printed part but this is just to show where things go, you should first insert the pipe into the printed part and them insert both into the Drive Shaft Assembly.

Note: To ensure that every key components sits centred with the threaded rod you can use PTFE plumbers tape around them.

Add the 6805 bearing adaptor and the 6805 bearing into the copper pipe. We will adjust this piece later on. The 6805 bearing might lock the adaptor in place. In this case it may be easier to insert the 6805 bearing into the top Z-support bracket.

4

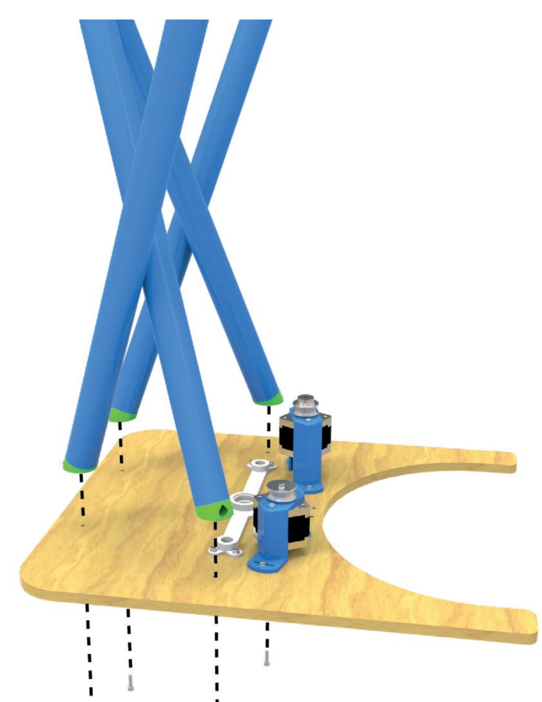


Parts:

Motor mount short - 1
Motor mount long - 1
M3 x 10mm - 4
Timing pulley 2.5mm - 2
M3 x 15mm - 4
M3 nuts - 4
M3 washers - 4
Pipes - 4
M4 x 40mm countersunk heads

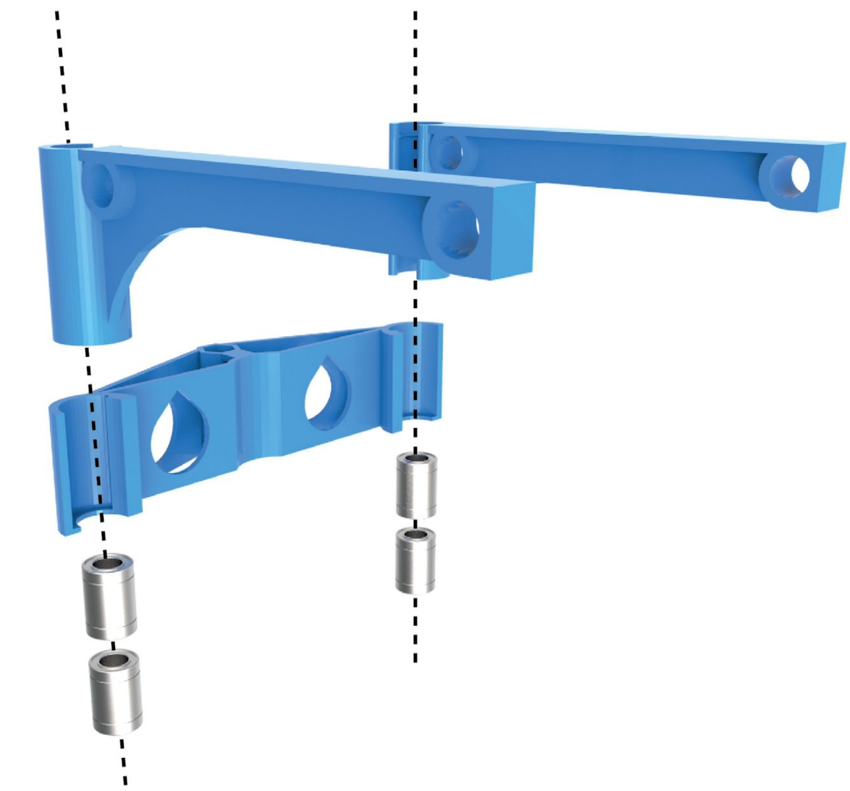
Mount the motors into the Motor mounts, both the long and the short using the M3x 10mm screws
and them mount them onto the bottom platform. The motor mounts perform best when the support wings are facing the drive wheels.

In this instructions we are using as a reference M3x15mm screws with respective nuts and washers but this depends on the thickness of your wood boards.



After the motors are assembled we can install the pipes on the bottom platform. Two choices are available: M4 nuts in the nut traps, or MDF panel screws self tapped into the pipe holders.

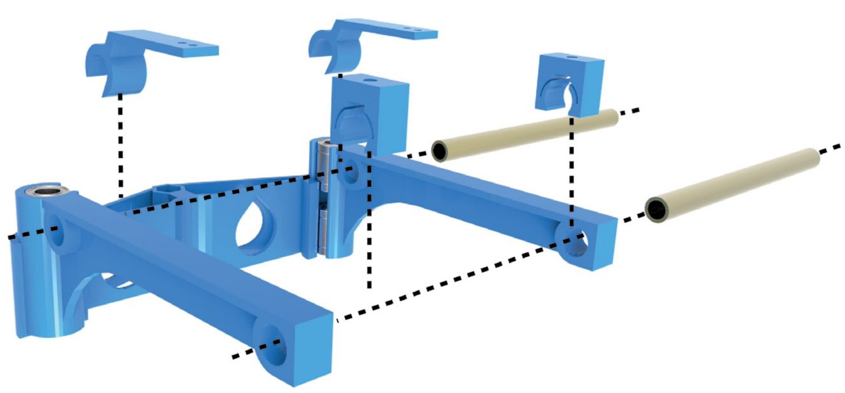
5



Parts:

Bed arm left - 1
Bed arm right - 1
Bed Z mount bracket - 1
LM8UU - 4
Bed rear mount clips - 2
Bed front mount clips - 2
15mm brass pipe x 200mm - 2
Universal printing platform - 1
M3 x 15mm - 6

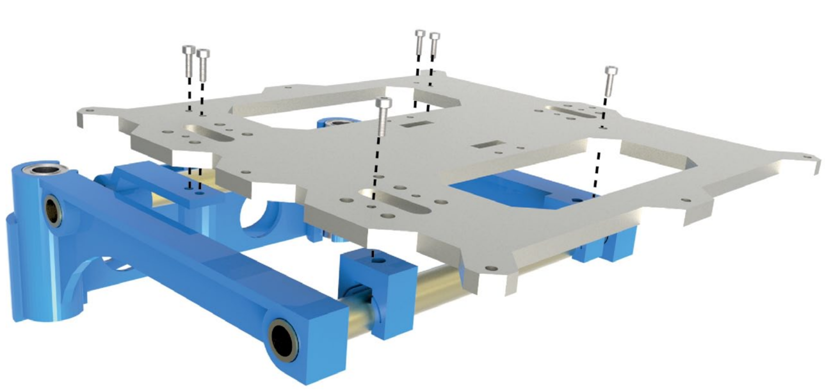
To assembly the printing platform we are going to start to insert the bed arms into the bed Z bracket and at the same time make sure to install the LM8UU linear bearings in their place. Check the bearing movement on a smooth rod. Bearing alignment needs to be good for smooth movement. Alignment can be tweaked by warming the arm slightly around the bearings with the rod inserted and applying pressure.



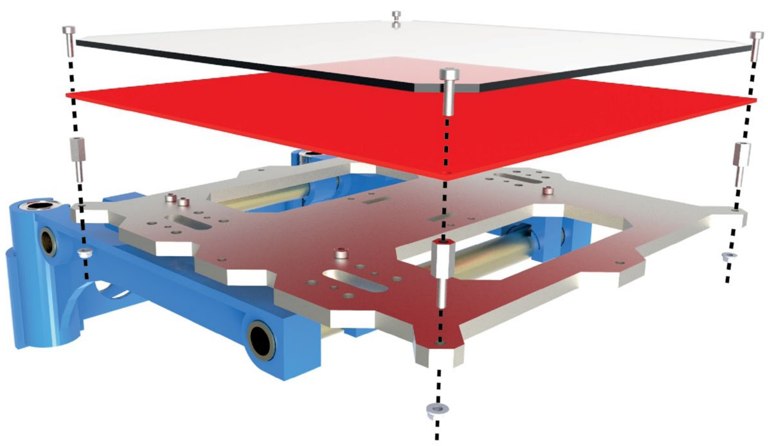
In order to give this assembly more structure and to be able to attach the universal printing platform into it we are going to insert the two 15mm brass pipes into the bed arms. This should be a tight fit, but if its not use the pumblers tape to get a tight fit.

Insert the mountings clips into the pipes.

After this is done attach the printing platform into the mounting clips and secure it with screws. The platform in the DXF is a good choice if you want to use the 200x200 prusa compatible heated beds. Use it as a guide - only the position of the clip mounting and the four (three) mount points are important.



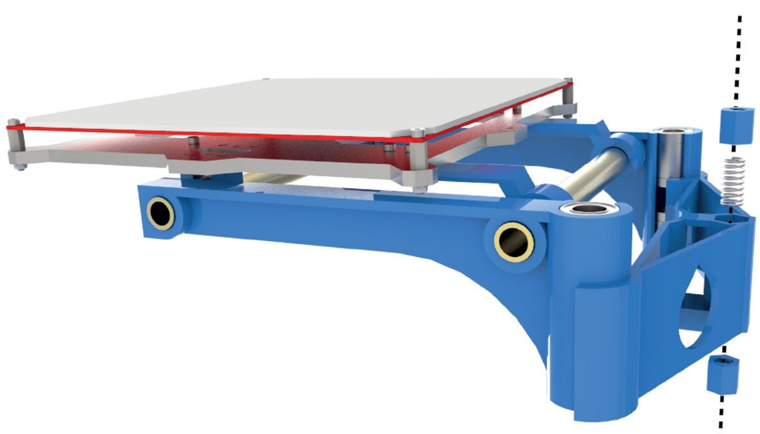
6



Parts:

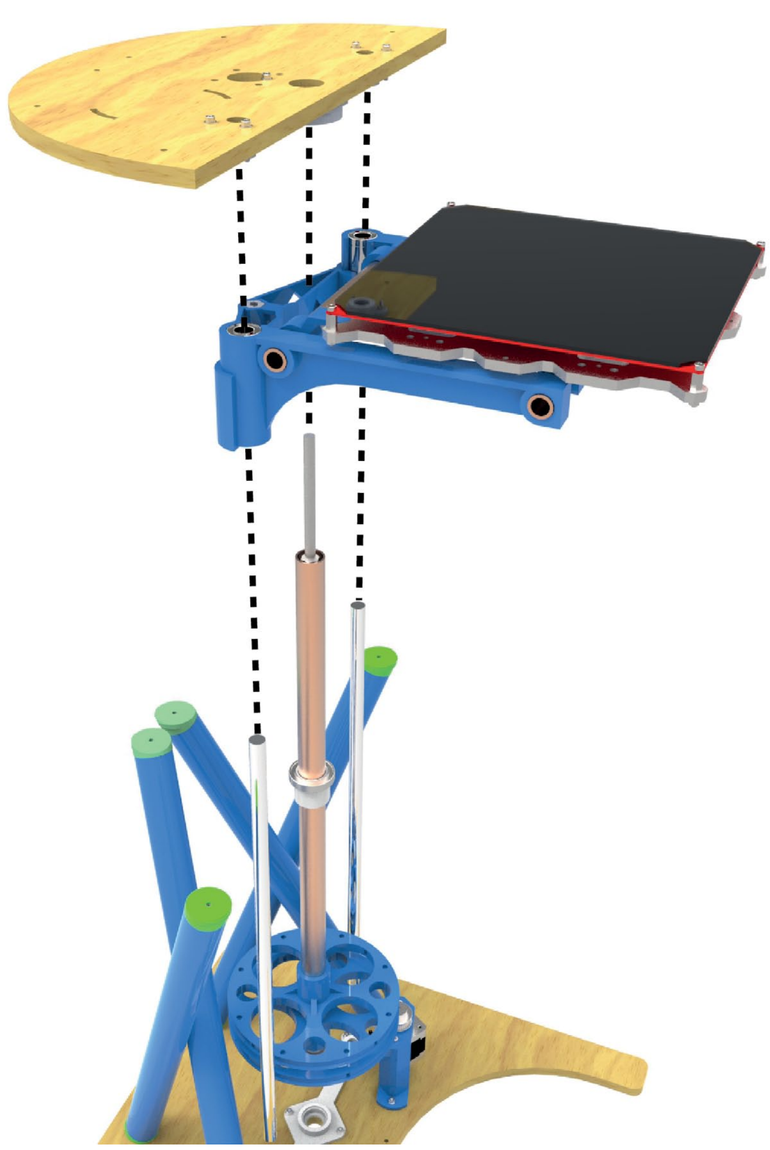
Glass/Aluminium printing platform - 1
MK2 heated bed - 1
M3 stand off - 4
M3 x 10mm - 4
M3 nuts - 4
Leadscrew nut - 2
Spring - 1

To finish the building platform we only need to add the MK2 heat printing bed and the 200x200mm glass/Aluminium sheet. Use bull-dog clips to secure the glass or 3mm Aluminium sheet in place.



After it just insert the two leadscrew nuts and the spring into the Bed z bracket. The bottom nut sits tight against the partition, while the top one presses against the spring to limit backlash. You can adjust the amount of friction by inserting the top nut deeper.

NB: When using Aluminium for your print surface make absolutely sure all electrical connections to the bed are insulated using some Kapton tape.



Finish the frame assembly by doing the following:

1) Push the assembled drive rod into the lower Z-support.

2) push the smooth rods into the holes in the lower Z-support

3) Install the assembled bed module onto the rods

4) insert the Z-drive leadscrew in the nuts of the bed support bracket

5) lower the top platform with the top Z-support installed on it over the drive shaft and onto the smooth rods, 6805 bearing and adaptor.

6) Attach the PVC pipes to the top platform. Note that the PVC pipes will not want to go to their designated positions without a fight. This is so by design, and the tension keeps the PVC frame stable. Work carefully not to dislodge the nuts in the nut traps.

7

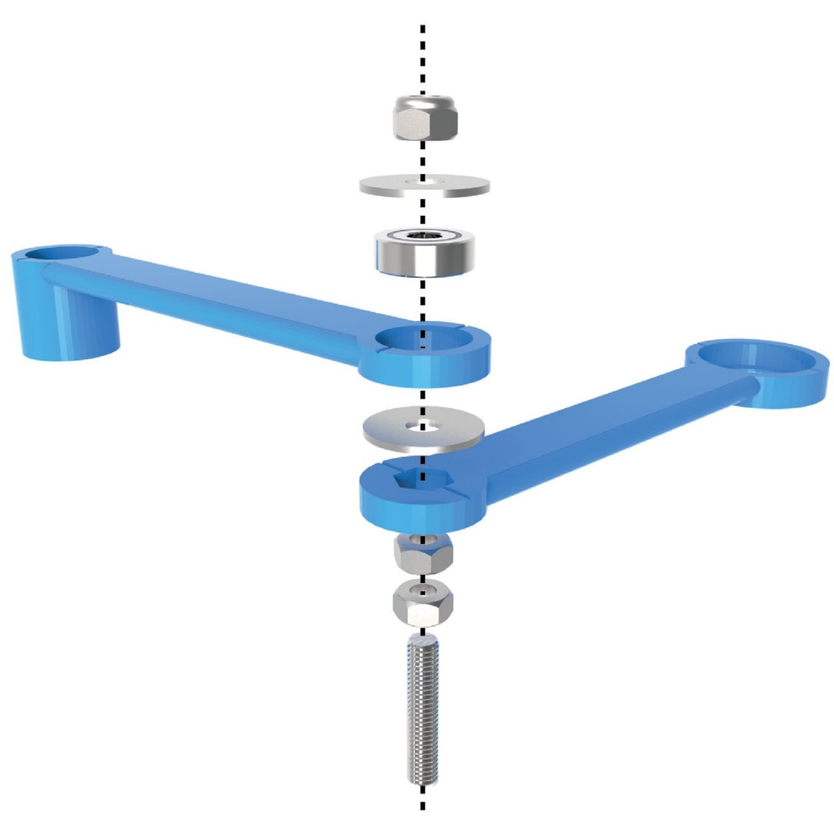
Parts:

Threaded M8 x 100mm - 1
M8 washer 28mm - 4
M8 nut - 5
608 bearing - 2
Morgan arm PSI a - 1
Morgan arm PSI b - 1

Start by inserting the two captive nuts into the morgan arm PSI b, and the two 608 bearings into the morgan arm PSI a. Don´t forget that apply some plumbers tape on the rod in the bearings to ensure they say concentric.

Now tighten the both arms together as the image shows.

8



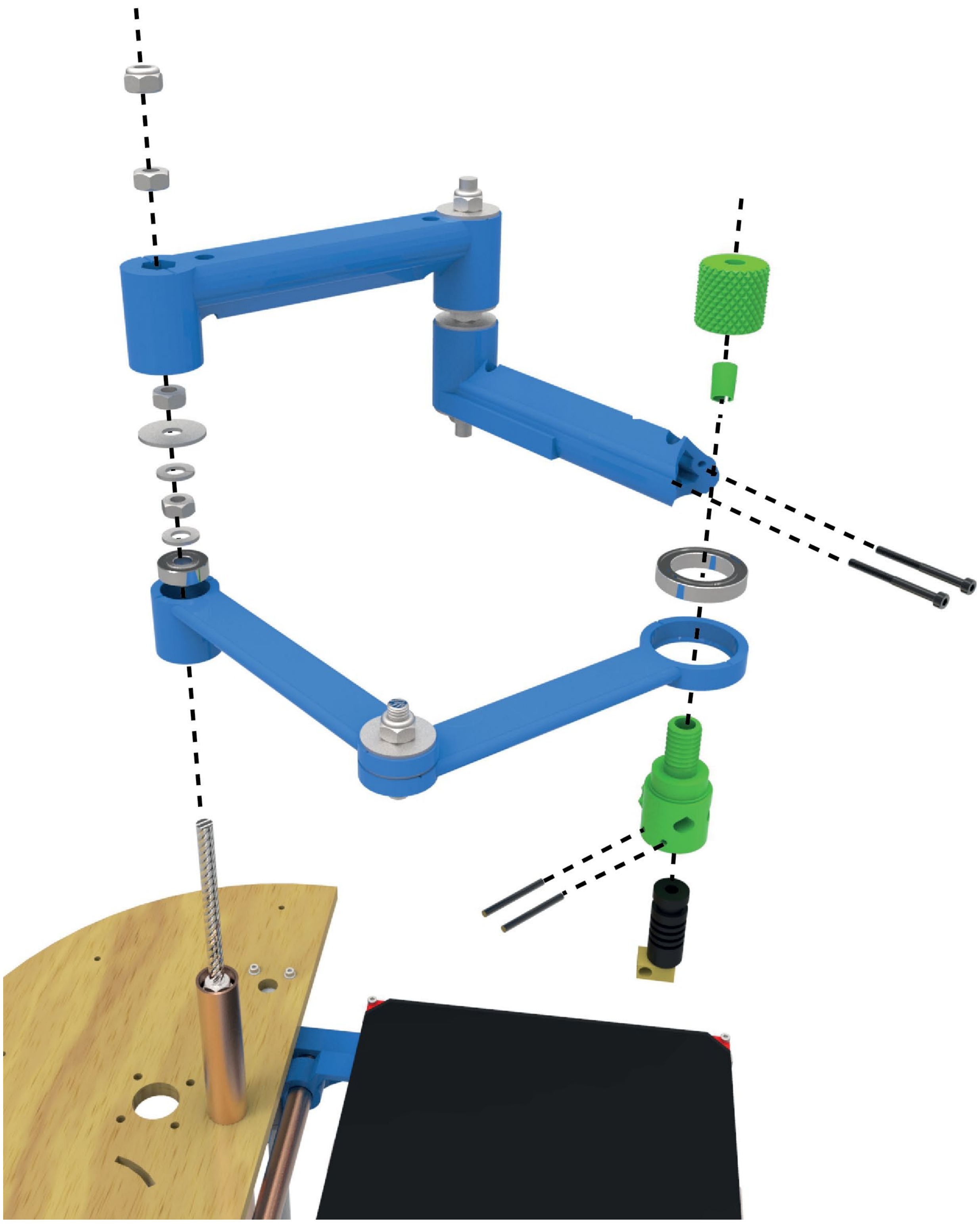
Parts:

Threaded M8 x 40mm - 1
M8 washer 28mm - 2
M8 nut - 3
608 bearing - 1
Morgan arm THETA a - 1
Morgan arm THETA b - 1

Here you should also start to insert the captive nut into the morgan arm THETA b and the bearing into the morgan arm THETA a (again the plumbers tape on the bearing).

Then assemble both arms together as the image shows.

9



Parts:

Morgan arms PSI
Morgan arms THETA
Morgan tools head - 1
Tightening cone - 1
Cap - 1
Hot-End - 1
M3 x 30mm - 2
6805 bearing - 1
608 bearing - 1
M8 washer - 1
M8 washer 28mm - 1
M8 spring washer - 1
M8 nylon nut - 1

On this step first assemble both arms into the drive shaft. Insert the 608 bearing into the morgan arm theta A, and the two captive nuts into the morgan psi a.

Insert the Morgan arms theta assembly into the drive shaft them by order:

M8 washer
M8 nut
M8 spring washer
M8 28mm washer

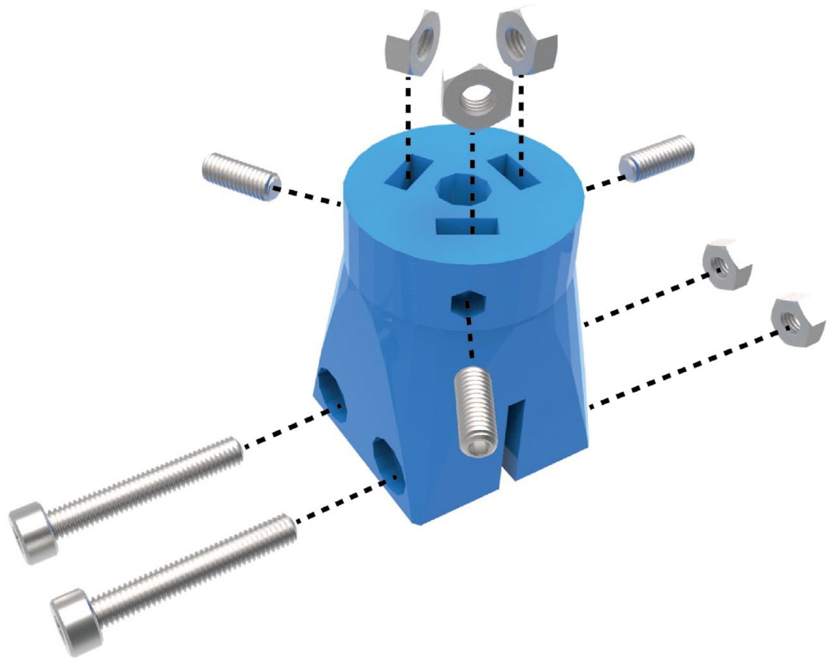
Then add the morgan arms psi sub assembly and secure it with an M8 nylock nut.

You can cut off the threaded rod 10mm above the Nylock nut, and add an acorn nut to round it off.

The second part of this step is to show how to secure the tool head into place. First insert the 6805 bearing into the Morgan arm Theta b, and then insert the tool head into the 6805.

To secure both arms subassembly together use the M3 x 30mm that pass trow the tool head and tight them on the morgan psi b.

The role of the tightening cone is to hold the bowden tube into place. It fits around the bowden tube with the thin tip downwards. Tightening the cap will work the cone into the hot-End effectively clamping the PTFE bowden tube in place.



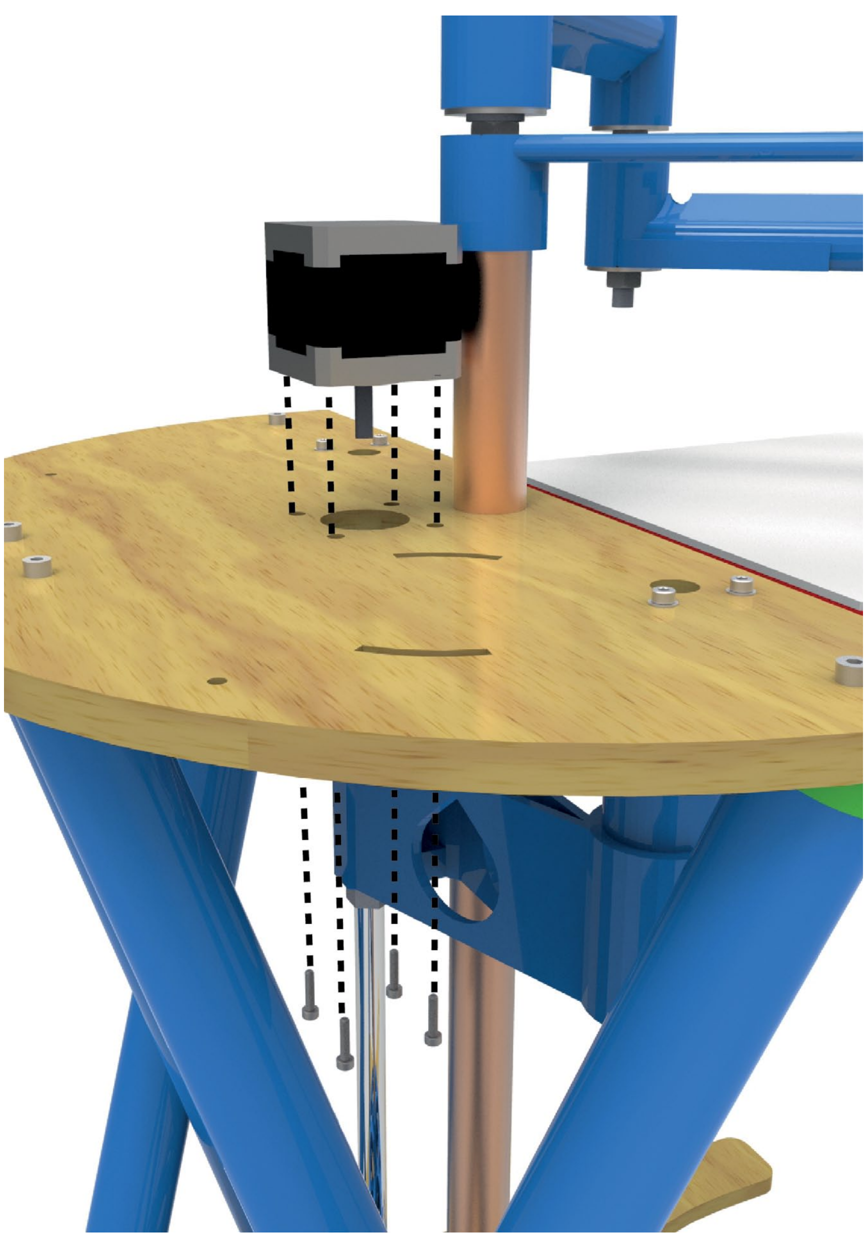
10

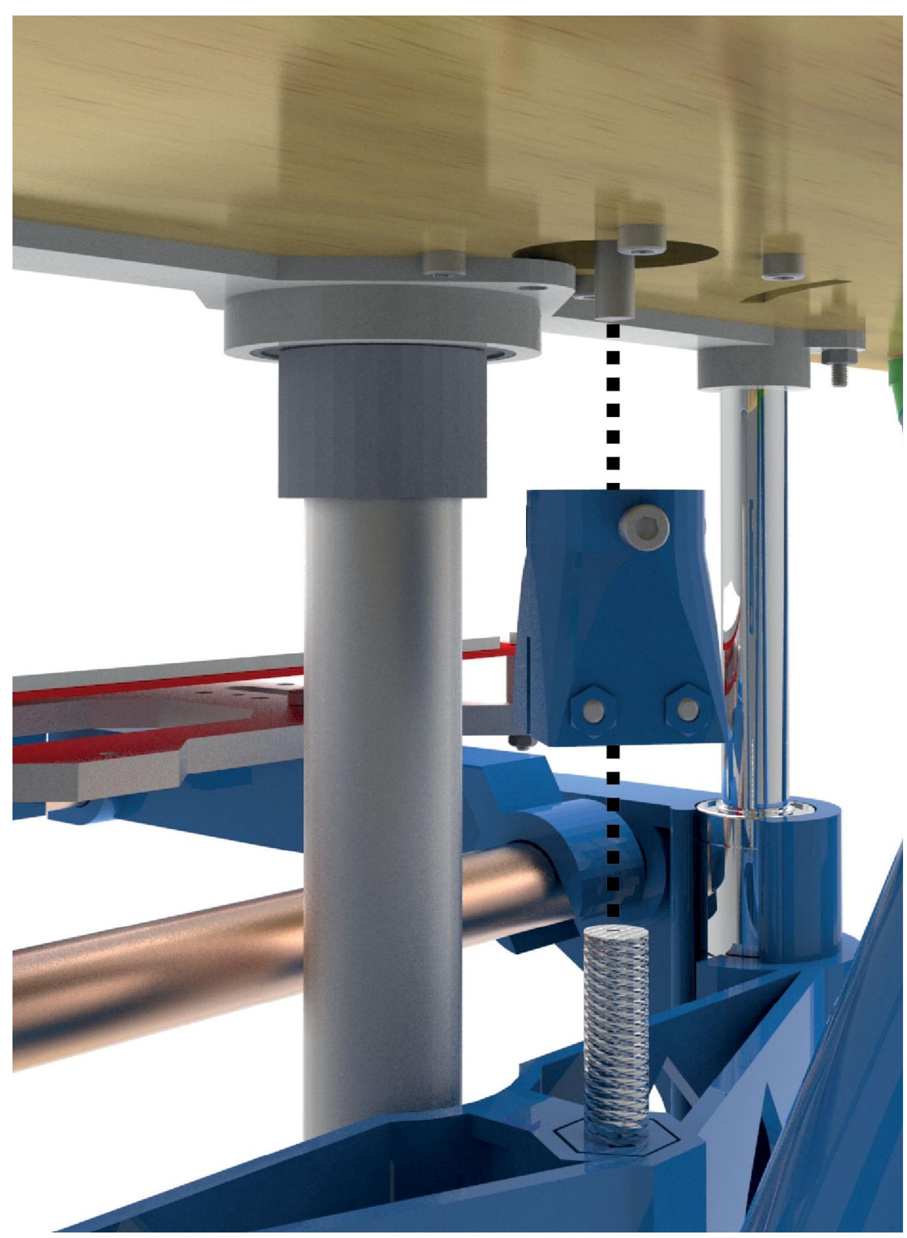
Parts:

M3 x 10mm - 3
M3 x 20mm - 2
M3 x 15mm - 4
M3 nut - 5
Leadscrew - 1
Nema 17 - 1
Leadscrew Shaft coupler - 1

It is now time to do the z axis assembly. First prepare the shaft coupler inserting the M3 nuts and the M3 screws.
If you have M3 hex “grub” screws (headless)

After that attach the nema 17 to the top platform, and them pass the leadscrew throw the bed Z mount bracket and use the lead-screw shaft coupler to secure the leadscrew into the nema 17 shaft.





11

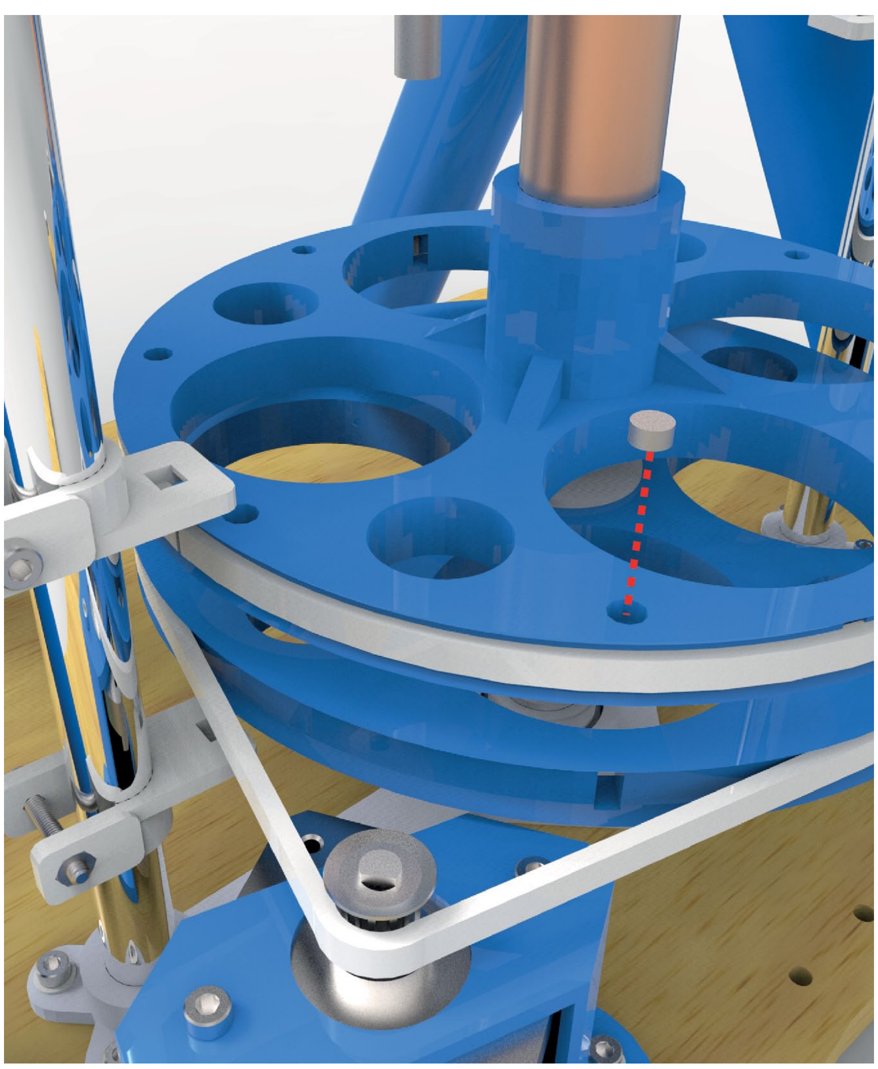
Parts:

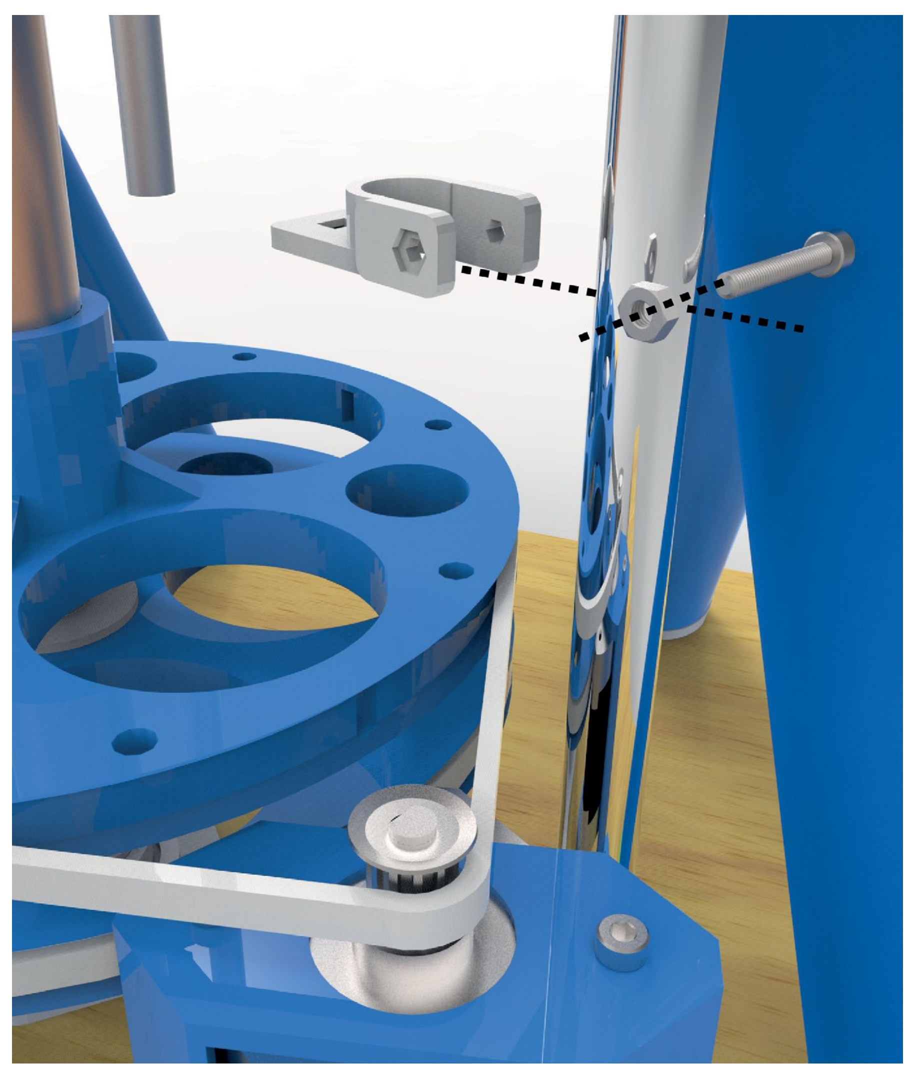
Hall endstop holder - 3
M3 x 20mm - 3
M3 nuts - 3
Timing belt - 2
Magnet - 2

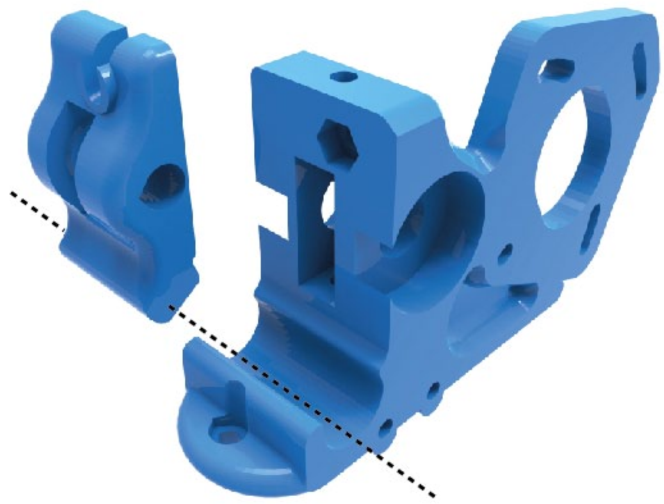
Time to deal with the endstops and the belts.

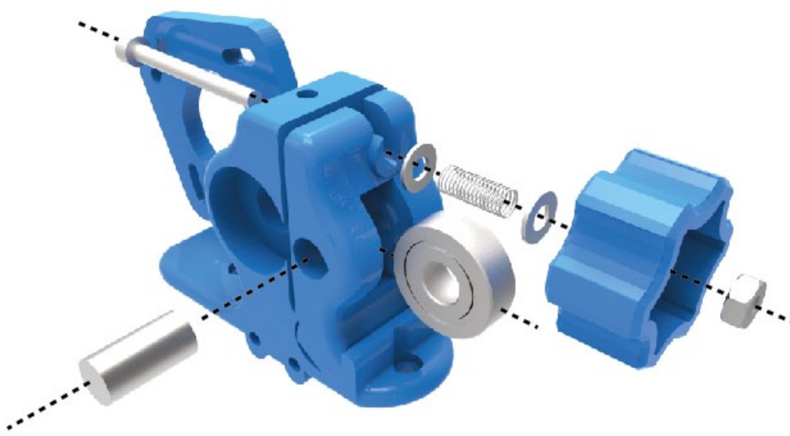
Morgan uses hall effect endstop sensors instead of the more traditional mechanical endstops. This means that we need a magnet to trigger the endstops. Quentin did a good video to show how to set them up, so if you have any doubts just check this link:

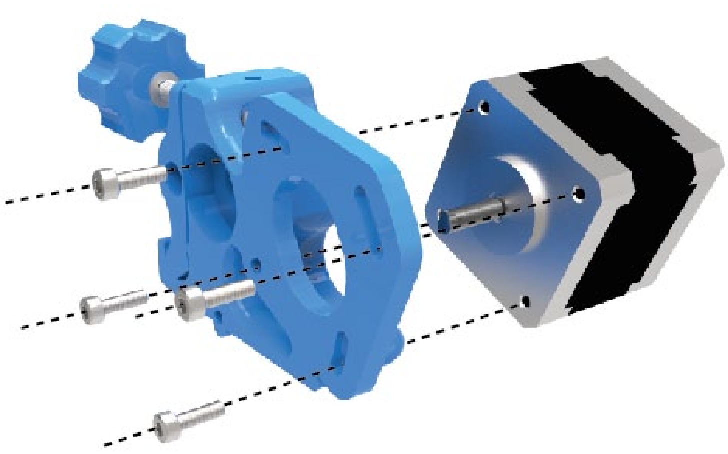
http://www.youtube.com/watch?v=dceSD7t-4rc

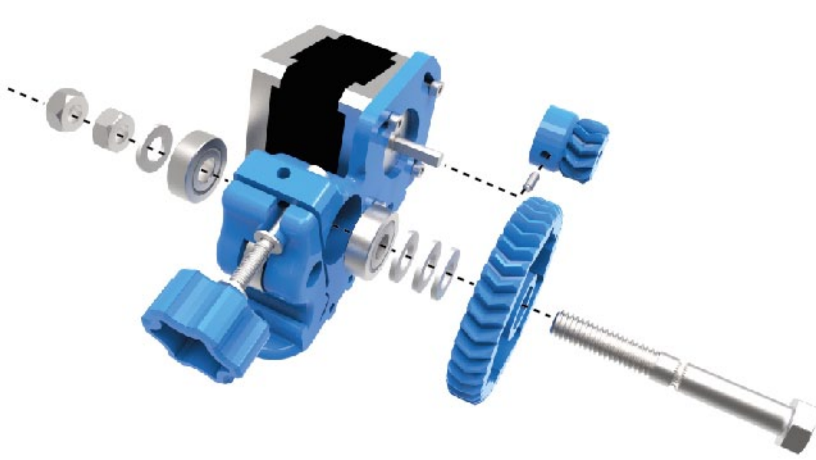












12

Parts:

Eckstruder Block - 1
Eckstruder idler - 1
Thumb knob M4 - 1
Eckstruder big gear - 1
Eckstruder small gear -1
Nema 17 - 1
608 bearing - 3
Spring - 1
M4 x 50mm - 1
M4 washer - 2
M4 nut - 1
M3 x 10mm - 4
Threaded rod 20mm - 1
M8 hobbed bolt - 1
M8 nut - 2
M8 washer - 5

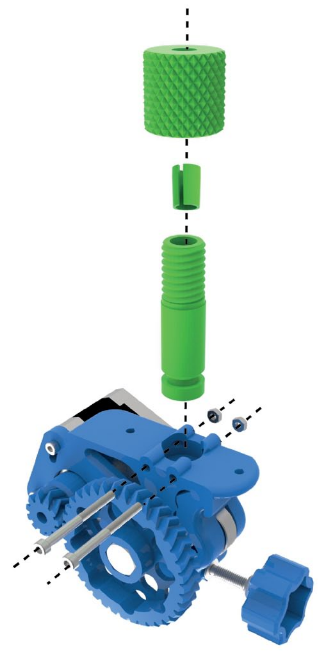
Start the extruder assembly with the eckstruder block and slide the idler into it.

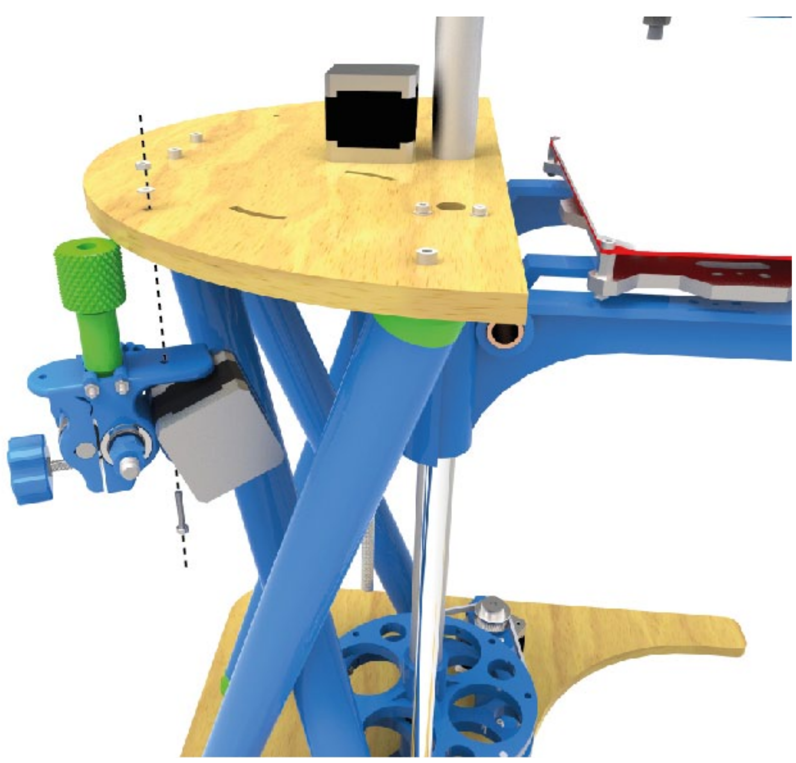
Them insert the 608 bearing into the idler and use the 20mm threaded rod to secure it in place. After that pass the M4x50mm screw throw the extruder block and idler and insert the spring, washer and the thumb knob (with the captive M4 nut) to holder the idler in the right place.

After that attach the nema 17 into the eckstruder block. The small gear goes into the stepper motor shaft and is secure with an M3 grub screw.

For last insert two 608 bearings into the eckstruder block and the hobbed bolt into the big gear. Then insert the hobbed bold in the bearings.

13





Parts:

Extruder bowden adaptor - 1
Tightening cone - 1
Cap - 1
M3x30mm -2
M3 nuts - 3
M3 x20mm -1
Bowden cable -1

In order to finish the extruder body we need to adapt it to became a bowden extruder.

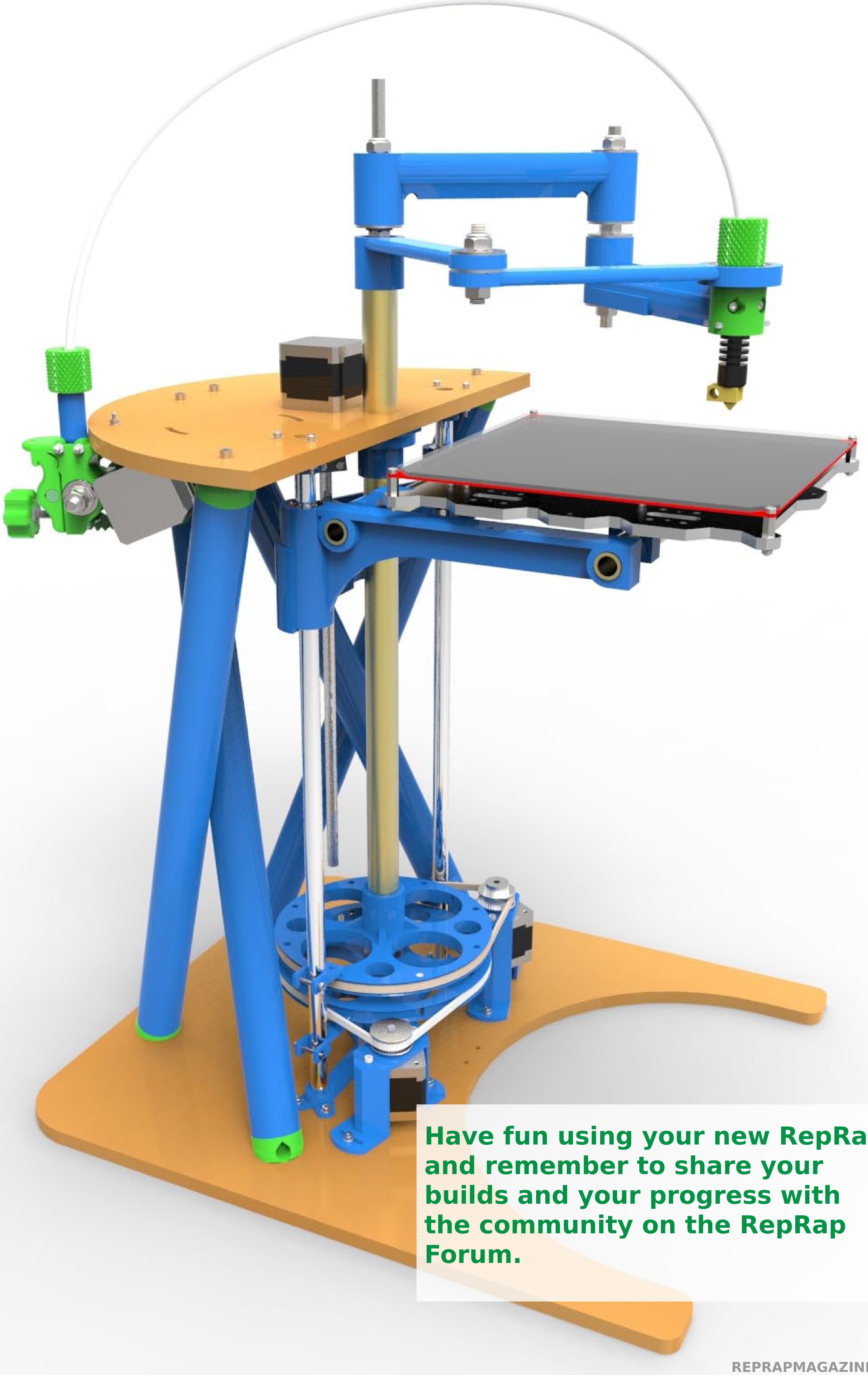
We do this by adding the extruder bowden adaptor in the place where the hot-End should go and secure it there with the M3 x 30mm screws.

Then in the top of the bowden adaptor insert the tightening cone and the cap.

Attach the extruder assembly to the top platform your printer.

Then add the bowden tube. You will need to unscrew both caps (extruder and tool head) and insert the bowden tube into the tightening cones. The thinner ends of the cones goes towards the front of the tube.

Then screw the caps again and make sure that the bowden tube is secured in place and wont release it self in the middle of a print job.



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