

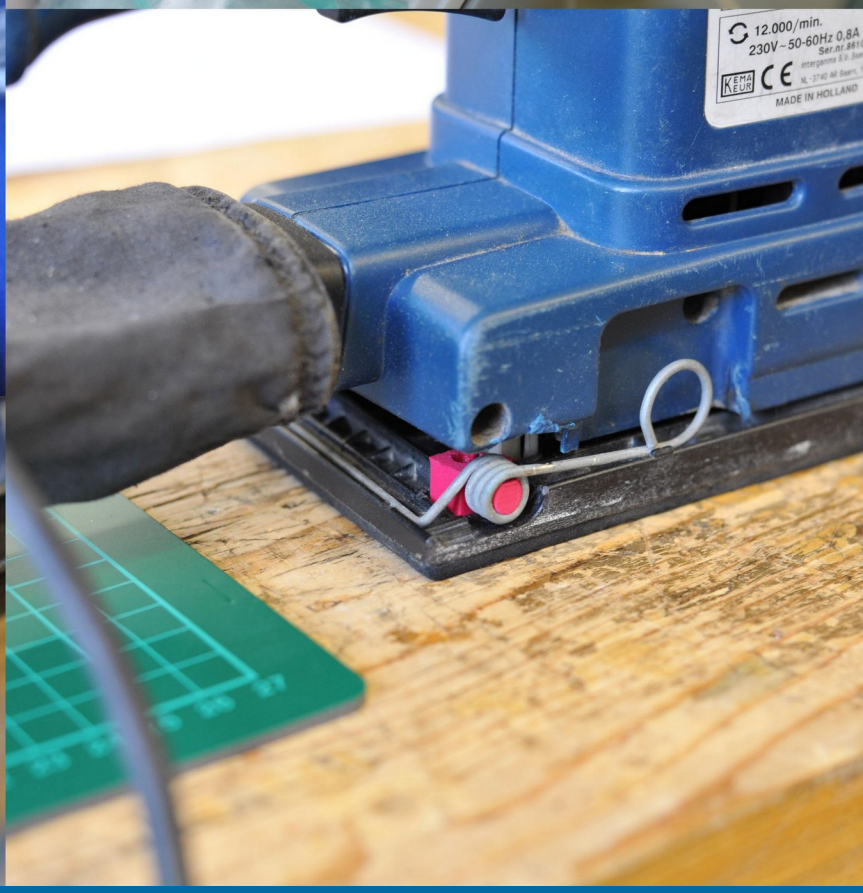

Enhancing 3D printing for repair

Appendices report

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Master thesis
Integrated product design
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May 2020

TU Delft

Interreg North-West Europe SHAREPAIR
European Regional Development Fund

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B. First Repair Café visit

On 07-12-2019 the first visit was made to the Repair Café in Delft.

Preparation

Research questions:

- What are the (desired) skills of the people at the Repair Café?
- What are the goals and motivations of the repairers?
- What are the expectations of 3D printing of the repairers?

Goals of the session:

- Introduce myself and my project to the people at RC Delft.
- Observe the repair processes of relevant products (with plastic parts) and document key moments.
- Co-Create 3D printing into the process.
- Invite founders for meeting on Thursday

Method:

- Observations
  - Create a journey map that documents the key moments in the repair process.
- Interviews
  - Find out about what their goals, motivations and expectations from 3DP4Repair are.
- Co-Creation session
  - Bring 3D printer and assist repairers by printing parts for them!

Results

Skills of the repairers

People at the repair Cafe have very differentiating skills. There are people specialised at sewing, electronics, fine mechanics, computers, microsoldering. There are also people who are not very skilled at repair, they are there to assist and learn from the repairers.

Journey map

The journey of a client with his broken appliance goes as follows: He or she enters the repair café waiting line in which the product is entered using a form. The product is then put on the waiting table and the owner can wait in the waiting room. When a repairer is free they choose a product from the table if they think they can fix it and if they feel like fixing it. The repairer and owner go into the workshop and try to diagnose the problem. They first to get information from the owner, if that's not enough to diagnose the problem, the product is taken apart. The problem is found. Or not then advice is given to the owner. When the problem is found the repairer goes ahead to disassemble the device and remove the broken part, or clean/oil seized parts, etc.

The part is either fixed with glue, or a new part is fabricated quickly using wood, wire or other materials, or a spare part is found from a donor device. There is a box full of Senseo parts for example. If that is not possible the owner is advised on whether to buy the part and come back next month, or to give up and discard the device.

Figure 1: A repairer fixing electronics and teaching another repairer how he is doing it.

Expectations from 3D printing

“I think we can print small gears and mechanisms from Nylon.”
“Rare parts such as a broken LEGO landing gear could be printed.”
“Plastic ring for a vacuum cleaner could be printed.”
“A broken plastic cover for a toaster could be printed.”
“It takes too much time, I heard a print takes 12 hours sometimes.”
“We need people to print for us.”
“People will not know what can be printed or not.”
“They will come and ask if you can print a new engine.”
“Consumers don’t know anything about repair, they always say: “Hij doet het niet” (“it doesnt work”) Ja maar wat doet hij niet?”

Figure 2: A repairer proposing a 3D printing job

Conclusions

The skills of the volunteers at the Repair Café are very differentiating, although mostly in the physical realm. The most notable were a clock mechanic, a micro solderer, seamstresses and an electrical engineer. The community in Delft has high level technical people because of it's highly trained demographic from the TU Delft and surrounding industries. However none but one person (an electrical engineer specialised in machine learning) had personal experience 3D printing. This is not representative for the average Repair Café, however it makes implementation of a tool like 3D printing easier. Further research must be done to map the skills at other Repair Cafés.

Looking at the visitor's journey at the Repair Café, we can conclude that the decision to 3D print a part can only be made after proper diagnosis, this diagnosis often happens quite late in the process, especially if the fault is not visible. It stresses the fact that there is very little time for 3D printing at the Repair Café. Options such as sending a part home the next day, ordering a 3D printed part from a local fab, or delaying the repair should be considered.

The expectations of the repairers with regards to 3D printing were differing, some had quite a realistic view on the technology and knew more or less what can be printed and not. Others were too optimistic in their expectations. One repairer rightfully asked: "Can a click assembly with fine hooks even be 3D printed?" It shows the need for a clear guide for what can be 3D printed and what can't.

C. Makerspace KU Leuven

Preparations

Research questions:

• Is there such a thing as separate maker and repair communities? To what extend? What are their characteristics? Why?

• To what extent is 3D printing used for repair activities? Which types and methods?

• What is the skill level of the people involved in the field of repair and 3D printing? To what extent do they overlap? Try to create (general) profiles. (on an individual level)

• What are the goals and motivations of the target groups?

• What are the needs of the target groups? Where do they differ? Why?

• Which physical and software tools are being used?

Possible methods:

• Observations of people at work.

• Interviews. (contextual inquiry: interviewing people in context)

• Probe: Explain the goal of the project: Enhancing 3D printing for repair by connecting repairers to makers.

Identifying question:

• Are you a repairer or a maker?

• How long have you been doing this?

• What is your background?

Questions for makers:

• Whats your process for 3D printing?
  ◦ Which software do you use for modeling?
  ◦ Which software do you use for slicing?
• Have you used 3D printing for repair purposes?
  ◦ What was your approach to draw the spare part?
• To what extend would you be interested in 3D printing for repair? Why?

Questions for repairers:

• What do you repair most often?

• What is your process for repair?

• How often do you need spare parts?

• Did you ever 3D print a new part? Or did you do this with another fab method?

• To what extend would you be interested in 3D printing for repair? Why?

Results of visit to Fablab KU Leuven / ShaRepair 26-11-19

Begeleiders fablab, Thomas and Marc were interviewed.

Short explanation and tour of the workshop. It featured multiple laser cutters and 3d printers.

Most visitors were students at that moment.

Introductory question, what is your opinion on 3D printing for repair?

Very critical feedback!

- CAD modelling is not accessible for most people.
- A good CAD engineer costs more than 60 euros per hour.
- When counting that price it's not worth repairing most products.
- Some engineers draw things voluntarily but only to reach a big audience with mass produced products such as Senseo.
- Manufacturers must be compelled to publish their CAD files online by law, thats the only way to make a difference.
- Copyright doesn't exist in the 3D space, only in 2D images.
- The demand is there but not enough people to CAD.

Interview with Marc Lambaerts:

Are you a maker or a repairer?

"I am a maker then!"

How long have you been doing this?

"10 years ago I founded this FabLab so 10 years."

What is your background?

"I studied bio engineering and later I was doing things to get people involved with STEM projects."

What is your process for 3D printing?

"Idea, drawing, slice, print."

What software do you use?

"I use Rhino mostly, I want to learn Fusion360, Thomas also uses Rhino." "Students here use SolidEdge, Solidworks or other pro packages depending on their study."

What slicer do you use?

"The one that fits the printer, so prusaSlicer for prusa, etc."

What was your process for 3DP for repair?

"Measure with calipers and take a photo as underlay."

Contact: marc.lambaerts@kuleuven.be

Meeting with Joost Duflou.

“They want to make a Sharepair app.”

Vak: Virtueel productontwikkeling, is teken iets aan de hand van foto’s, vervorming is groot probleem.

“Fablab moet zelf runnend zijn, geen service, wat sommige mensen verwachten.”

“Wij factureren voor workshops van groepen om het lab te runnen.”

“Maar Fablab is de front end, aan de back end hebben wij high tech 3D scanners en metaalprinters, en andere CNC technieken die we ontwikkelen zoals CNC plaatvervorming.”

“Sommige mensen denken dat alles kan met 3D printen, die zien voor zich dat je zo een metalen object uit een bak poeder kan trekken.” “Komt door de gelikte filmpjes in de media.”

“Het probleem met 3D scannen is dat het onderdeel vaak kapot is.”

“wij maken implantaten op maat met bot reconstructie en 3D scanners.”

Lunch in Cafe met ShaRepair.

Restarter.org is een Brits onderzoek naar reparaties, net als repair monitor.

Leuven repair community is iets wat wij op korte termijn willen opzetten.

EU regulatie.

IDE academy

“Prusa lanceert zijn eigen open source versie van thingiverse!”

Alternatieve doelen voor repair om jongeren te motiveren, repareren voor het klimaat?

Leerdoelen.

Wat zijn de niveaus van de betrokkenen?

Mensen die te lui zijn om te tekenen, onze gratis printers staan stil bij Materialize.

3D printing barometer, Materialize.

Verwachtingen managen! Mensen weten niet wat mogelijk is en wat niet, en of het rendabel is. Een titanium part kan geprint worden maar is onbetaalbaar.

Valse sustainable promise van transportkosten.

Grasshopper Rhino

Nils van Materialize: nils.faber@gmail.com Is twee keer per maand in delft.

“Meeste workshopgangers geen vervolgambities meer, het is te moeilijk voor ze.”

“Ik gebruik Rhino.”

Conclusions

3D printing for repair is more difficult than most people think. Repairers often underestimate the complexity of the process and the limitations of the technology.

The expectations of non CAD drawers are too high. They think that an object can be quickly 3D modelled while that specific object can be very hard to model.

They often get unfeasible requests at the fablab.

Students are by far the biggest users of the FabLab at KU Leuven. This shows that makers are fare more common among engineering students than among the local population.

They already did some repair projects using 3D printers.

CAD drawers are rare and expensive if you have to pay them per hour.

Figure 3: Fablab KU Leuven - courtesy of sheffieldhardwarehackers.org.uk

D. HCC 3D Club Delft

HCC 3D Delft meeting 21-11-19

At the meeting 12 people showed up, from a total of around 25 members.

Starting up:

For around 10 minutes everyone was setting up their laptops, they were having trouble connecting to the internet, which was required for the online Onshape CAD program.

We got a small introduction from Henk, the Onshape expert, who gave an onshape workshop the previous time. They were supposed to do a homework assignment. Draw a miniature house and print it.

3 people actually did the assignment.

The properties of onshape were discussed:

-"It's basically the Google docs of CAD software."

-"It's easy to share docs with peers for working together or helping each other."

-You can work in teams, and view each other's workspace.

-Free but public.

-If you share, the email address must be the Onshape address!

-Big resemblence with Fusion360.

-Selection/section view doesn't work off site.

First member presents homework.

He is used to work with Sketchup but has put a lot of effort into building the house in Onshape. He succeeded by using non conventional techniques.

Expert gives feedback: "Beware of design intent from the beginning so that you don't run into boobytraps later on."

This member printed the house out of several parts in different colours.

The second member didn't run into design problems according to himself. But he did have trouble printing the house without support material, which he wanted to avoid using.

Expert notes: "Cura has a new support material option: Tree support, which is easier to remove."

Third member: Didn't manage to draw the house completely in Onshape, but did manage to draw other parts such as a replacement part for a parasol. "Compared to sketchup it is much easier to fillet a part and extrude holes."

Expert goes on to show how he drew the house according to his correct 'design intent' methods.

Shows features of Onshape, such as drawing tools and even the Android App with which 3D models can be managed and shared.

The next meeting on the agenda were to include a 3D scanning firm, with a visit to a 3D scanning firm planned.

Conclusions

HCC 3D is a local community that focuses on learning and keeping up to date on 3d printing and CAD modelling.

The skill level varies in the group but is very limited to amateur software packages such as Sketchup. They are willing to learn but have difficulty with newer cloud based engineering software.

Some members already engage in repair using their 3d printing skills. They use photo's as a starting point to draw their 3D files.

The instructor Henk was very skilled, he was a retired constructor who worked with CAD professionally. His skills and tools are more than adequate for 3d printing for repair. Contact: Henk de Vlaam designintent.pe@gmail.com

Onshape is a very powerful cross-platform CAD program that is proprietary but free for non-profit making hobbyists. This may become the future of CAD modeling and online collaboration between makers through CAD software.

E. 3D printing exploration

Creality Ender 3

The Creality Ender 3 is the most common 3D printer for makers with a small budget. The printer itself costs around 200 euros. I decided to buy an Ender 3 for myself during this project in order to get familiar with the most common 3D printer and what its possibilities and limitations are. To see if it is capable of 3D printing parts for repair, or if another more high end printing technique may be necessary.

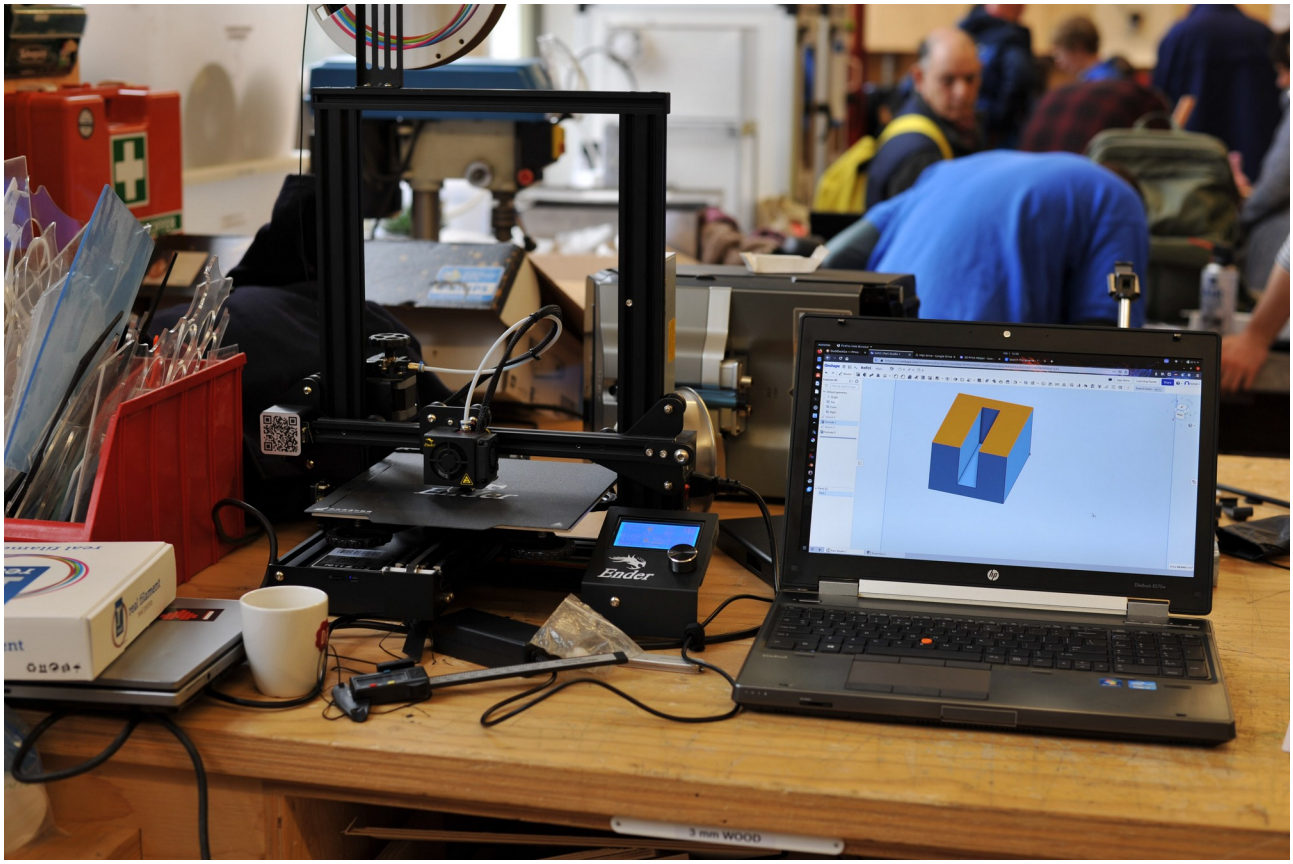


Figure 4: My Ender 3 printing a spare part at the Repair Café

During repair sessions at the repair café and at home the Ender 3 proved to be a very capable printer for repair. The print quality was good, the reliability was high meaning almost no failed prints. The resolution was its main down side, it has a standard 0.4mm nozzle which allows it to create features such as holes that are no smaller than 2mm in diameter. This means that it isn't capable of printing very small gears with teeth thinner than 1mm for example. Nevertheless taking the price, ease of use, reliability and strength of parts into account, it is by far the best choice at this moment for consumer repair applications.

Case study: The rise and fall of 3D Hubs

Goal:

Learning from the case of 3D hubs which served a very similar purpose, connecting designers to makers with printers.

Research questions:

What were the pros and cons of peer to peer 3D printing?

Why did 3D hubs delete it's peer to peer marketplace?

How can lessons be learnt from 3D hubs and incorporated into a new concept?

Case

3D hubs was established as an online peer to peer marketplace for 3D printing. It allowed individuals with a 3D printer to offer a printing service to makers by uploading an STL file to a printer nearby. The network grew steadily, makers with printers joined from all over the world, until every big city featured hundreds of printing hubs.

However 3D hubs encountered issues in their scaling up, they found that the big money was not found in consumer printing, but in business to business. Therefore they focussed less and less on the community based printers. And finally as of October 1st 2018 3D Hubs canceled the peer to peer network and switched over to centralised manufacturing. To the surprise and anger of many of it's users they decided to delete their unique network that featured tens of thousands of printers at its peak. There were no alternatives, and no one has yet created a replacement network.

"On Monday, October 1st, 2018, we're going to completely switch our 3D printing service to the Fulfilled by 3D Hubs offering. This means that it will no longer be possible for Hubs outside the Manufacturing Partner Program to receive orders on 3D Hubs."("3DHubs Killing Off Its Community?," 2018)

3DHubs Killing Off Its Community? 3D Printing Company Commits Suicide for No Reason. (2018, September 12). Retrieved December 4, 2019, from 3DPrint.com | The Voice of 3D Printing / Additive Manufacturing website: https://3dprint.com/224758/3dhubs-killing-off-its-community-3d-printing-company-commits-suicide-for-no-reason/

Conclusion

Pros: Cheap 3D printing service, Fast and local (pick up option), personal communication with maker.

Cons: High variation in quality, lots of rejects, customer service disputes, low margins.

3D hubs was sold off to investors, which was probably the main reason why their peer to peer network was shut down. This network didn't contribute to the main profit and worked as a competitor to the B2B workshops. Probably many of the founders didn't agree with the decision but were forced by the majority of shareholders.

Lots can be learnt form the case of 3D hubs.

First of all the concept of an online peer to peer 3D marketplace was decidedly successful. It shows that there are thousands of makers around the world with a 3D printer who are willing to serve others by 3D printing parts for them at a reasonable cost.

F. 3D scanning exploration

FabScanPi

Assembling and testing the open source FabScanPi 3D scanner was done to test whether such a 3D scanner is a viable tool for digitizing broken parts for 3D printing for repair.

The scanner was a self build package that consists of a lasercut multiplex wood and electronic modules. The scanner runs on a Raspberry Pi 3b+ computer which controls the turntable, the camera and the LED flash.

A line laser is pointed at the object and the deflection of that laser is used by the camera to construct a 3D point cloud. This point cloud can then be turned into a 3D polygon model using external software.

The process of assembling and setting up the scanner was very laborious and took lots of patience. The Raspberry was connected via a local network and can be controlled via any browser.

Figure 5: FabScanPi - Courtesy: Mario Lukas - FabScanPi Community

The calibration process was done using a checkered cardboard plate. This process took a while to get right. The first scans were disproportionate and warped.

After hours of tinkering a usable scan was produced. See figure.

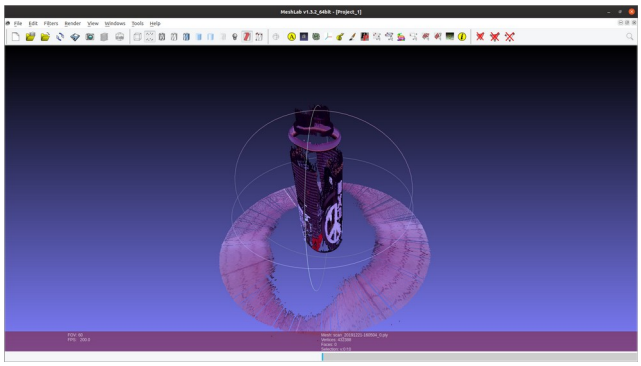


Figure 6: The first scans were warped like this one.

Conclusion

This method of (low end) 3d scanning is very cumbersome for novices and even challenging for an experienced tinkerer. Therefore it is not suitable for the average repairer. It is simply too error prone and not at all user-friendly. Next to the scanning itself it requires extra software which is also not easy to use and which makes the process very time consuming from a physical object to a 3D model.

This problem exists separately from the accuracy problem, which makes it impossible to achieve the tolerances that are desired for small plastic parts.

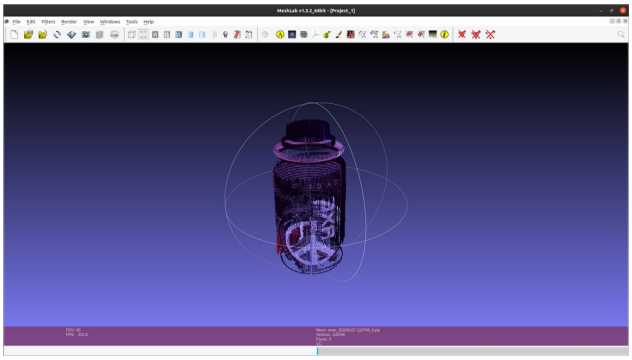


Figure 7: Finally the warpage was solved through better calibration and correct settings.

Photogrammetry using Meshroom

Creating 3D models through photogrammetry using a Nikon D700 full-frame DSLR Camera with a 50mm f1.8G lens and Meshroom.

Meshroom is a powerful open source photogrammetry suite in which a series of photos of an object can be processed into a 3D model. The software matches the images together and produces a point cloud by matching features in the images. The point cloud and texture file can then be used to create a 3D model for 3D printing.

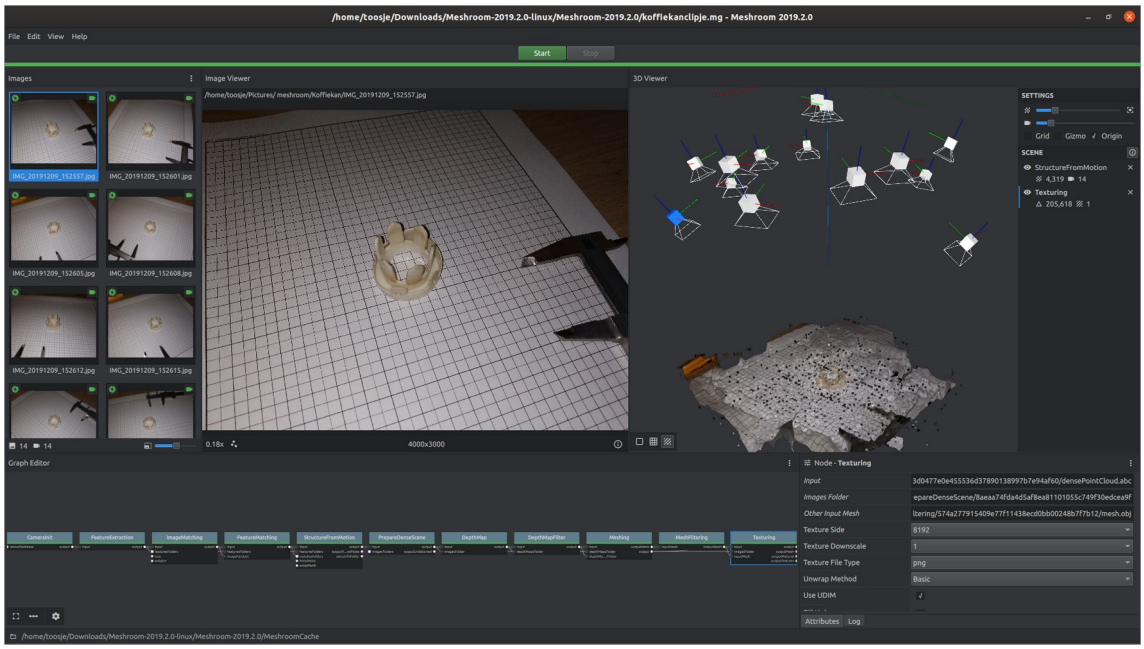


Figure 8: Photogrammetry of a small object using a phone camera

Small objects were difficult to rebuild. Especially using a phone camera and a limited amount of photos. In this case 14 photos were not sufficient to re-create this part of a coffee flask.

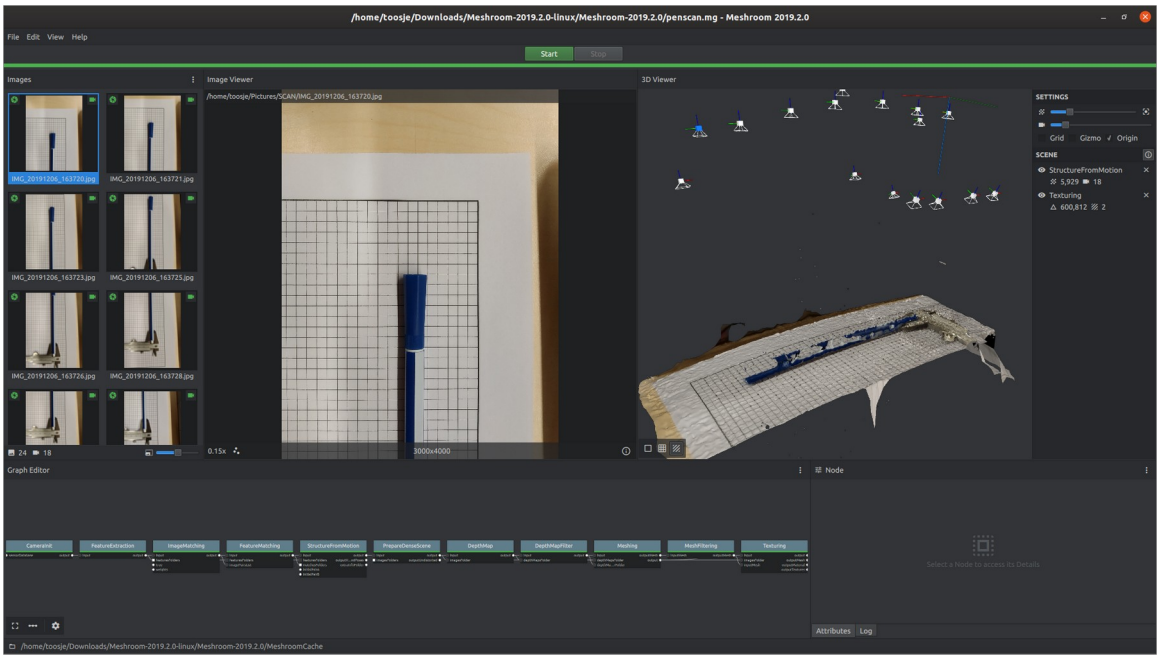


Figure 9: Photogrammetry of a pen using a phone camera from above only

Another important factor was the angle of the photos, taking photos from one angle will result in a warped model because there is very little information to reconstruct the height of the object in this case.

Using a high amount of photos using a DSLR, and a textured surface and object will yield better results. This brass part was rebuilt using 67 photos and the results were acceptable.

However the resulting point cloud needs to be cleared up and converted to a non manifold part before it can be 3D printed.

Another downside of photogrammetry is the computing power it requires. An NVIDIA graphics card and 16GB RAM were needed to run the meshing process. And even with suitable hardware the entire process took a couple of hours depending on the amount of photos.

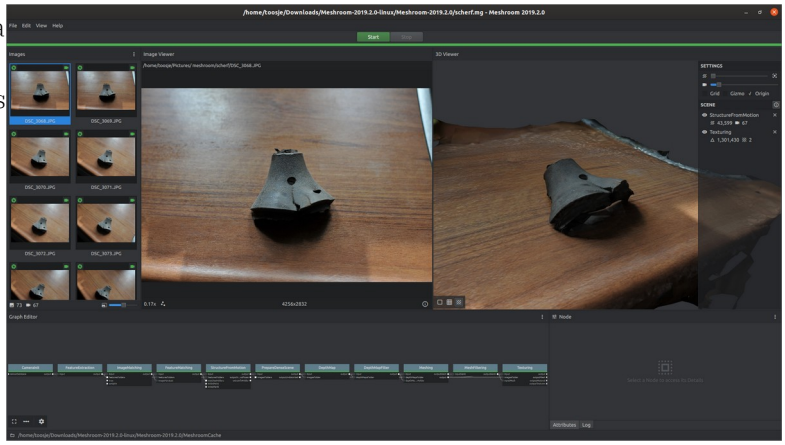


Figure 10: Photogrammetry of a small object

Large objects such as a water pump and a tractor were relatively easy to scan, and yielded fairly accurate and pretty results. This was due to several reasons. The complex textures caused the photogrammetry software to have no shortage of features to extract and match images together. The large size caused the camera to be further away from the subject. Meaning that more of the subject was in focus than shooting images at close range. Having sharp images is vital for good feature extraction.

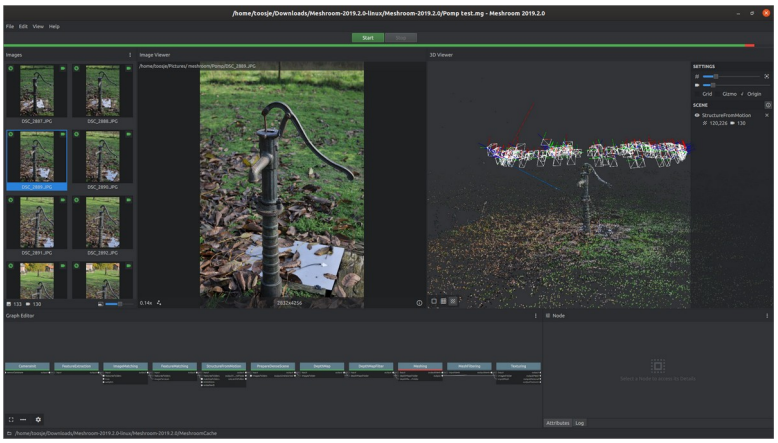


Figure 11: Photogrammetry of a water pump

Conclusion

Photogrammetry is a very powerful tool that can turn a set of regular photos into a 3D model. However it is very error prone, it requires a high number of high quality photos to work. And photographing small parts sharply is a challenge that is very difficult to achieve for most repairers using a smartphone. Although in the future phone cameras may reach a level where it becomes easier and will result in more accurate results.

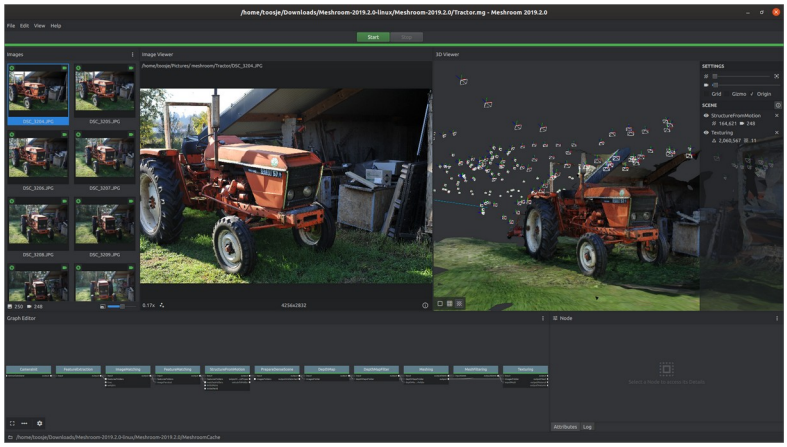


Figure 12: Photogrammetry of a tractor

Ruler app

Ruler app was used to measure objects.

A reference object or ruler was used to calibrate the app. A squared background was used to test the offset in different areas of the image. This resulted in offsets varying from 0.1mm to 1mm. This is largely due to the lens deformation towards the edges of the image. But also due to parallax. Another problem was to identify the exact edge of an object.

Figure 14: Measuring a battery lid using the ruler app with a gauge block as reference

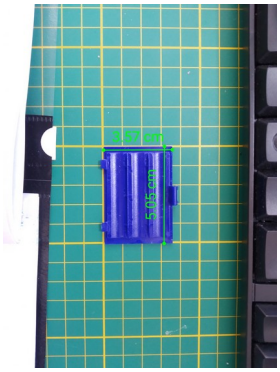


Figure 15: Measuring a battery lid using ruler app and a cutting mat as reference.

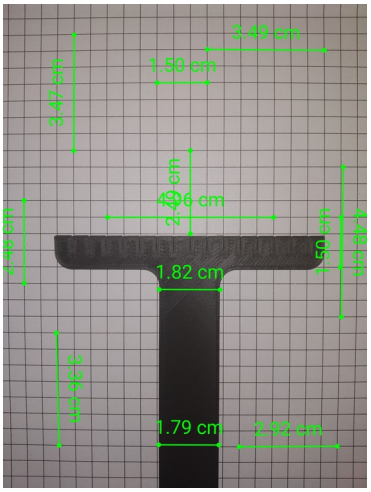


Figure 13: Measuring the errors in different areas of the photo using squared paper.

Conclusion

The ruler app can be very useful to quickly take measurements from a photo. However the accuracy is very easily lost when photo's are taken at a slight angle, when there is depth involved or when measurements are taken outside of the center of the image. This makes it very tricky to achieve high accuracy and that makes it unsuitable for small plastic parts. However for rough applications where an accuracy of 1mm is sufficient enough it may be useful.

G. Comparing measuring tools

Classic metrology

Metrology is the science of measurement, it dates back to the beginning of human technology. When measurements were relative, making wooden sticks of the same height to get a straight house. As civilisation got more advanced, so did its measurements and standards. At the beginning of the industrial revolution there were numerous units of distance. Every major city in Europe had it's own inch, coming from the Roman word, uncia, meaning unit. Luckily the introduction of the metric system by France and mainland Europe in the early 1800's made measurements much more consistent, allowing people over vast distances to communicate precise measurements and collaborate in engineering projects.

Fast forward 200 years, and we are just in the midst of the digital revolution. The Internet allows people all over the world to communicate, collaborate and share information. This information consists of text, photos, video and audio, and more recently 3D object files are shared among makers. The rise of 3D printing in combination with online sharing promises a future in which people can print their own products and spare parts.

Just like in the 1820's the metric system is the standard for online 3D part files. The success of part sharing depends largely on maintaining a certain accuracy. One milimetre must be the same for the repairer, the designer and the 3D printer. 3D printers always have a certain offset, therefore the dimensions of a 3D file need to be as close to the basic size of a spare part. Therefore the measuring or metrology must be accurate.

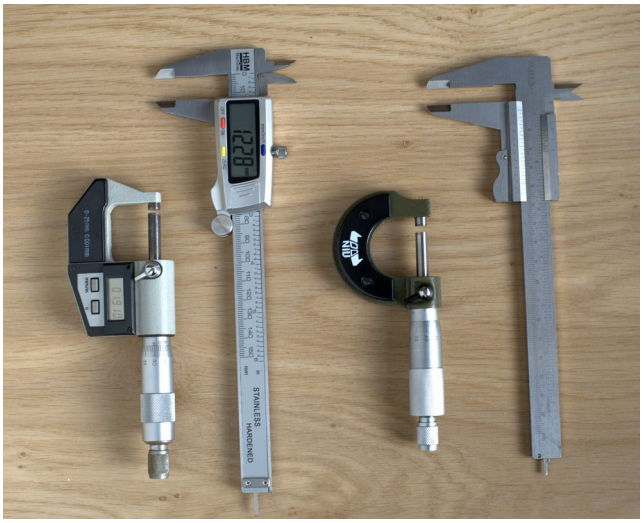


Figure 16: Digital and classic measuring tools

Classical measuring tools as we know them today have been around for more than 100 years. The ruler, the vernier caliper and the screw micrometre are the most well known designs that are still in use today. Albeit with a digital readout for better accuracy and usability.

As with any measuring tool or fabrication method, tolerances are defined and checked to ensure that parts actually fit together. Engineers have to religiously conform to the norms of tolerancing to make sure parts are within their specified dimensions. However for makers and repairers these practices are less familiar. They are usually not confronted with real engineering documents in which tolerances play a role, they usually work under the motto of *measure once, cut twice.* However, if long distance digital fabrication is to become successful, tolerances must be taken into account, because making a part twice isn't a viable option here. Accurate measurement before and after 3D printing is paramount when it comes to achieving the right tolerances.

Cost vs accuracy

As a rule of thumb in production techniques higher accuracy (or lower tolerances) costs more. In measuring instruments this is the same case. However for this research we compared modern and old measuring tools to see which come out on top.

The accuracy of calipers always higher than that of a ruler because the caliper relies on a contact measurement instead of a visual measurement. This is a major difference because contact measurements are not subject to bad vision, angle of vision and small size. Identifying a 0.5mm difference on a ruler is about as far as precise a human can see without enhancement. Of course using a loop or microscope this can be increased. There are measuring microscopes that can measure extremely accurately, but at a very high cost.

Modern 3D scanners can also be used for measuring objects. Their advantage is that they can capture the entire geometry of a part which can be used to reconstruct and 3D print a new one. However these scanners are either cheap and inaccurate or very expensive for more accuracy. The Einscan-SP was used for this comparison together with other more classic tools such as the calipers and the ruler.

In this comparison it soon turned out that the main competition was between the high-end Einscan 3D scanner with 0.05mm accuracy, which costs around 2500 Euros on Amazon. https://www.amazon.co.uk/dp/B078W44SWR?

Figure 17: Einscan SP - courtesy: Shining3D

And a mid-range Chinese caliper such as the Shahe 150mm caliper, with an accuracy of 0.04mm which costs around 25 Euros on Aliexpress. https://nl.aliexpress.com/item/32645456925.html

Figure 18: Shahe 150mm caliper - Courtesy: Shahe instruments

	Cost	Accuracy
High-end digital caliper	100	0,02
High-end 3D scanner	2500	0,05
Low-end 3D scanner	200	0,5
Ruler	2	0,5
Photo ruler app	1	1
Low-end digital caliper	5	0,2
Mid-range digital caliper	20	0,05

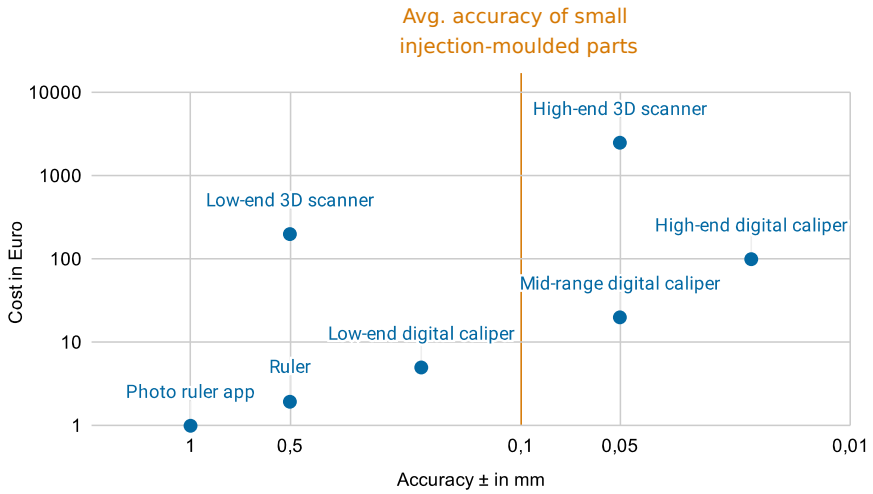


Figure 19: Cost vs accuracy of measuring tools

Ranking

Using a ranking system the difference is made clear between the measuring tools. The criteria 'cost', 'accuracy', 'learning curve' and 'speed' were based on the research results from the explorations at the repair cafe and maker community. These factors are vital for repairers who have little extra time on their hands, limited financial resources and limited digital skills.

	Cost	Accuracy	Learning curve	Speed	Total score
Mid-range digital caliper	4	5	4	5	18
High-End 3D scanner	1	4	2	2	9
Phone ruler app	5	1	3	3	12
Low-End 3D scanner	3	2	1	1	7
Ruler	5	1	5	4	15

Figure 20: Ranking the top 5 measuring tools

H. Describing a 3D object

History of Computer Aided Design

Figure 21: Engineers at the drafting table

Before the digital revolution, engineers designed their objects on the drafting table. Using pen and paper to create 2D projections of a part was tedious work that demanded focus and discipline. The copy or blueprint of these drawings were the instructions for machinists to machine the part.

In the 1970s and 80s, increasing computing power enabled objects to be designed digitally in Computer Aided Design programs. In 1981 CATIA was released by IBM and Dassault Systémes, as the first commercial CAD software package.

At first these were very basic programs, more resembling of a drafting table, but later on these became very powerful 3D software packages that allowed a single engineer to design, validate and produce parts.

Figure 22: CATIA in 1981

CAD packages for makers

Nowadays most people can afford a powerful computer that is able to run CAD programs. The software itself has become extremely versatile and user friendly, (for engineers). Browser based apps like Onshape even allow CAD to be run on almost any platform. Free, open-source variants make CAD accessible to almost everyone. Nowadays, a computer with CAD, a slicer program and a 3D printer are all you need to design and produce a part. A small and simple part can be designed and printed within 15 minutes.

Tinkercad

One approach to get repairers more involved in 3D printing is enabling them to draw a CAD file. One of the repairers at the Repair Café told me that “I have a 3D printer and I use Tinkercad for my 3D files. It isn’t great but it allows me to make basic things.”

Tinkercad is an online CAD package for children and hobbyists who don’t have professional CAD skills. It allows users to draw basic shapes and add or subtract them, this allows users to make a lot of different shapes, however it doesn’t have any of the engineering functions that a professional CAD package has. Therefore it can be difficult to create a correct drawing of a technical part such as a gear.

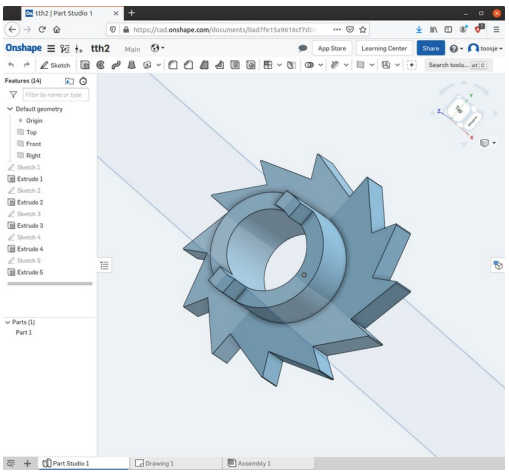


Figure 23: Onshape in 2020

I. 3D printing & repair databases

Repair databases

The research questions that are to be answered by looking at repair data are:

Can 3D printing add significant value to repair initiatives?

In order to answer this question the database from Restarters was analysed for data that showed how many repairs require a spare part in the first place. This database has labels that indicate if a part is needed, and also a description that can elaborate on this. The data in figure 25 was cleaned up by removing the unknown entries, and this gave the result in figure 24.

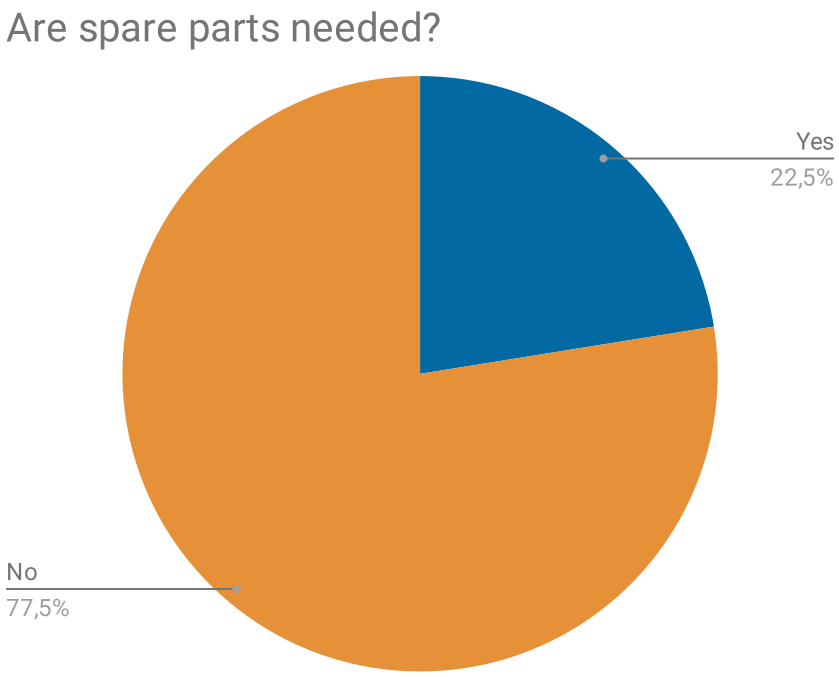


Figure 24: The need for spare parts in repairs from the Restart database

Are spare parts needed for the repair?		Needed anyway according to description	Are spare parts needed for the repair?			Are spare parts needed?
Yes from 3rd party (label)	980		Yes from 3rd party	980	Yes	2289
Yes from manufacturer (label)	364		Yes from Manufacturer	364	No	7901
Yes according to description	945		Yes according to description	945		
Not needed (label)	8212	311	Not needed	7901		
No data (label)	5825	634	Unknown	5191		

Figure 25: Results from seaching the Restart database if spare parts are necessary

3D model databases

To what extent is 3D printing already used for repair?

From Thingiverse, a 3D model database with over 1.8 million models entries with repair keywords were searched.

This yielded over 12000 results that are visualised in figure 26. It shows that repair related search terms are numerous, they make up a very small percentage of the entire Thingiverse database. Roughly 0.7%. More repair related search terms can of course be used but this will not amount to a high percentage of the Thingiverse database.

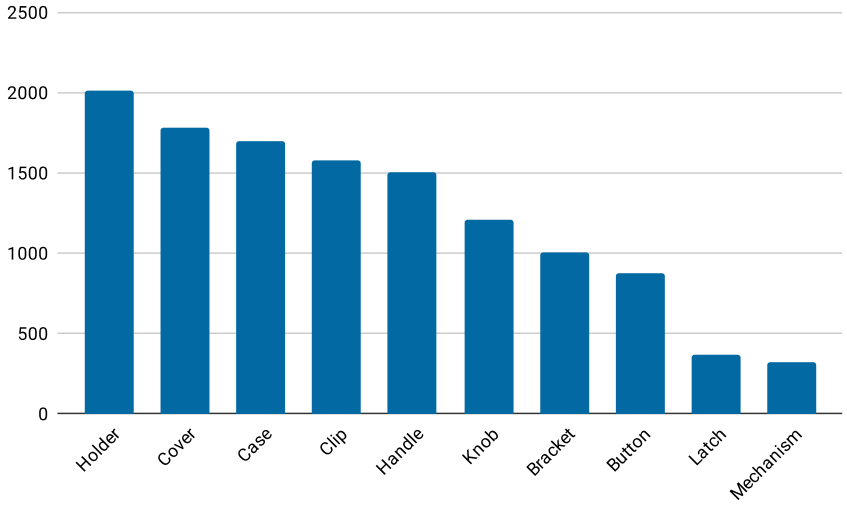


Figure 26: Thingiverse repair related search terms

Thingiverse										
Search terms	Holder	Cover	Case	Clip	Handle	Knob	Bracket	Button	Latch	Mechanism
	2010	1776	1694	1572	1504	1207	1000	874	368	316

Figure 27: Thingiverse repair related search terms raw data

The MyMinifactory database was also searched for repair related objects. Their database is categorised into a repair section which made the search easier. The number of models in these repair categories were counted and visualised in figure 28.

The numbers amount to a much smaller total than Thingiverse. However it contains less pollution by other maker projects.

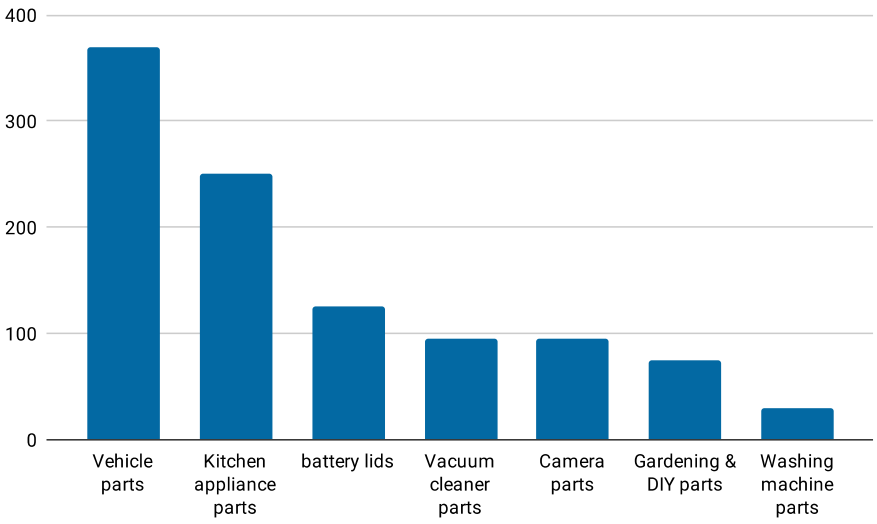


Figure 28: MyMiniFactory repair categories chart

MyMiniFactory							
Categories	Vehicle parts	Kitchen appliance parts	battery lids	Vacuum cleaner parts	Camera parts	Gardening & DIY parts	Washing machine parts
	370	250	125	95	95	75	30

Figure 29: MyMiniFactory repair categories raw data

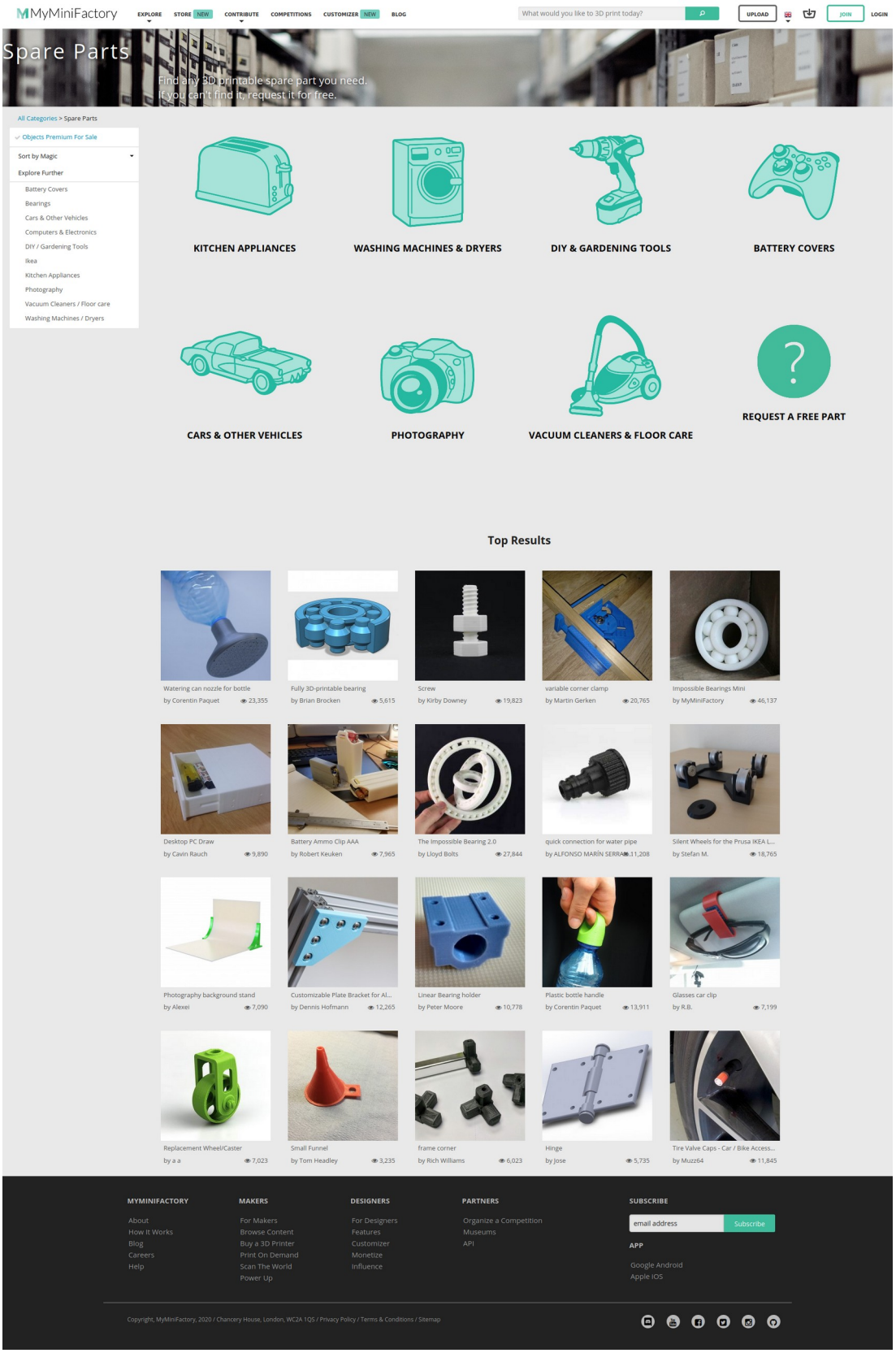


Figure 30: MyMiniFactory repair categories

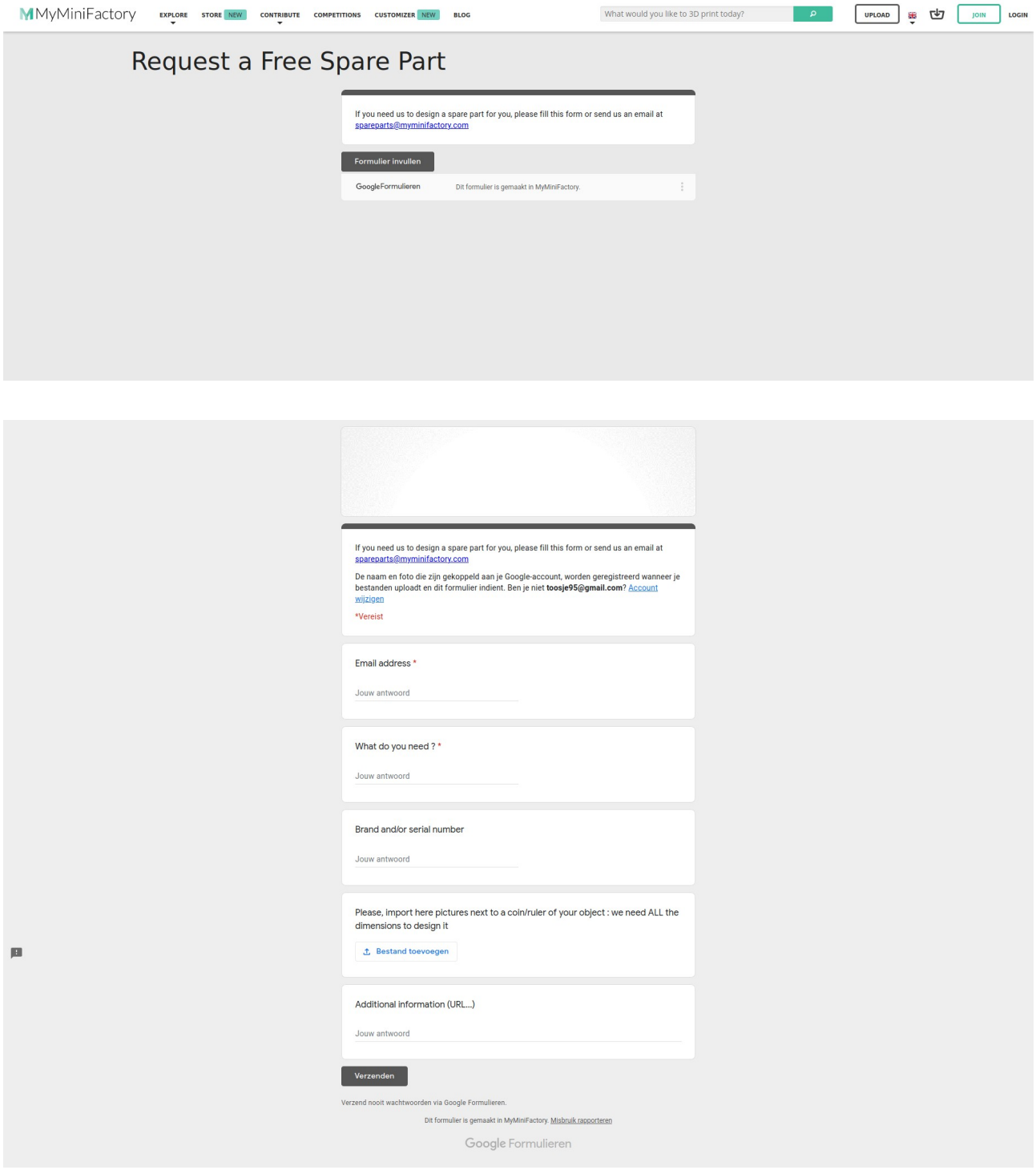


Figure 31: MyMiniFactory - Request a free spare part form

The repair section on MyMiniFactory includes a “Request a Free Spare Part” page. This leads to a google forms where some basic info and files can be uploaded. The instructions advise the user to “take pictures next to a coin/ruler”. Which shows that the concept of requesting a part is being applied to some extent. However the advise of taking pictures next to a coin/ruler will yield parts that are not very accurate. Resulting in deviations of up to 1mm.

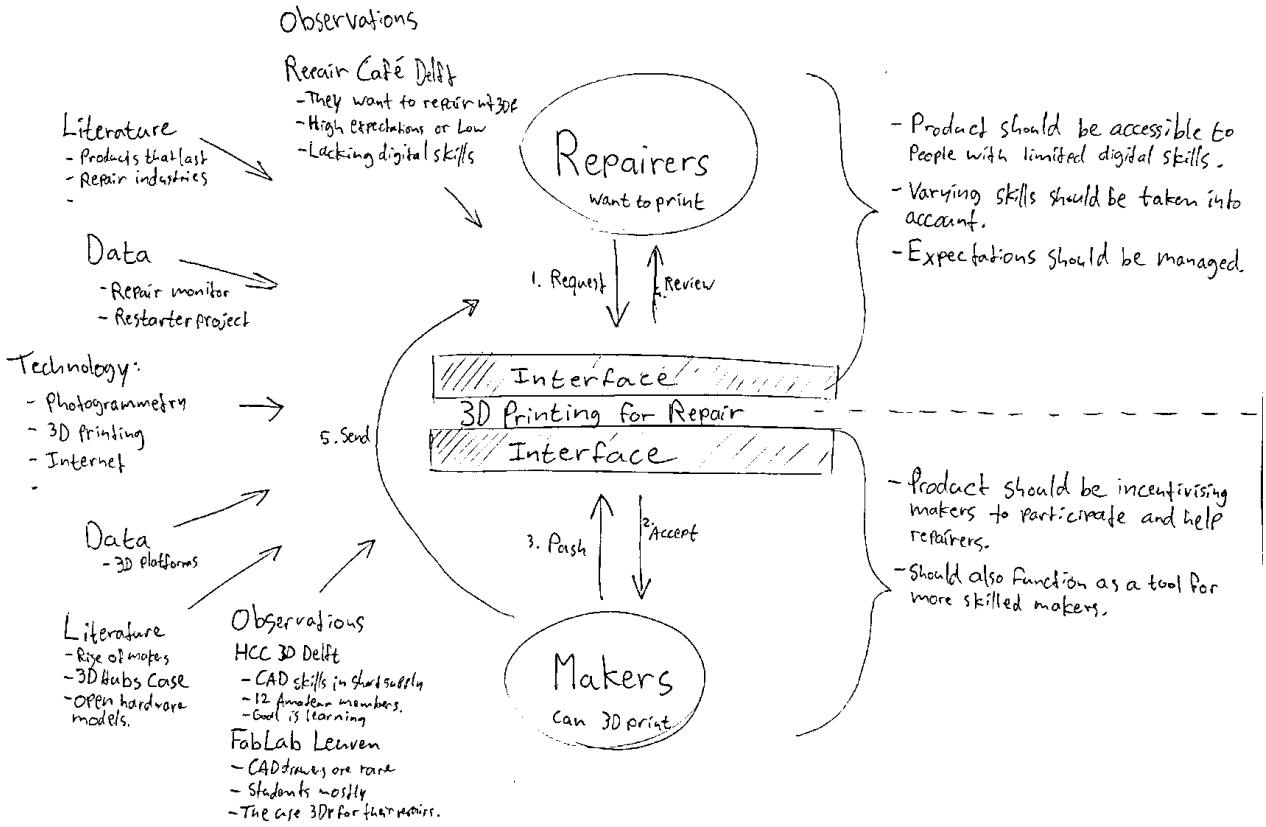
Conclusions

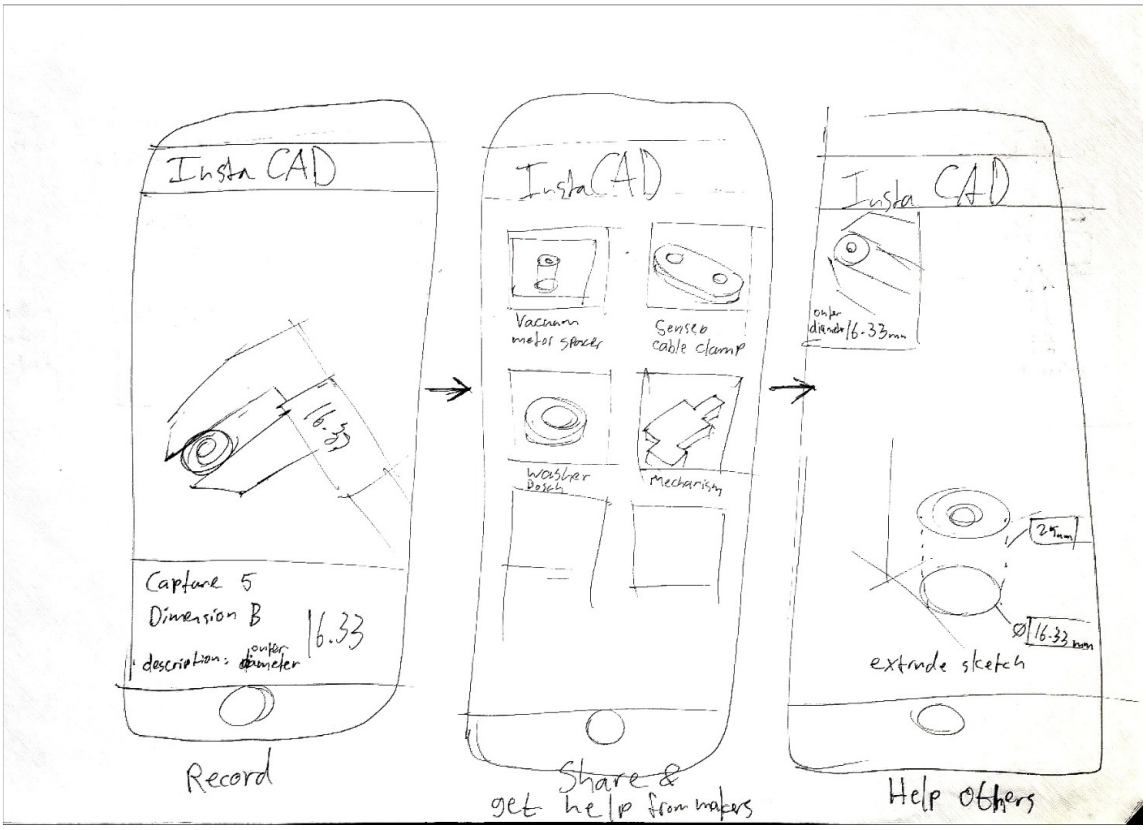
There is significant demand for spare parts at Repair Cafés , currently 23% of the repairs need a spare part. However this may not be a good indicator for 3D printing parts. The parts currently used in repair cafes include electrical and metal parts. Another factor is that 3D printing allows a different kind of repair that repairers and users are not full aware of. The ability to create new plastic parts. At t he moment a broken plastic part is seen as something that can either be glued or is else is unfixable. Plastic parts are generally not sold by manufacturers. Therefore it may take time for repairers and consumers to recognise that broken plastics can be fixed through 3D printing.

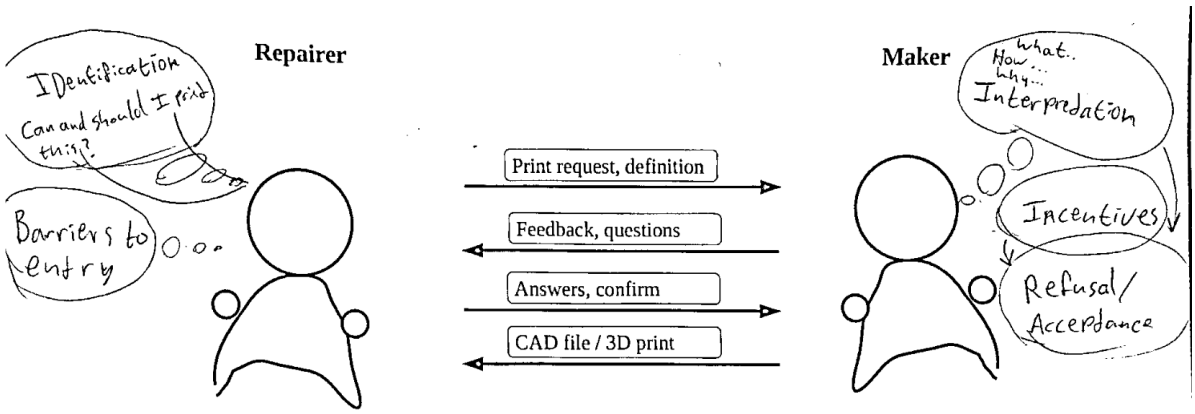
Platforms like Thingiverse an MyMiniFactory enable makers to recreate spare parts, which according to their databases happens already. However it makes up a very small percentage of all the 3D printing projects out there. It may take more time and more people involved to increase this database to a level where there is actually a chance of finding the part that you need.

J. Early ideation

Sketches







Information layer: Inform and assist repairers to identify and evaluate parts for printing.

Physical layer: Effortlessly record object geometry, measurements and requirements, digitally.

Strategic layer: Align the incentives for each of the stakeholders and promote contribution.

K. Iteration 1

Guide & Teach repairers

Filtering infeasible print requests is important to manage expectations of the repairers, and to prevent unnecessary work for makers. At first a paper questionnaire was made.

Developing a paper or digital guide that helps the repairer decide whether something can and should be printed is the first step.

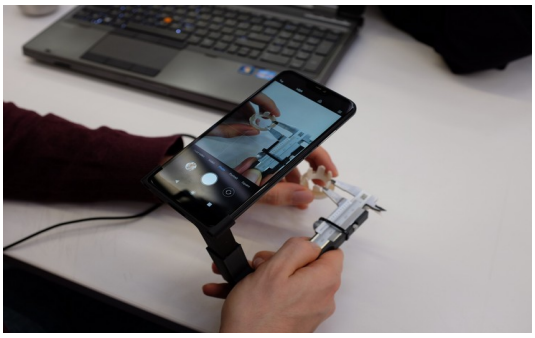


Figure 32: Phone calipers attachment

Enhance Communication with makers

Makers who are capable at CAD are rare, and may not always be locally available. Therefore it would benefit repairers if they could digitally communicate part dimensions and geometry to makers online.

Digitising part dimensions at 0.1mm accuracy can't be done cheaply and easily with 3D scanners. That is why a new, hybrid scanning and measuring technique should be developed.

Recording digital photos with a smartphone can be done by anyone these days. These photo's record a significant amount of data and have reasonably good sharpness and resolution.

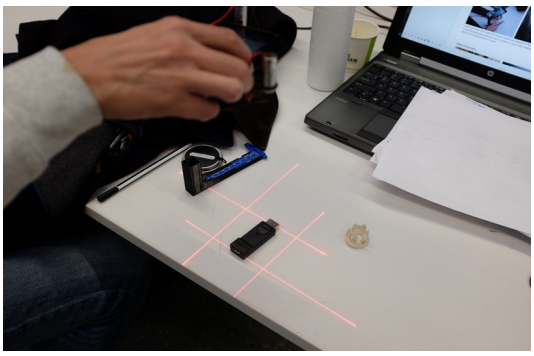


Figure 33: Phone laser attachment

Quick iterations of photo-modelling in combination with rulers and lasers showed that extracting measurements from these photo's yields inaccurate results, due to parallax, lens deformation and incorrect edge detection. A more reliable measuring technique is the classical vernier caliper. For 10 Euros an accuracy of .05 mm can be reached. A rig was prototyped to attach the calipers to a smartphone for quick digitisation of measurements. And it was tested by recording a part's dimensions and letting a maker reconstruct it in CAD. A few errors were encountered, but it worked after answering some extra questions. These errors and feedback were used to make the next iteration.

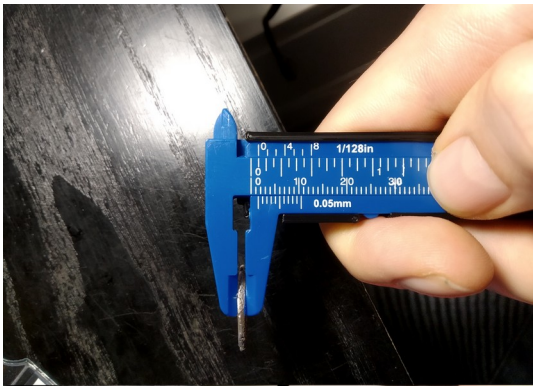


Figure 34: Phone calipers photo measurement

Implementation & Incentives

Second Repair Café session 04-01-2020

At the second Repair Café session I temporarily installed myself as an in-house maker with my 3D printer, assisting the repairers by printing parts for them. I learnt that although I didn't announce my plan beforehand, there still was demand for 3D prints, but they mostly resulted from the repairs themselves. Specific demand for part production is not yet present, because it hasn't been an option until now. This shows that spreading awareness and correct information is one of the most important factors in order to implement a fixed "3D printing ambassador" at the Repair Café.

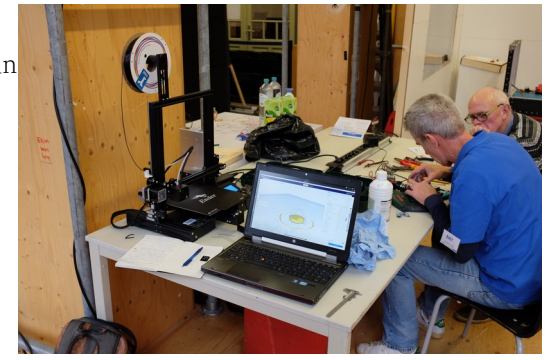


Figure 35: 3D printer at Repair Café

By talking to the repairers I did find out that there were some enthusiasts who could potentially become 3D printing champions or ambassadors. Two of them already had a printer at home and one even has some basic CAD skills.

Main insights

This first iteration was the first time the concept took shape in the form of prototypes. The first prototypes gave very positive results, but also showed lots of inadequacies. The caliper prototypes worked but were in no way superior to a normal digital caliper and there was not much added value of attaching to the phone.

The first embodiment at the Repair Café showed that there was already some demand, and that small parts can indeed be printed in this short time span.

Figure 36: 3D printed replacement bracket

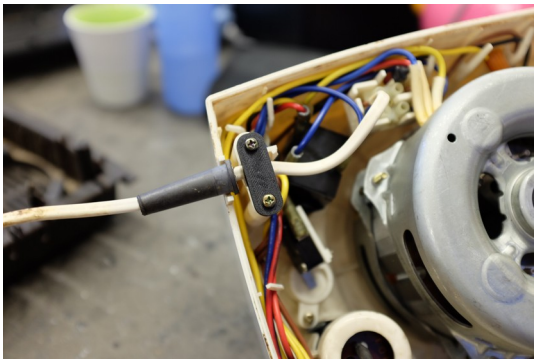


Figure 37: Installing the bracket

L. Iteration 2

Sketches

3DPR checklist

How important is the fix to the client?

1	2	3	4	5
Toaster				Heirloom

Can it be glued or fixed in another way?

Yes No

Can it be bought reasonably quickly and cheaply?

Yes No

How big is the part?

<5cm3 5-10cm3 10-100cm3

How complex is the part?

Simple Medium High

What are relevant operating conditions?

Forces	Low	Medium	High
Heat	20C	20-50C	>80C
Humidity	Normal	High	
Food grade	Yes	No	
Aesthetics	Yes	No	

Advice:

No-Go!	Probably not	Tentatively	Sure go ahead!

3D printing for repair categories. V1

These categories are meant to advise repairers whether to use 3D printing for a repair.

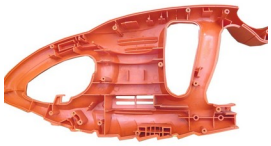
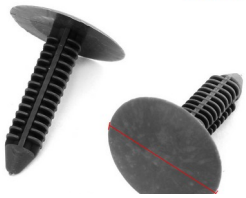
https://forms.gle/BTHDWk5uiwVgZhVK8

1. Not worth it

Not worth printing because CAD drawing and printing would take too much time compared to the added value.

Examples: -Screws, pins. (that can easily be replaced by standard materials)

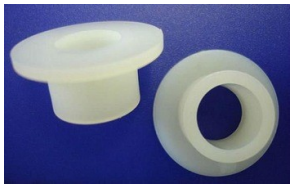
-Entire product housings: Too complex and time consuming to print, try glueing the old one.


2. Standard

Standard, very simple parts: Generate a part from a parametric model or existing model from the internet. If a model is not available go to category 3. custom.




3. Custom

Custom parts: Search for the part in the database, if it is not available, create and upload a metrology collage and ask the community for CAD support.

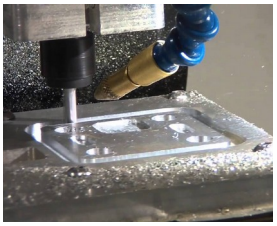




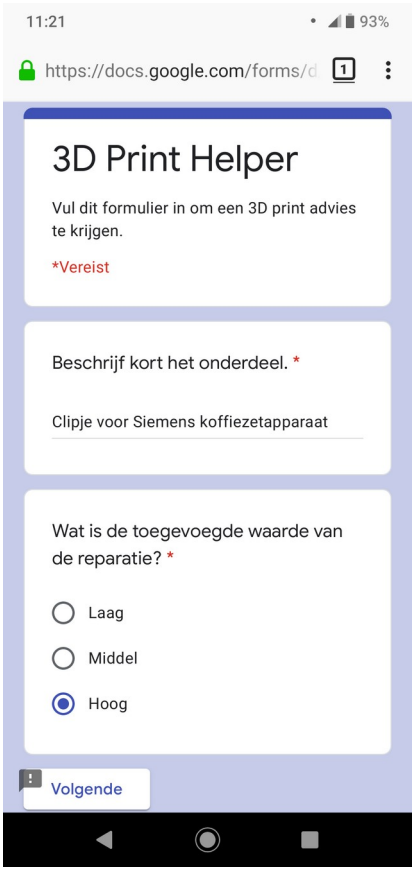
4. Not printable (with an FDM printer)

Physical properties of FDM don't fulfil the part requirements. (High temperature, high strength, high precision. Choose another printing or fabrication technique. (SLS printing, CNC milling, etc.)






Prototypes



The google forms can be accessed at: https://docs.google.com/forms/d/e/1FAIpQLSdWrtuFPOJORE19GZT6mwuPXp2IIDUNUypy5QKbHO9jtGwLkw/viewform

Tests at Repair café 3

Preparation:

Notify Repair Café and volunteers that 3D printing student is available.

Gather materials and create prototypes to be tested.

Goals:

Idea generation & Co creation

Evaluate current set of concepts through mvp testing.

Allow for quick adjustments and iterations during the session.

Concepts to be tested:

3D printing guides (paper)

-V1 Paper

-V2 Web form

-V3 Integrated App

“Cybercaliper” (minimum viable product)

-V1 Calipers + Cutting mat + Phone on stand + Remote shutter button

-V2 Calipers with integrated bluetooth shutter and data transmission.

-V3 Cybercaliper + App

3D printing station within repair café (myself)

-V1 (04-01-2020) Intall in 2nd room, without pre announcement. Try to assist in printing fixes that were encountered during repairs.

-V2 (01-02-2020) Install in 1st room, with announcement. Assist in dedicated fixes.

Planning:

10:30 Build up: Set up 3D printing station within the repair café. As close to the repairers as possible so that they are visually reminded of my presence.

Collect print jobs from repairers themselves. (they were told to look for 3D printing examples / jobs) Give them the 3D printing guides, let them fill in the guide for each print job.

Collect the forms, evaluate results.

Approved print jobs should now be digitised by the repairers. One by one show them the cybercaliper. And let them digitise their parts.

When their examples are done: use own examples from sample kit to test.

Observe and record video, photos.

11:00 Clients arrive. Survey the incoming products for possible 3D print fixes.

11:30 Get printer running for repairer prints.

12:00 Lunch (Evaluate results from before the break, make adjustments if necessary)

13:00 First client print?

13:30 Second client print?

14:00 Third client print?

14:40 Fourth client print?

15:00 closing time

Repair Goals:

Test the three aspects of the current concept. Minimum n=5

At least one repair should be competed using the entire concept method.

Record video, photos of every important step and test.

(At home) recreate all of the cybercaliper samples and fixes. Report errors/ problems.

Results

3D print helper

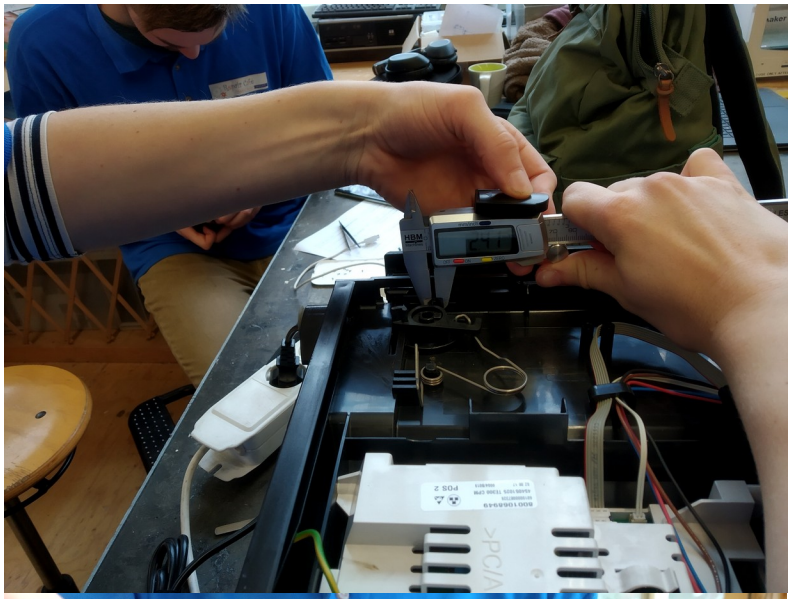
During the tests, the outcome of the 3DP helper was always positive advice, probably because the parts that were entered were all printable. More tests should be done with parts that are unprintable or edge cases to see how the program handles that.

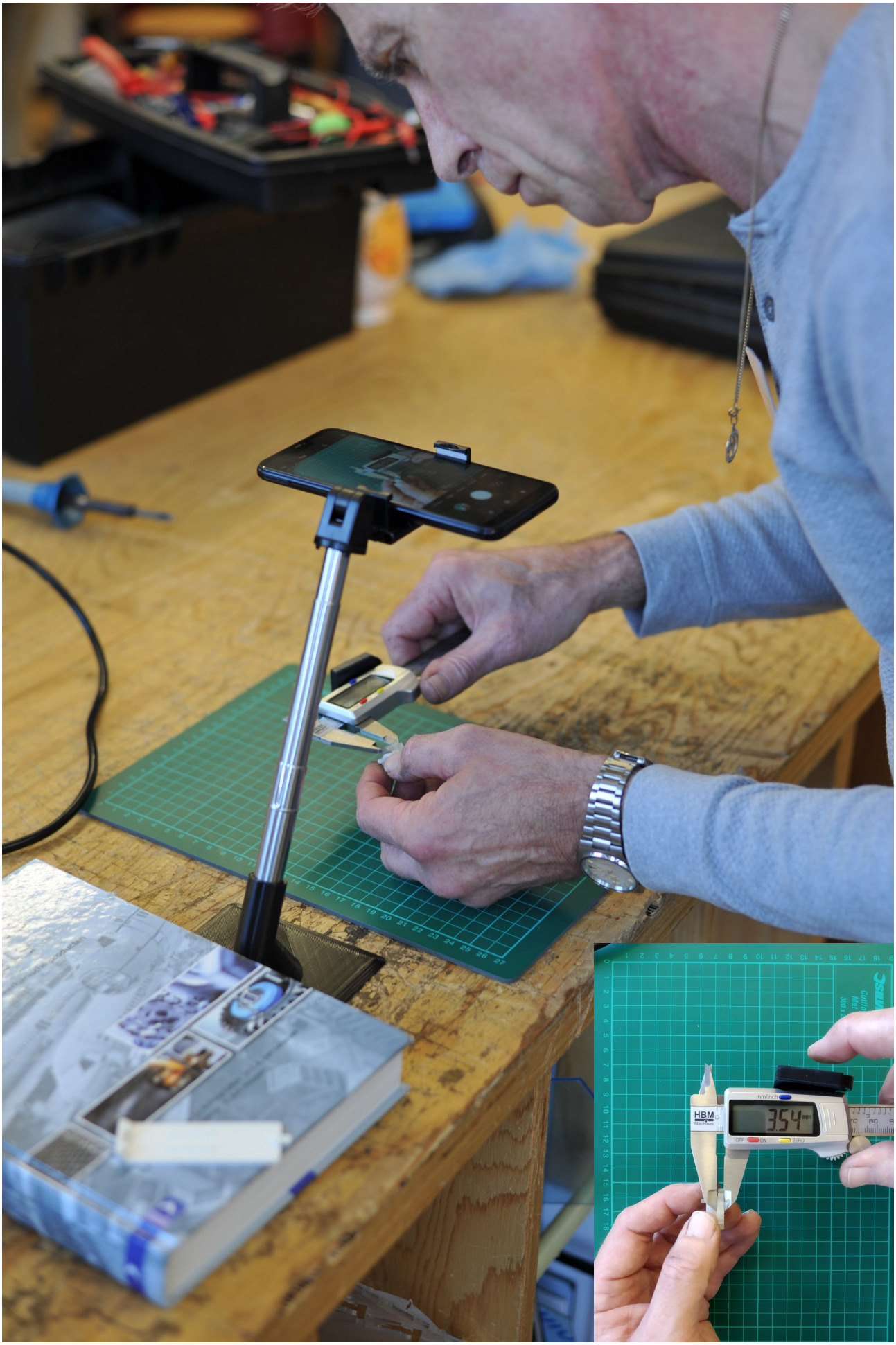

STAINLESS
HBM
SILVERLINE
A4


SILVERLINE
A4
SILVERLINE
Cutting Mat
A4

Portability can be important when measuring dimensions on a big product such as a coffee machine.

The phone had to be taken out of the holder and held by someone else. In this case the system did not fulfil its purpose smoothly, it was quite cumbersome.

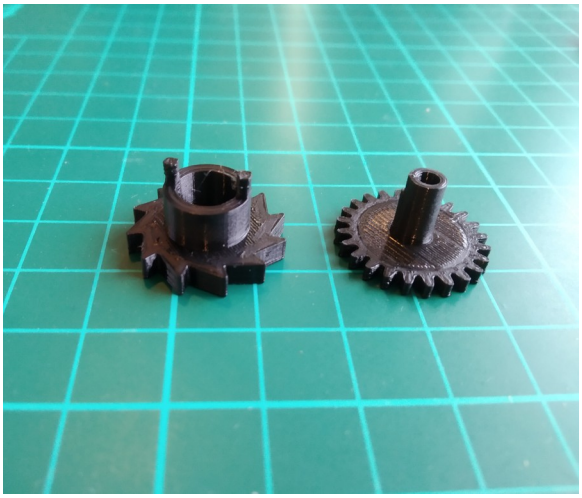


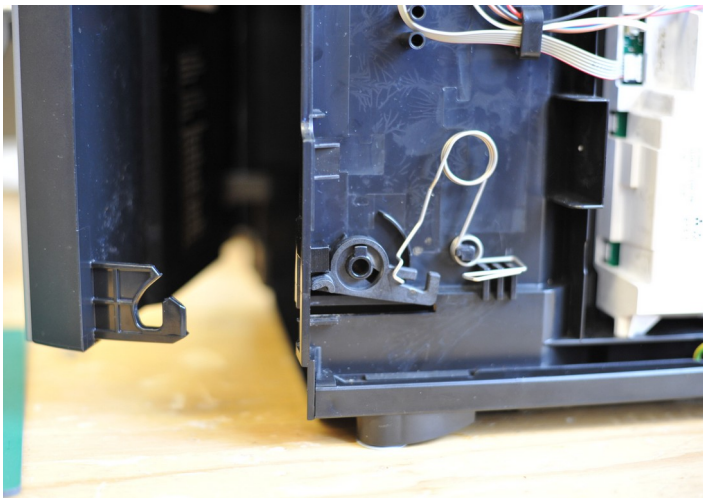

HBM
3.54

Since my presence was announced, some repairers had brought printable parts with them. The printer was almost constantly printing because of this. The next time even more jobs will be on hand, because the repairers said they had stuff at home they would like to have printed.

One spontaneous 3D print was also done for a coffee machine. A part of the maintenance door latch was missing and was printed.

Also some plastic gears from a clock were printed, the owner was a repairer, he will test if the part holds.





M. Iteration 3

Prototypes

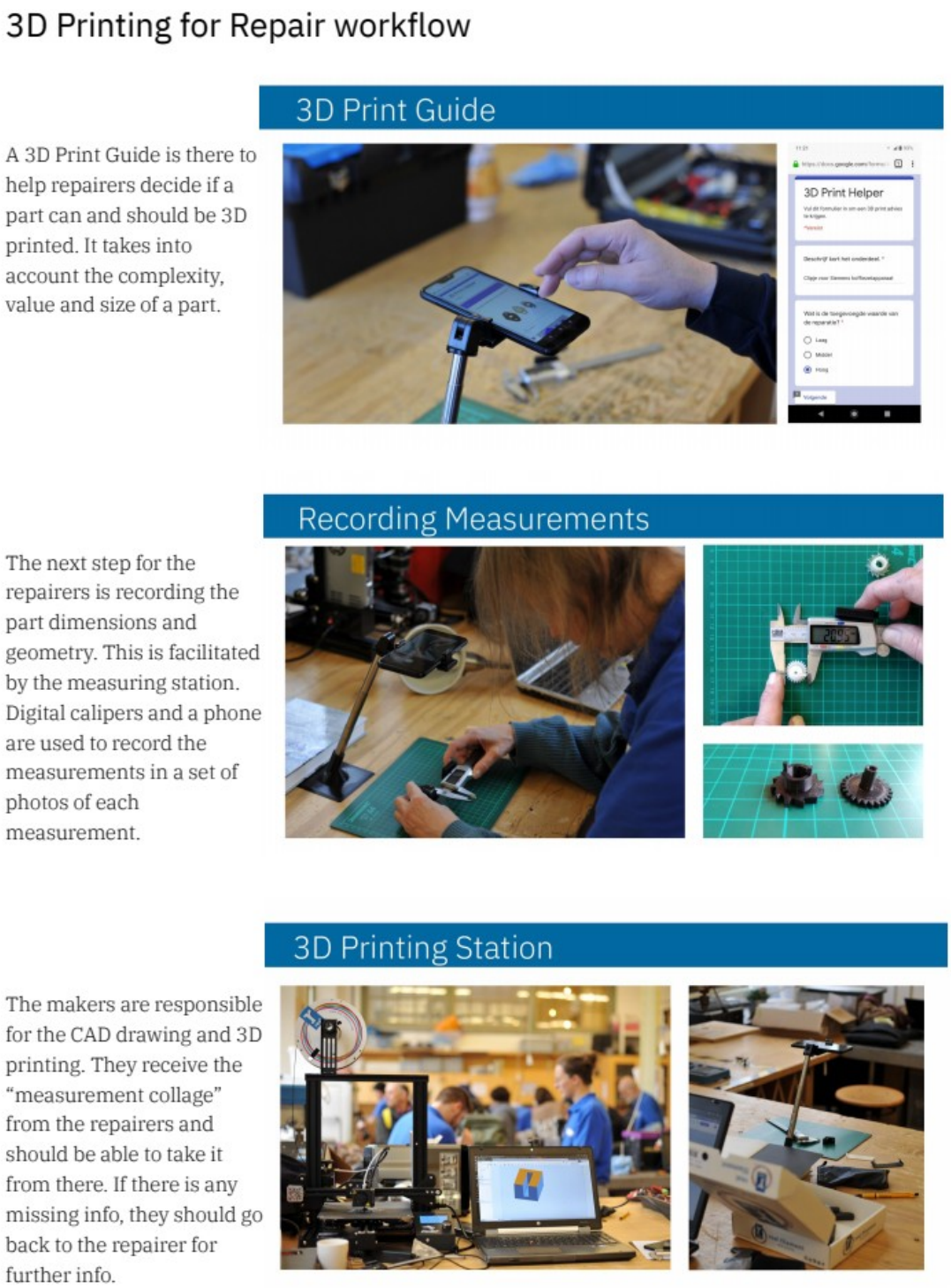


Figure 38: A poster made to explain the concept to the makers and repairers in Belgium

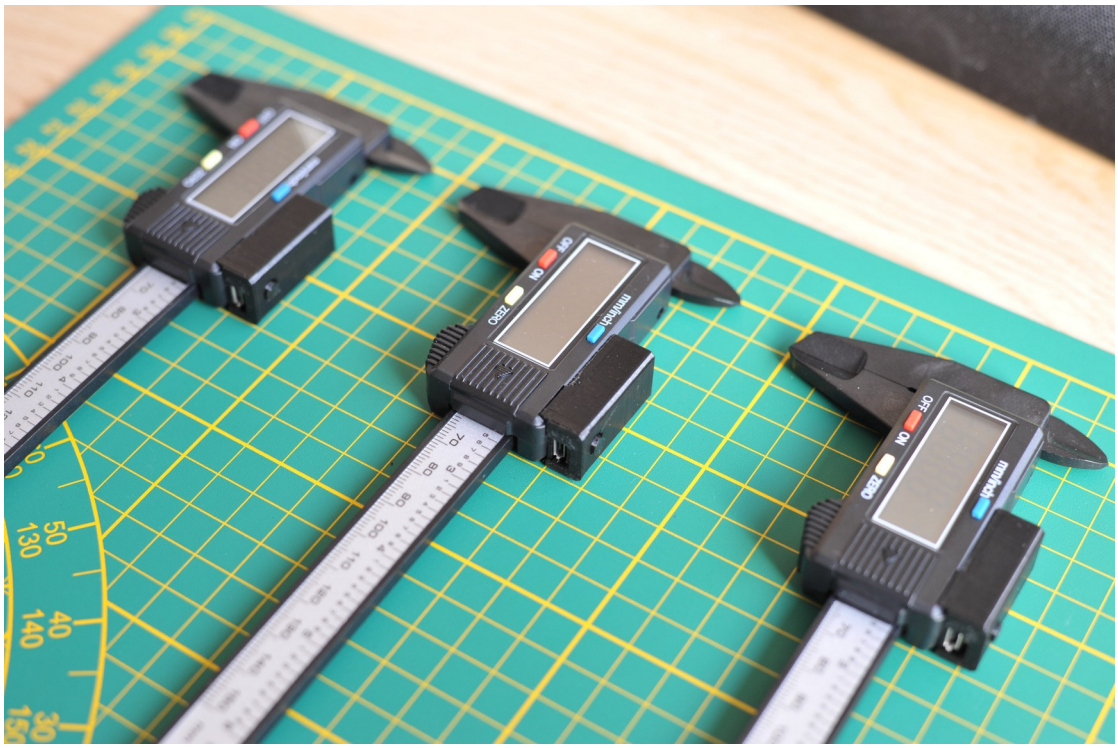


Figure 39: The prototype calipers with the bluetooth shutter button prepared for the test sessions in Belgium

Workshops in Brussel and Liège

Presentation and user test at FabLab iMal Brussels

Goals

The goal of the presentation was to introduce the makers and repairers to the project and gather feedback from them. Then in the second half the audience is involved in a user test/ repair challenge. The goal here was to test the latest prototype calipers and App. There were four measuring stations prepared.

Presentation

In the presentation I explained the goal behind my graduation project. I explained some history of 3D printing and why it can add value, why it isn't used much today and how I am trying to change that.

Feedback: Some of the audience confirmed that 3D scanning wasn't practical for them yet.

They liked the simplicity and old school use of the calipers.

They recognised the value of combining the skills of repairers and makers.

Using the App

The app was a google forms document that could be found under a displayed link. Four out of ten participants managed to open the link and follow the instructions. Only two however were able to complete the form by sending the measurement photos. The rest were able to hand in their photos using the USB cable.

The questions in the app were sometimes difficult for a participant to answer. They sometimes doubted a lot between the multiple choice questions such as value, part size and complexity.

Some participants were unable to use the app because it required having a google account which they didn't have/wanted to use.

Using the Calipers

After filling in the App, the participants were asked to make a measurement collage of the part they were remaking. This turned out to be a clear assignment for most of them since they started to work immediately. However every participant had their own way of taking the measurements. Some took a lot of dimensions, some only took a few. The order of measuring varied. The quality of the cameras also varied. The quality of the lighting varied. Most of the measurements that

were taken were correct (direct contact measurements), clamping the object with the caliper, some where however incorrect (visual measurements) by holding the caliper near to the object.

Discussion

By doing the test simultaneously with ten participants was quite chaotic. It caused me to spread my attention over the four groups. This meant I couldn't intervene every time something went wrong. This caused some participants to make big errors like taking much too few measurements or getting stuck using the app. Or getting stuck trying to connect the calipers.

I learnt from this that the process in its current form needs more guidance and that if I should do more individual tests so that I have more time to intervene with the participants when something goes wrong or they get stuck.

This also shows that better instructions are needed beforehand for the participant to know what to do.

Some participants who didn't use calipers (often) before, were not aware of the four measurement features a caliper has. (Outer dimension, inner dimension, depth and height)

It also shows that the process right now is not so clear or self explanatory that every participant knows what to do at every moment in time. Adding more guidance and self explanatory elements to the process may solve this.

For the next day I planned to have a single measuring station so that I could guide the participants where necessary.

Reflection Brussels

What went well?

Attendees of the presentation and workshop were very engaged with 3D printing for repair. They were very willing to test and contribute.

Two out of 10 attendees managed to complete the process with, handing in their collage through google forms.

Most of the other attendees managed to hand in their photos in another way.

A mailing list was made that included all the enthusiast attendees.

What could be better?

The order during the workshop was hard to attain, too many questions and too little guidance. Which left no time for me to take photos and video. Better instructions should be given beforehand next time.

What went wrong?

The participants didn't finish three parts during the tests, most of the time they lost interest after one or two parts. Maybe they didn't know what to do next.

Bluetooth connections failed in the beginning, it was hard to find which caliper was connected to which phone, and an old Samsung didn't seem to work.

The google forms requires users to log into their google account, some refused to do that.

The language barrier caused a low count of attendees, (since some people left because of that reason before my presentation) and it caused instructions not to be understood in some cases. Next time this should be taken into account, for better results the native language should be closer to mine.

Reflection Liège

What went well?

The one-on-one tests were much more orderly and practical. The test subjects demanded a lot to attention, they had a lot of questions and some didn't know what to do. The one on one allowed me to intervene when something went wrong. The participants varied a lot in skill, there were repairers from local repair Cafés, makers and novices. This allowed for wildly varying test results, but gave a good impression of what went wrong with whom.

What could be better?

The planned tests were quite long, so doing three part per participant was unrealistic. Therefore only one or two parts were tested by most participants. A more time realistic test plan must be made next time, taking into account the volunteering nature and attention span of the participants. No longer than five minutes per participant that keeps them away from other activities.

What went wrong?

One of the maker participants wanted to recreate a part using the entire process. He managed to get very close but he failed in one aspect of the part recreation. A piece of plastic wasn't visible on the collage for him, so he didn't include it in his model.

Next steps

The concept has shown to be a viable method of recreating parts and creating substitute parts. However it still needs some critical improvements, such as:

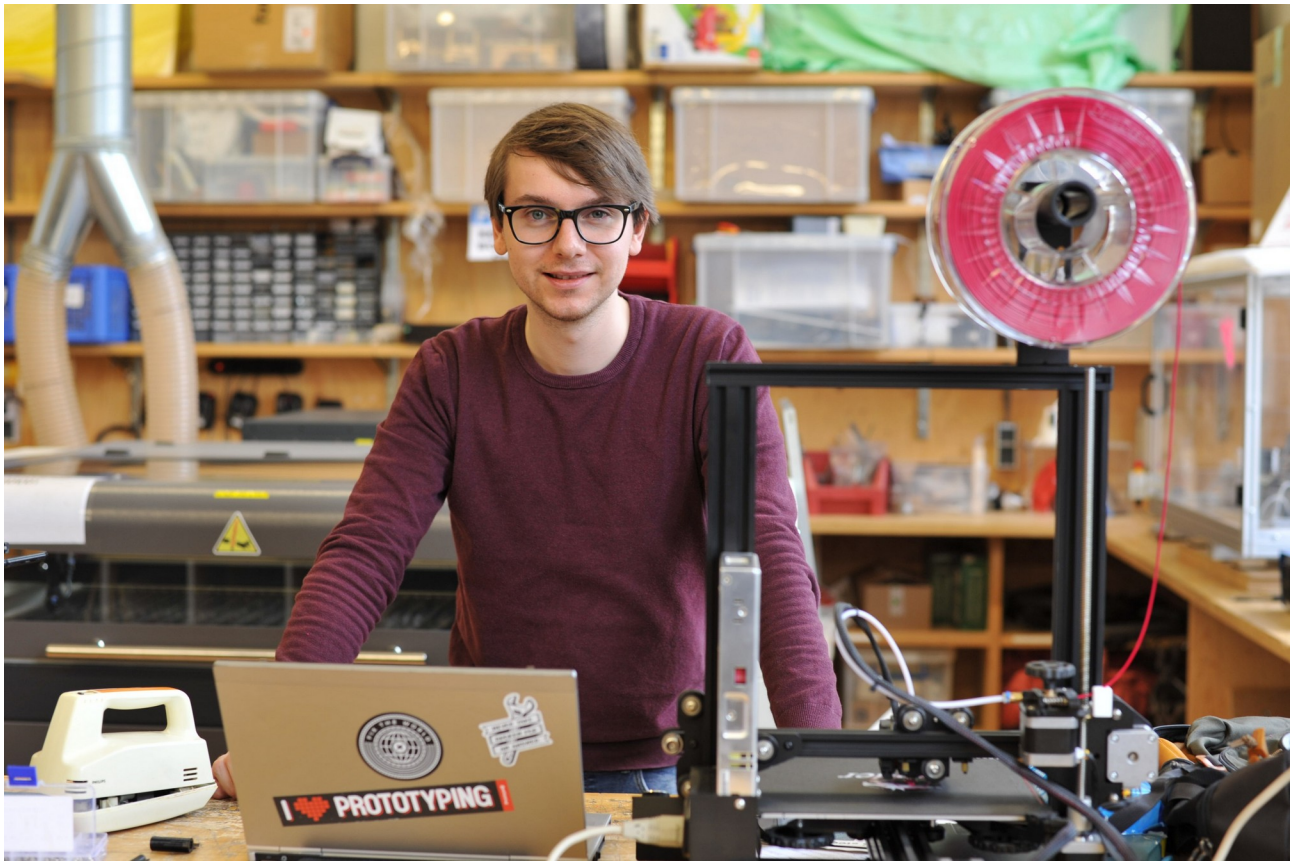
- Better part overview. (isometric view, top, bottom, right, left (technical drawing style)
- Better photo ordering, collage generating methods.
- Better part lighting, contrast. (Background colour, caliper colour)
- Taking into account varying phone specs: camera quality, speed, Bluetooth version.
- Sending measurement data to phone. (removing the need for screen readability)
- Integrated app that combines all of the above elements.
- Strategic sharing of information via online channels. (webpage, social media, youtube.)
    - Split in two (open source hard / software + paid hardware and services)
    - Web page and domain
    - YouTube promotion plan

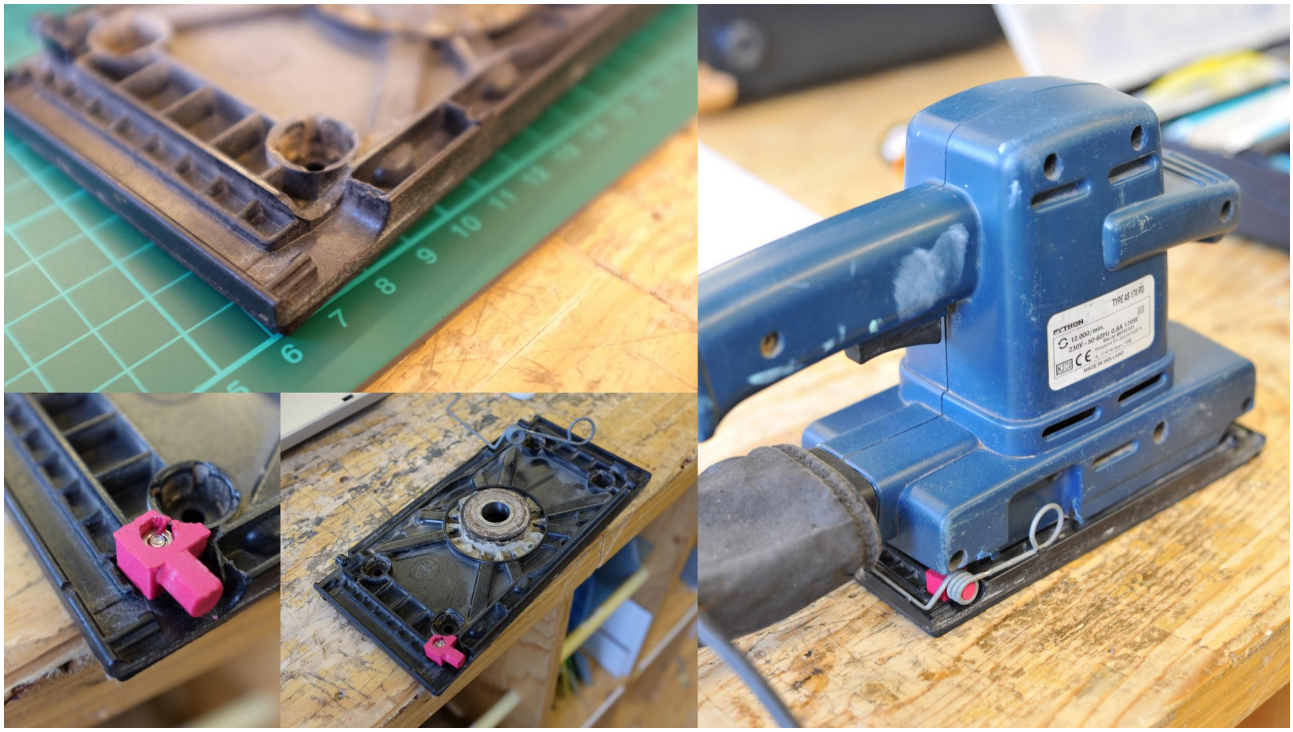

real filament


cura

N. Iteration 4

Repair cafe 4





Enhancing 3D Printing for Repair

a 3D printing toolkit for repairers

Vision

Most repairers are mechanically oriented people, they are not very familiar with computers and digital technology. In order for them to reap the benefits from the digital 3D printing revolution a translation must be made between the new and the old repair methods.

Repairers are mechanically minded people. They have trouble using computers.

The digital art of 3D printing, a potential asset for repairers, can be made accessible to them.

By translating the mechanical into the digital world.

Concept

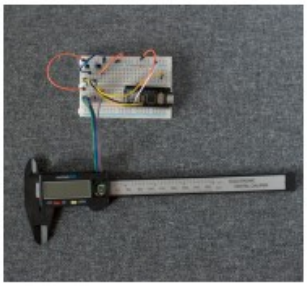
Reverse-Engineering Toolkit

CyberCaliper Phone App

Implementation

Road map for implementation of the concept into the user group.

Organise workshops
Build a regional network.



Publish the Open Source Project.
Build an online community.

Launch CyberCaliper Startup
Products: Hardware.
Services: Workshops, education.

Figure 40: A poster used for explaining the final concept to makers and repairers

O. Toolkit prototype

CyberCaliper

With the goal of testing the concept of uploading measurements to the web platform, the CyberCaliper was prototyped. This is a caliper that consists of a good quality Chinese caliper by ‘Shahe’. This caliper is fitted with a custom casing with modified electronics including an Arduino Nano and a HC-06 Bluetooth module.

The cybercaliper hardware was prototyped by disassembling several calipers and modifying them into a caliper that can connect via Bluetooth and send measurement values by pressing a button on the caliper.

Interpreting the data from the caliper

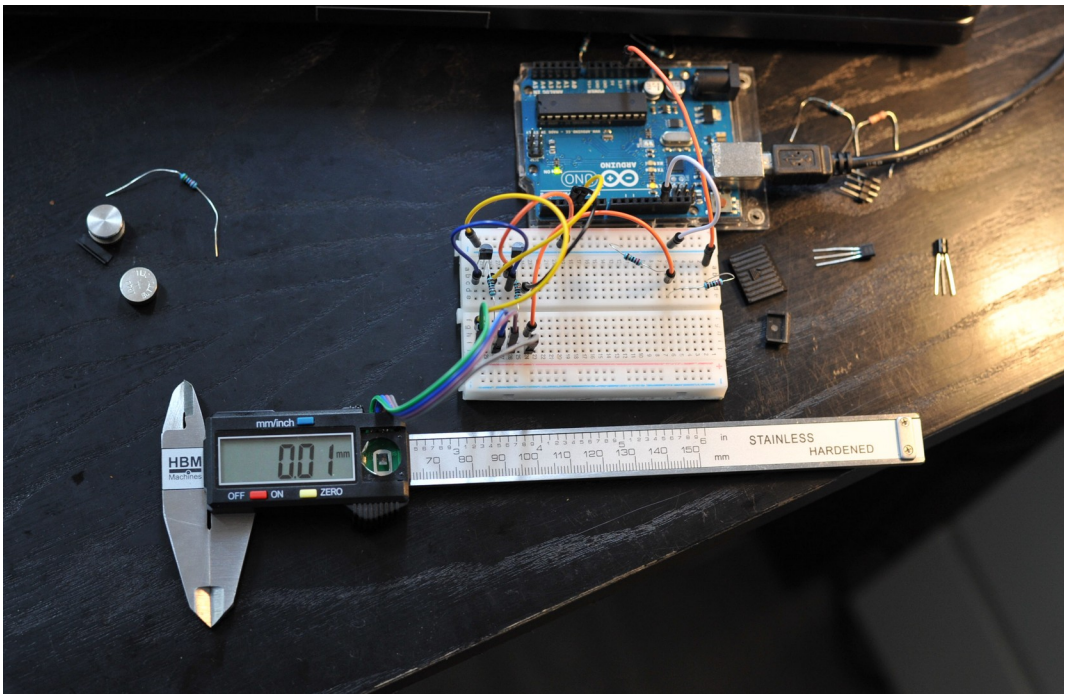


Figure 41: Reading the data from a caliper using a voltage level shifter and an Arduino

Prototyping the case

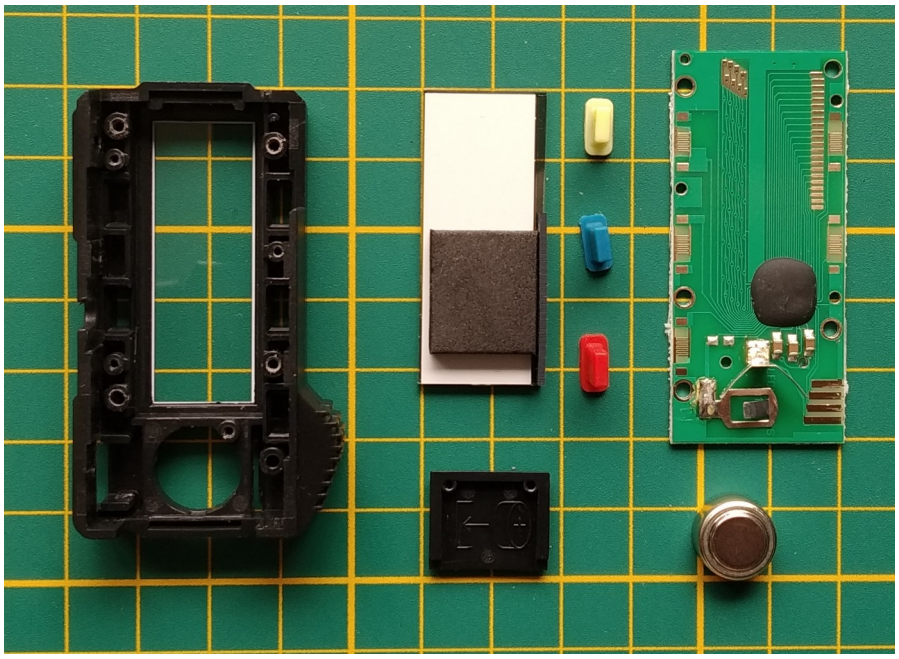


Figure 42: Reverse engineering an existing caliper case

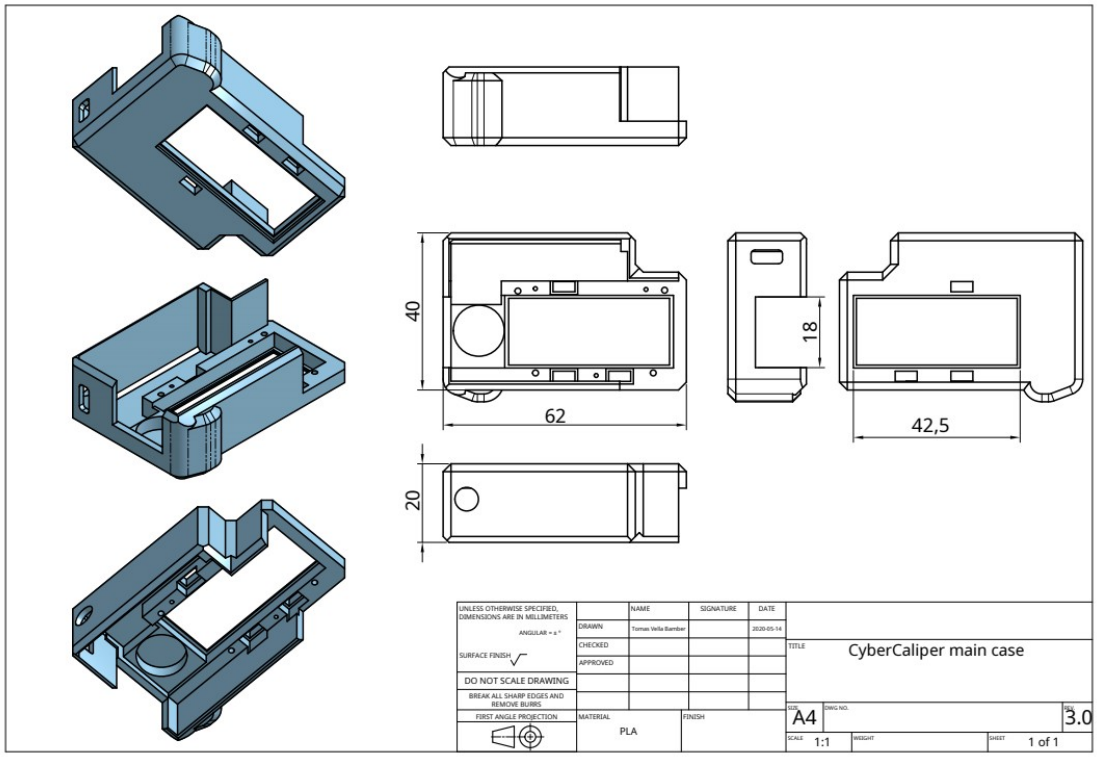


Figure 43: Technical drawing of the CyberCaliper case

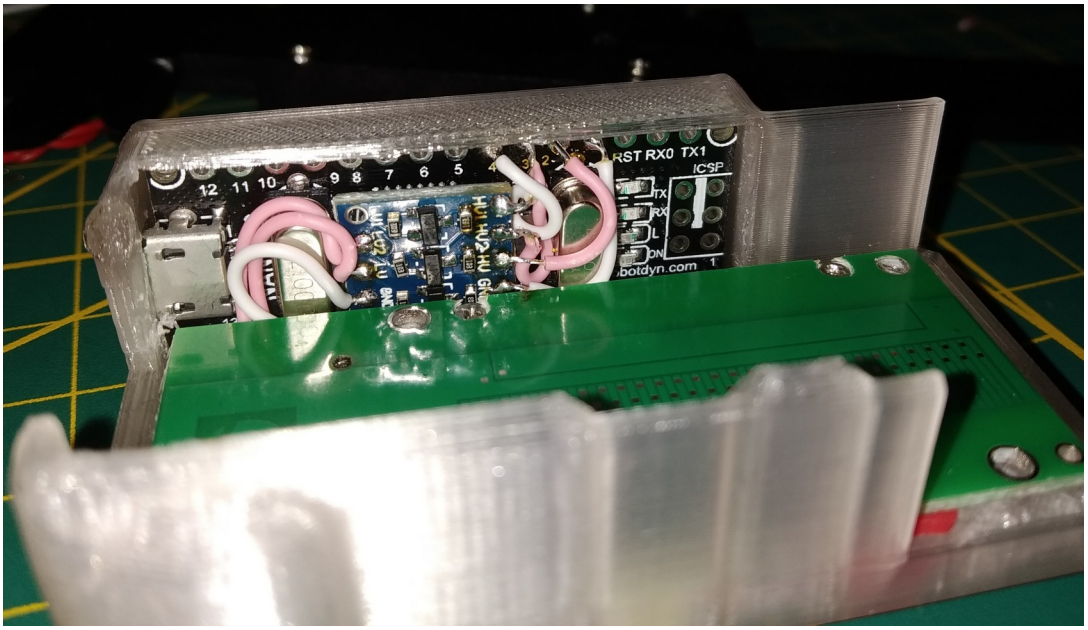


Figure 44: Fitting the electronics into the custom case

Figure 45: Testing the shutter button on top of the case

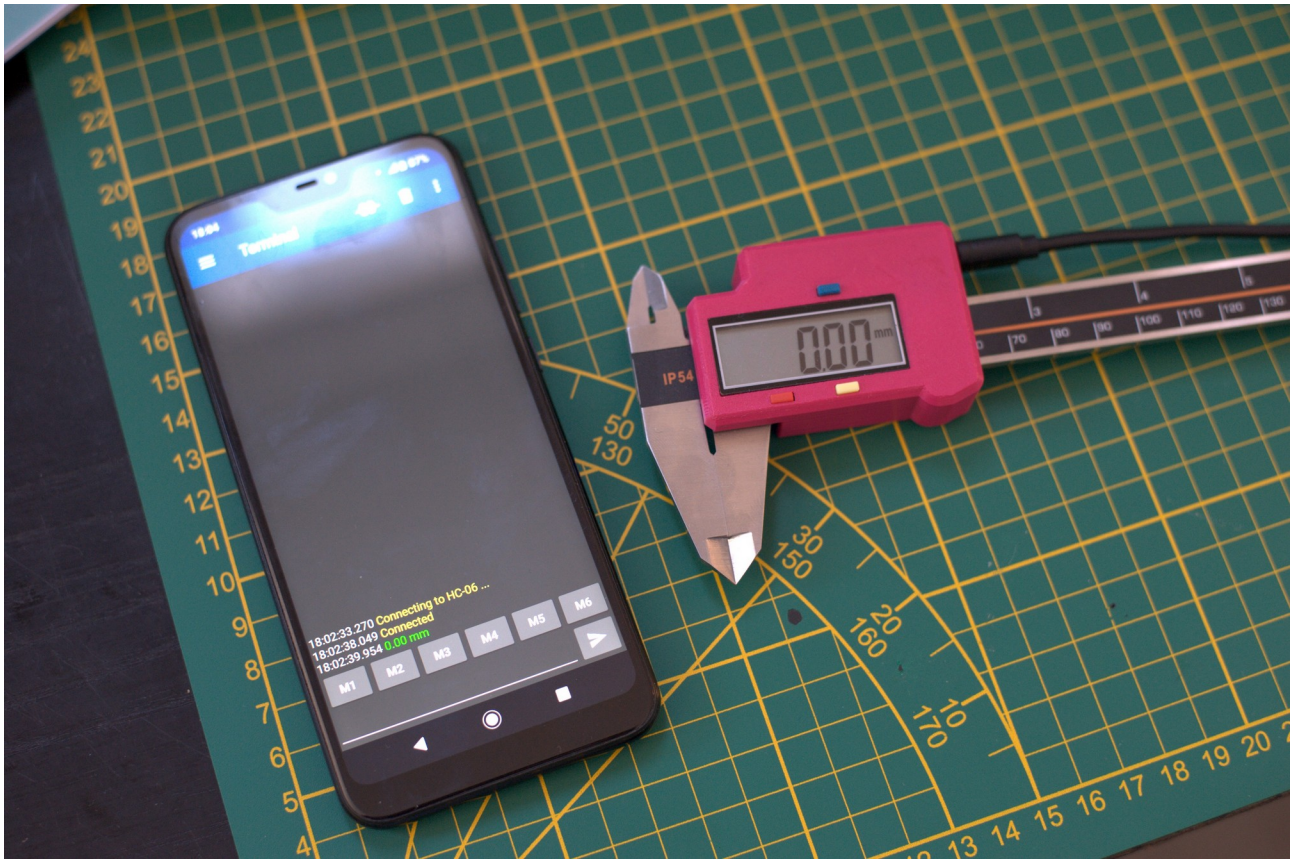


Figure 46: Testing the data transfer through Bluetooth between the caliper and a phone

Connected via Bluetooth to the phone, pressing the button on the side of the caliper will send the measurement data. This can be used by a phone app to trigger the camera shutter and embed the data into the image.

CaliperCam App

An attempt was made to prototype a phone app that could connect to the caliper and embed the data into a picture. Parts of the app were working however the prototype was discontinued because it wasn't a crucial element for testing the concept concept. In addition the Coronavirus pandemic meant that all physical tests were canceled.

The CaliperCam was able to show the camera and connect to the Caliper. However it didn't embed the data from the caliper into a photo yet.

After this stage was reached the work on the app was put on hold.

Figure 47: Screenshot of the CaliperCam prototype app

Accessories

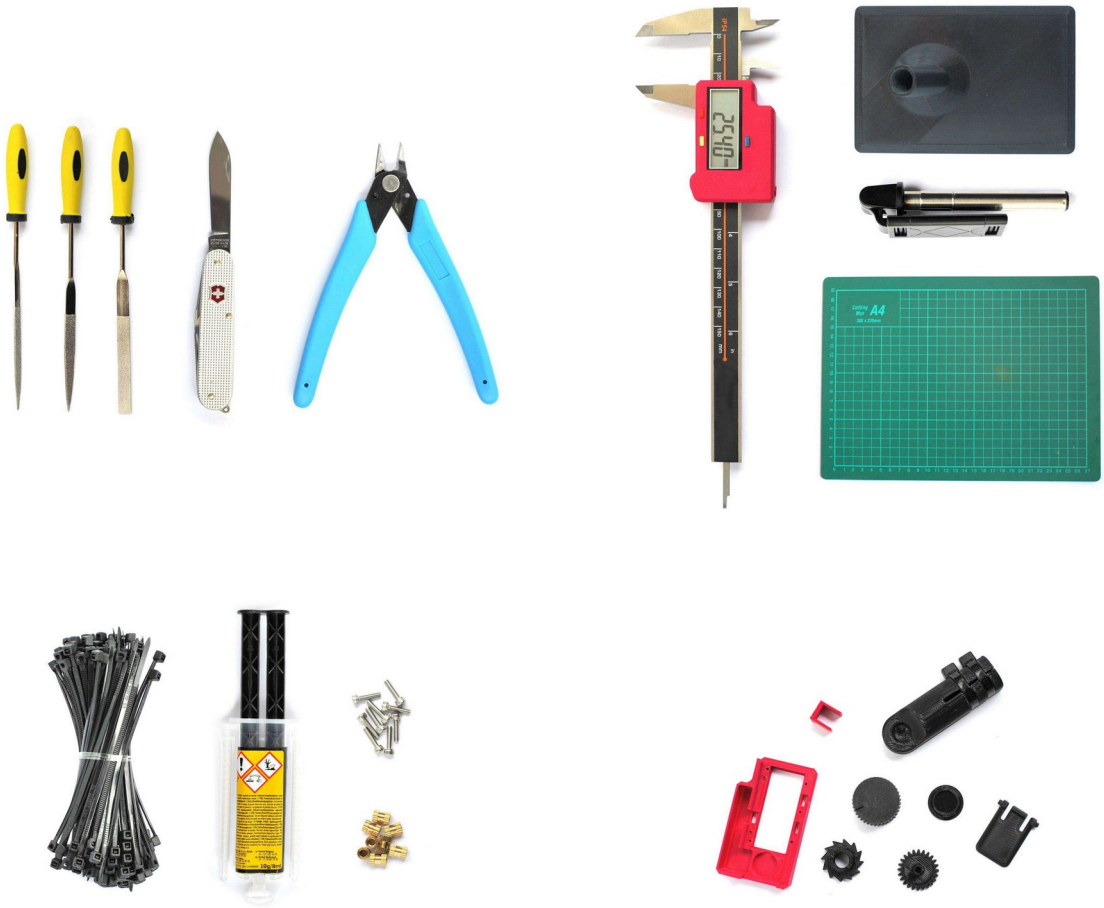


Figure 48: Digital representation of the toolkit

P. Web platform prototype

MakerMarket

A digital prototype was created in the form of an interactive website where users can make an account and post a 3D printing for repair request. The website was written in HTML/CSS and PHP a basic back end language in which user accounts and file uploading can be managed. This was linked to a MySQL database where the user entries are saved. The images and 3D files are saved in the site directory.

The open source Bootstrap 4 toolkit was used to create the front end HTML and CSS elements: https://getbootstrap.com/

The backend image uploading system and login system were modelled after the PHP tutorial by mmtuts.

Login system: https://youtu.be/LC9GaXkdxF8

Gallery: https://youtu.be/msO37iodcw8

The 3D model viewer in the comments section was implemented using the open source “STL viewer” Javascript plugin: https://www.viewstl.com/plugin/

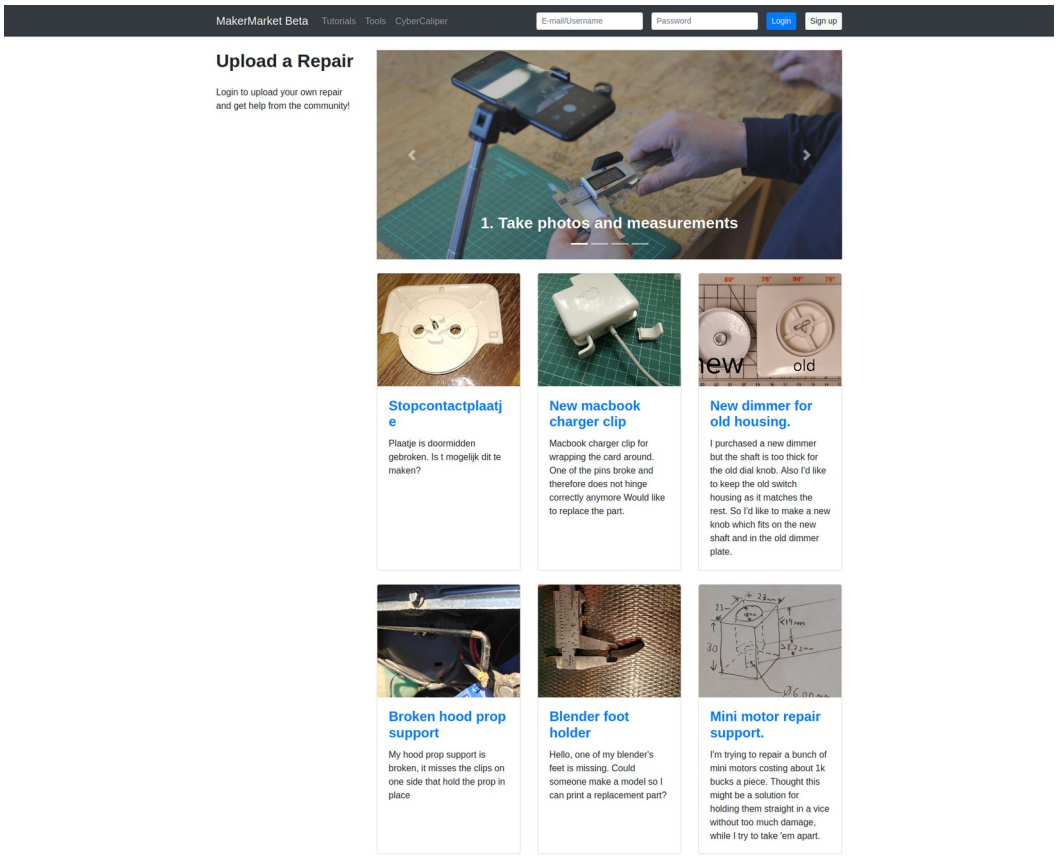


Figure 49: Home page of the MakerMarket prototype

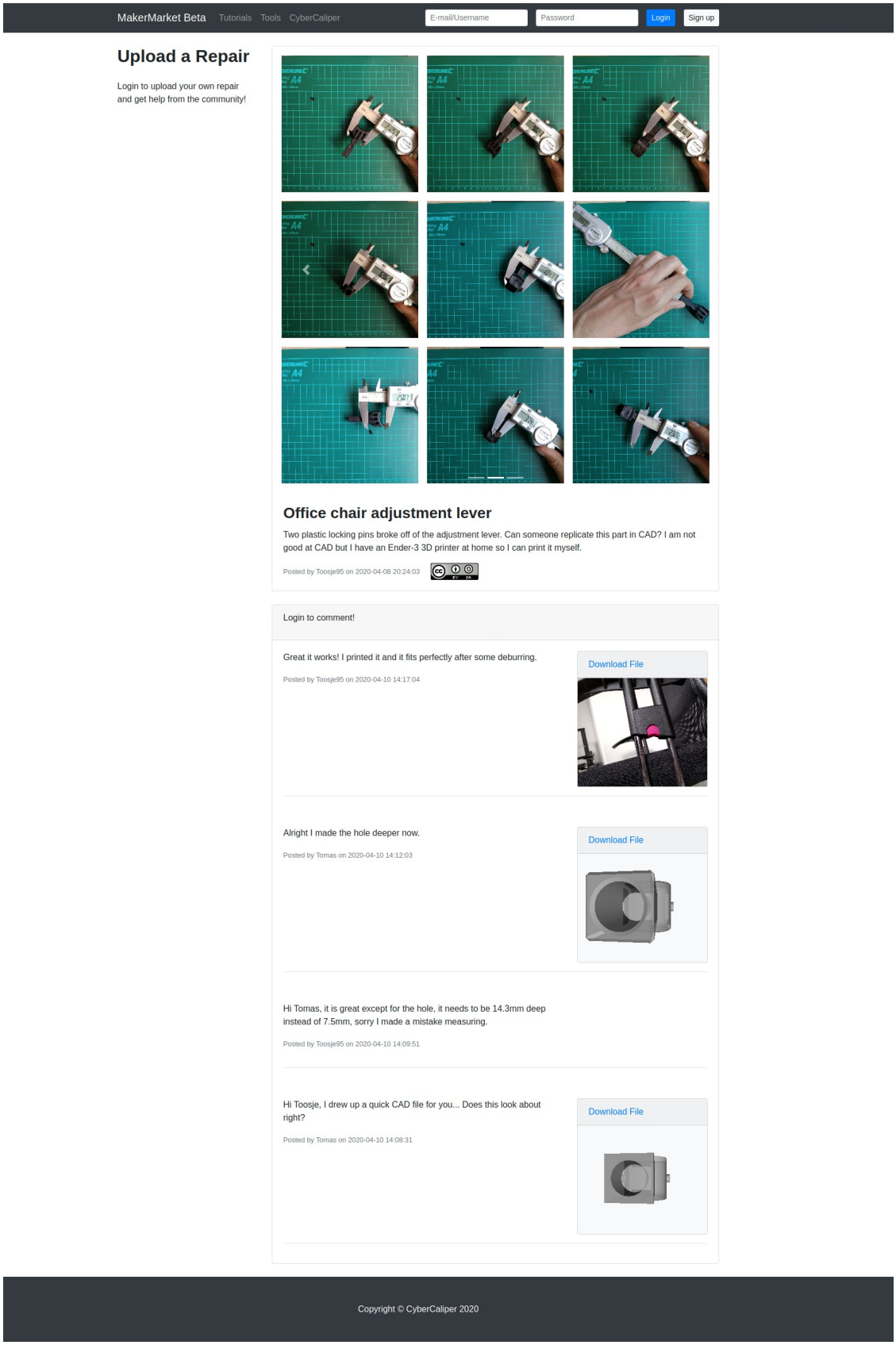
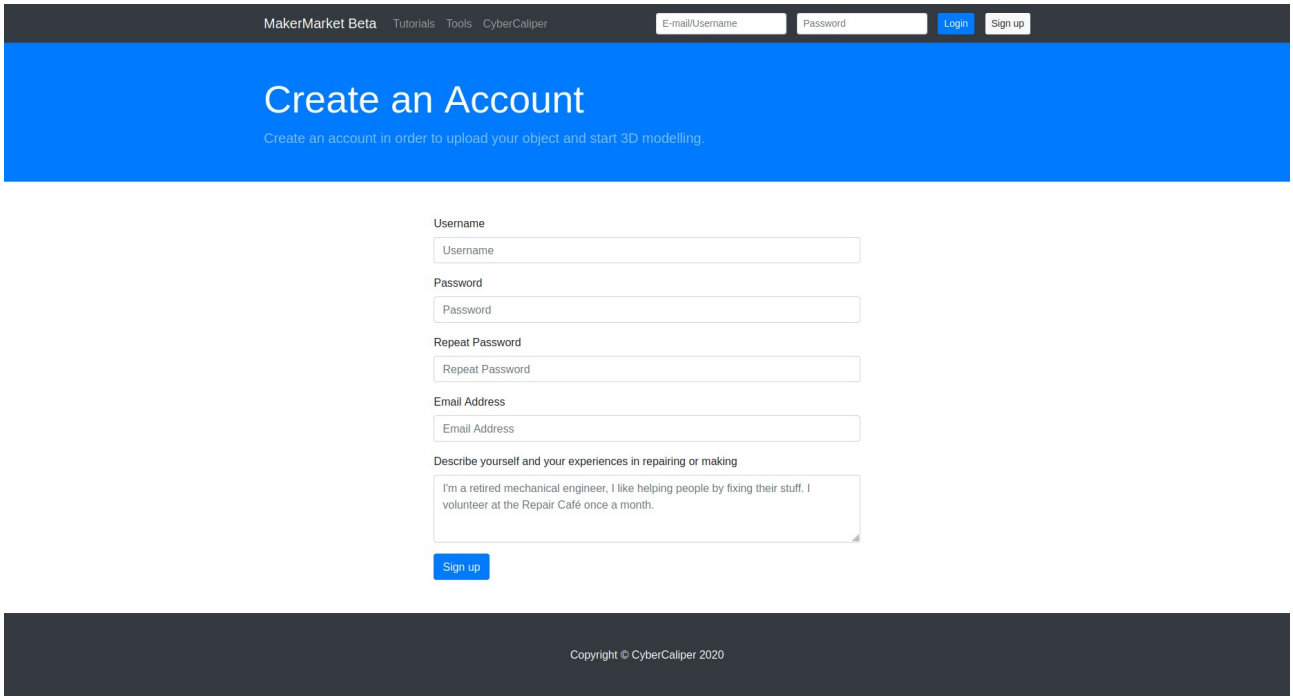
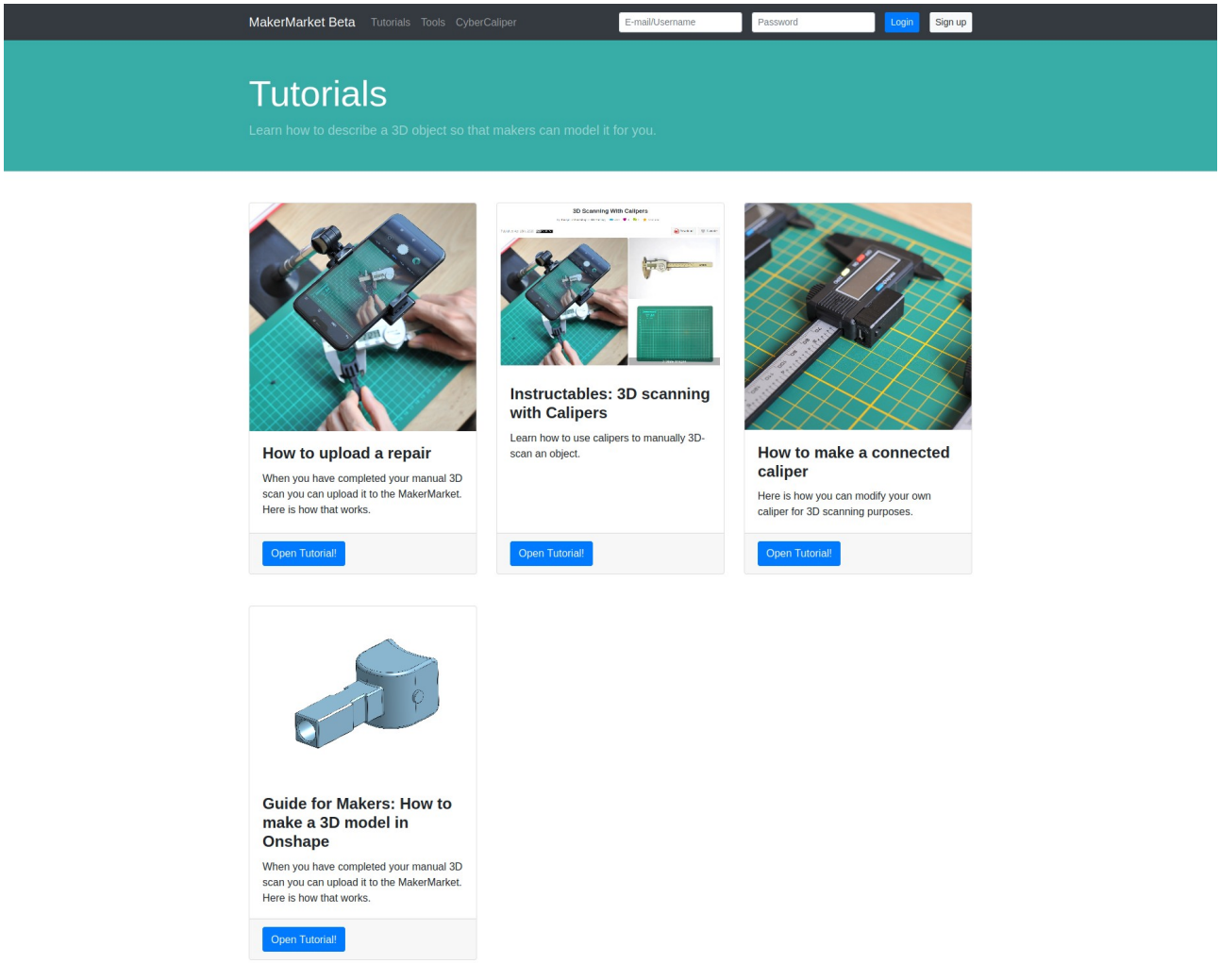


Figure 50: Detail page of an example post, the envisioned communication between the maker and repairer can be seen in the comments.

Signup



Tutorials



How to upload an object

Learn how to describe a 3D object so that makers can model it for you.

Gather the tools

- Digital Calipers
- Phone with a working camera
- (optional) Cutting mat or squared paper as a background.
- (optional) Selfie stick or other phone standard.

Step 1. Inspect your object

Look closely at your object and check the following:

- There is any damage to the part?
- How many measurements are needed to replicate the part?
- Are there any parts missing that need to be rebuilt?

If you can answer all these questions continue to step 2.

Step 2. Setup your measuring station

Make sure there is enough light, sit down next to a window or a very bright light.

Make sure your caliper is set to zero by gently keeping it shut and pressing the zero button.

Setup a phone standard, or let someone else hold your phone if possible. Or you can rock it in one hand.

Step 3. Take some overview pictures

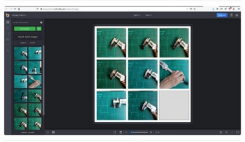
Make sure to capture the whole object in a 3D-view from several angles so that the maker gets a better idea of the geometry of the object.

Step 4. Scan the part

Now put the phone in the standard if you have one.

Start taking pictures while measuring with the calipers, this can be tricky with one hand, make sure the measurements don't shift while taking the shot. Get help from someone if it doesn't work.

Make sure to keep the part in the center of the picture and that the screen of the caliper is readable.



Step 5. Create a collage

Make a collage from your measurement photos.

You can do this at: Befunky website

Or use the mobile app: BeFunky app

Feel free to use another collage making software if you feel like it.

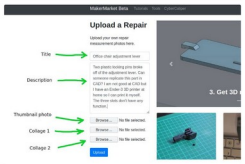
Make sure you don't forget photos, make two or max three collages if you have more than 9 photos. Its better to have double measurements than to leave one out.

Zoom in on small features to make them more clear, make sure all the measurements are readable.

Step 6. Describe your object

Add a detailed description of your part with relevant information such as:

- What the function of the part is.
- What kind equipment or product it belongs to.
- What kind of stresses are on the part under normal use?
- What kind of temperatures does it resist?
- Point to features in the pictures if necessary.
- Are there any features or adjustments you want that are not seen in the pictures?
- Are there any features that have broken off and got lost?



Step 7. Upload

Upload a title, description and collages to the *MakerMarket*!

Step 8. Communicate with makers

Makers will respond to your post with questions at first. Make sure you answer them precisely in order to get a correct 3D model.

Links

Instructable: 3D scanning using Calipers
Office chair example

Tools

MakerMarket Beta Tutorials Tools CyberCaliper E-mail/Username Password Login Sign up

CyberCaliper

A caliper designed specifically for 3D printing for repair.

Interested?

Email address

Subscribe to Mailing List!

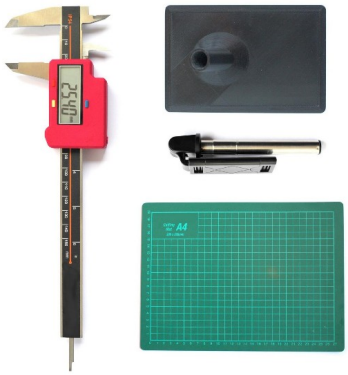
Description

CyberCaliper is designed to enable online 3D printing for repair collaboration.

It connects to your phone via Bluetooth, by using the CyberCaliper App you can quickly make measurement collages with the shutter button on the Caliper.

Contents

- CyberCaliper Kit
  - CyberCaliper
  - A4 Cutting mat
  - Universal phone standard
  - Plastic case



Specifications

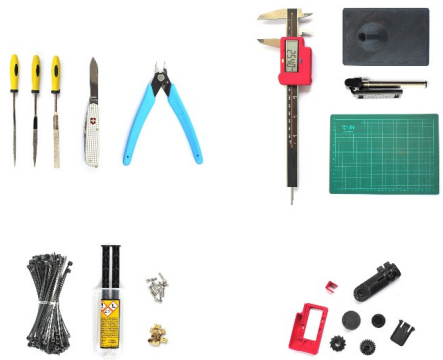
- Connectivity: Bluetooth
- Charger: microUSB
- Units: Millimeter, Inch
- Reach: 0-150mm
- Accuracy: ± 0.02mm
- Resolution: 0.01mm
- Measuring options:
  - Outer dimension
  - Inner dimension
  - Depth
  - Height
- Material: Stainless Steel

Copyright © CyberCaliper 2020

MakerMarket Beta Tutorials Tools CyberCaliper E-mail/Username Password Login Sign up

Starter Kit

Everything you need to start using 3D printing as a repair tool.



Interested?

Email address

Subscribe to Mailing List!

Description

In order to make a good measurement collage you need the following:

A digital caliper

A selfie stick (or something that can hold your phone)

A cutting mat (or another clean background)

Contents

- CyberCaliper Kit
  - CyberCaliper
  - Cutting mat
  - Phone standard
- Deburring tools
  - Precision hand file set
  - Carving knife
  - Cutting pliers
- Fastening materials
  - Tie wraps
  - Epoxy glue
  - Hex bolts set (M3)
  - Brass inserts set (M3)
- 3D Printing samples
  - Clock gears
  - Caliper case
  - Keyboard standard
  - Mitutoyo battery cap
  - Generic volume knob
  - Steam switch for iron
  - Bike mudguard clamp

Q. Expert interview

Repairer’s 3D printing starter kit - Test plan

Problem definition

The Repairer’s 3DP toolkit is designed to support repairers in the envisioned 3D printing workflow, however the composition of the kit has not been validated yet. By asking experts in the field of 3D printing for repair, who have experience in explaining and training people in 3D printing, valuable feedback can be gathered.

Goals
To validate the current design proposal of the 3DPR toolkit and gather expert insights and recommendations so that it can be redesigned for the final design proposal.
Main research questions
To what extent is the overall concept clear?
To what extent is the purpose of the toolkit in the overall concept clear?
To what extent is the purpose of all the elements in the toolkit clear?
Does the expert want to add or remove elements?
What are the experiences of the expert in introducing people to 3D printing for repair?

Method
Conduct an expert evaluation interview (30 minutes)
Start by presenting the concept to an expert in 3D Printing for Repair, using digital prototypes and visuals.
Follow up with questions from the interview script, and react depending on the feedback.
An interview script will be created as a guide for the interview.
The meetings will be recorded and analysed later.

Timeline
April 6-10 Write test plan
April 13-17 Prepare prototypes and visuals
April 20-24 Execute session

Deliverables
The main insights will be gathered in a visual overview or evaluation card format.
A list of recommendations based on the feedback from the expert on how to redesign the toolkit.
Report additional insights gained during the interview that are relevant to the overall concept.

Materials

Physical prototype toolkit

- CyberCaliper prototype
- Scanning accessories
- Deburring and reworking accessories
- Fastening materials
- 3DPR samples

Digital representation: Product page on cybercaliper.com

External dependencies

Find suitable experts who are willing to cooperate.

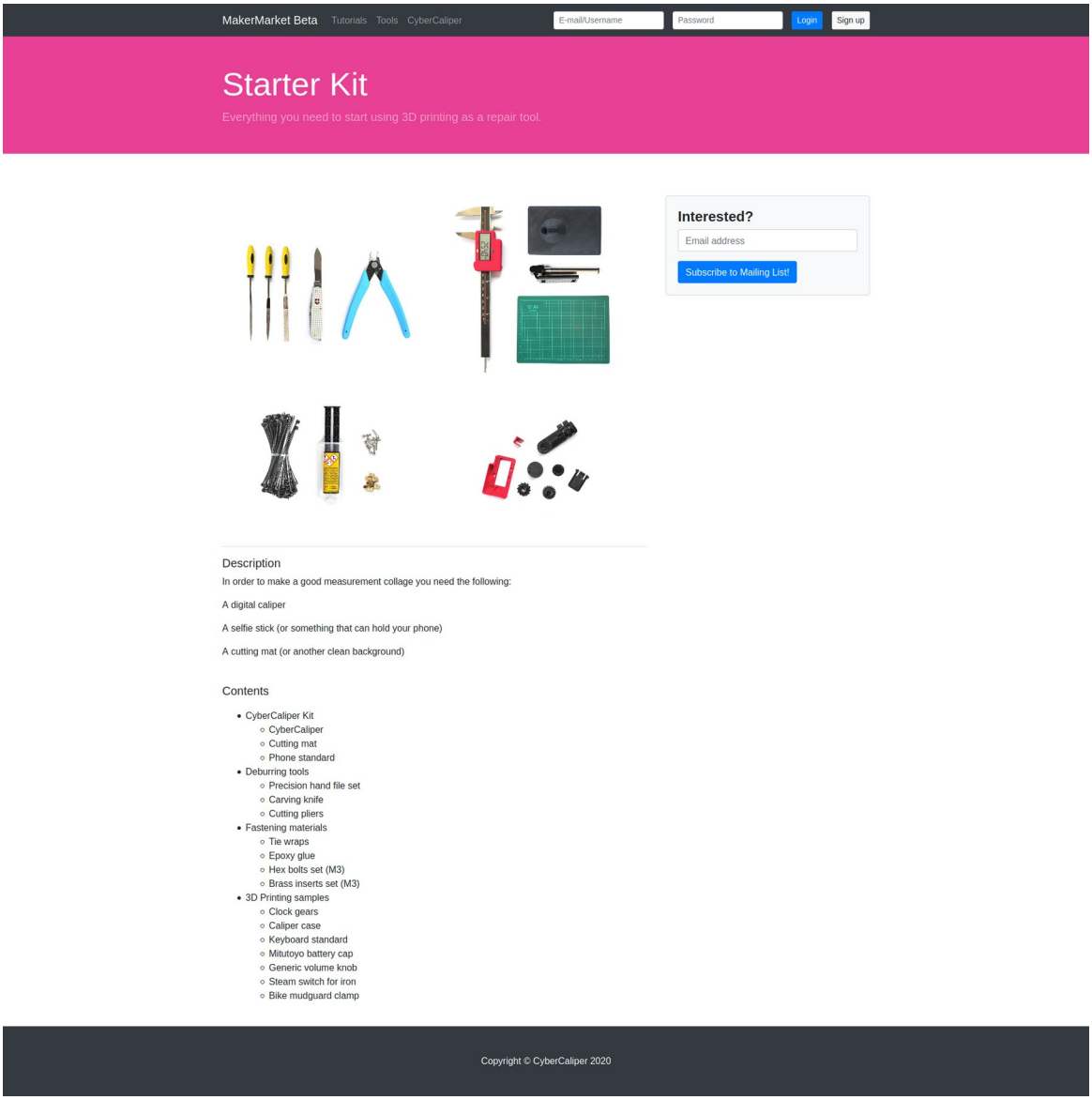


Figure 51: The repairer's starter kit as presented to the expert.

Results

The interview lasted for 1:30 minutes. A transcript was made of the most important quotes. These were ordered in an insight list in which the insight, quotes and recommendations are made for a certain topic.

Insight list

An insight list was made based on a modified version of an observation log from Valsplat, a Dutch UX research consultancy: https://valsplat.nl/resources/observation-log

- positive: green,
- neutral: blue
- negative (low impact): yellow
- negative (medium impact): orange
- negative (high impact): red

Anika interview insights	Expert interview with Anika Paape		24-04-2020	
General context	Specific context	[1]	Insight description	Quotes	Recommendations
Concept	Manual 3d scanning		The concept is straightforward because they already thought of something like it.	*"We thought about a concept like this as well. We didn't think of going for digital calipers. Which of course works much better for photos."*	Beware of others copying the idea because the it is very straightforward.
Concept	Clarity of concept		The overall concept isn't clear at first glance.	*"Now I understand much better what you are doing."*	Visually explain the concept so that it becomes clear after visiting the front page of the website.
Concept	Network		They are willing to cooperate and share the concept with their network.	*"We have a long list of interested people, I can share it over our mailing list."*	Keep them in mind for future tests.
Concept	CAD modelling		The bottleneck of CAD modelling is recognised by them. Language is another big barrier.	*"We have two bottlenecks: Language barrier and CAD modelling."*	Language barriers must be looked into further because it is a very important aspect when applying the concept among European repairers.
Concept	Approach		She sees the potential and thinks it could work.	*"Your version is cool, I think it could work!" "Your project is a very clever approach to this!"*	
Toolkit	Providing toolkit		It's not clear at first glance that a toolkit will be available.	*"Are you going to share a complete toolkit as well?" "Do you have like a structure for the phone?"*	Make it clearer on the website which tools can be bought where.
Concept	Repairers getting support from makers		They don't recommend repairers to learn CAD by themselves, but to get help from others instead.	*"We recommend people in Repair Café's to get in touch with local makerspaces." "It's not time efficient to learn CAD in spare time for most repairers." "There are people who are very enthusiastic about 3D pritning in Repair Cafés" "Really show the process, show what parts are good for 3D repair and which are not. And redirect their enthusiasm about 3DP to get help from makerspaces." "Everything else is more frustrating usually."*	The idea of repairers getting support from makers is sound. Using the enthusiasm of repairers to get help can be more looked into.
Concept	3D scanning		They came to the same conclusion: That 3D scanning is not a practical tool for repair at this point.	*"3D scanning we need to talk about a lot. It's hard to explain to people that this is not a good way to copy a part. People usually don't believe us."*	This part of the concept is sound at this point in time. However may be subject to change in the future.
Toolkit	Cooperation		Cooperation with ifixit as a distributor of tools?	*"How would you distribute the starter kit, would you have a cooperation with iFixit?"*	Look into different ways of distributing the tools to the repair community.
Toolkit	Generic tools		There are too many generic elements in the toolkit.	*"My first thought that there may be a bit much in there. For your toolkit you would use an existing caliper."*	Don't include those generic elements, maybe give them the option to buy it, or recommend where to buy it.
Toolkit	Providing the toolkit		It's not clear how people are going to get a cybercaliper.	*"So people would buy a new caliper and open it up?" "So there are two approaches a DIY kit, and a ready to go kit."*	Make clear what paths there are to get or make a caliper.
Toolkit	App		An app is not recommended for the user group.	*"I don't think I would recommend an App, just becaus of the demograpics of the people who are going to use it."*	Don't make the app mandatory for using the concept. Only use the app for the bluetooth connection with the caliper and taking photos. The rest can be done via the website for mobile.
Concept	Website		A website may be okay for them.	*"I think they are ok with a website but an App may be too much aof a hurdle."*	
Toolkit	Generic tools		The generic tools like the cutting mat are not interesting and everyone has them. So not essential in the toolkit.	*"I think the people who are interested in the concept will be interested in the Caliper an maybe the phone holder. But every RepairCafé I went to was really stocked up on tools. And for makerspaces it's the same. I would focus on the core things here. Maybe not even the cutting mat."*	Leave the generic tools that most people have out of the toolkit. Have them as an option instead.
Toolkit	Samples		Samples are a good tool for inspiration and education of repairers getting started with 3D printing.	*"I think if you're getting into the topic samples are always nice. Although you do need to think about resources. Maybe you can use rejected parts for that."*	Include the samples and try to source them for free from 3D printing waste/ rejected parts.
Concept	Challenge makers		To attract makers you need to challenge them, e.g. by allowing them to creatively enhance CAD designs, or providing a diy cybercaliper kit.	*"To get makers involved you need to challenge them. You can lure them in by making a redesign challenge. When 3D printing a part it can be enhanced. And it would be nice if there was a do it yourself kit." "We suggest to have an event with a local makerspace to build the caliper as a challenge."*	Really challenge makers by building in challenging aspects into the website. Such as creative 3D printing for repair challenges. And a DIY kit to build your own cybercaliper.

Figure 52: Insight list from the interview with Anika Paape

R. Online user test

Test plan

Problem definition

A design proposal for the web platform has been prototyped. Many assumptions about the concept and the usability still exist within this proposal. These assumptions should now be evaluated and adjusted where necessary.

Goals

The main goal is to test the validity of the concept itself by observing whether the participants understand the system as a whole, the purpose of the elements and whether they can navigate and use the system to accomplish a given task.

With the insights from this test a redesign proposal will be made, it should form the basis of a system that is ready for implementation.

Main research questions

Are the repairers able to grasp the purpose of the concept as a whole?

Are the repairers able to grasp the purpose of the elements of the prototype?

To what extent are the Repairers able to post a repair request without external help?

What is the quality of the Repairer's posts; do they contain enough data to describe the part?

To what extent can Makers use the posts to model parts from them?

How does the communication between Makers and Repairers flow on the platform?

Method

Start by asking a small group of Repairers to post a part (that they want to reproduce) on the MakerMarket using the available tutorials and examples to guide them.

Wait for their responses, and help them on their way if they get stuck by communicating in a group chat or video calls outside of the platform. (an online focus group).

Analyse the posts they made and analyse how much data is missing and if they are clear to the Maker.

Next ask a small group of Makers to respond to a posts and to try to model it, and to ask questions to the repairer if necessary.

Observe the communication between the makers and repairers and analyse the end results.

Repeat the test at least twice in order to eliminate bugs that arise during the pilot test.

Timeline

April 6-10 Write test plan

April 13-17 Prepare prototypes

April 20-24 Execute tests

Deliverables

A visual card with the most important results that emerge from the test.

A list of recommendations about how to adjust the concept for the final design proposal.

A list of usability recommendations in order to redesign the final proposal.

Document other important insights that arise while doing the tests.

Materials

A functioning posting and communication system with:

- Ability to upload collages or upload multiple images (10+)
- Upload posts with long textual descriptions.
- Ability to upload PDF files and text documents
- Ability to upload and view 3D STL files.
- The ability to contact the participants outside of the system if necessary.

Tutorial for beginners to make posts with their available resources.

- Overall explanation of the concept
- Specific explanation of the task
- Example posts.

Adequate communication channels parallel to the platform.

- Whatsapp
- Email
- Jitsi video conferencing

External dependencies

Finding enough repairer participants with enough time, skills, tools and a part to scan.

Finding enough maker participants with sufficient CAD skills and time.

Results

The tests were executed in the period of 23-04-2020 until 03-05-2020.

In total 8 participants managed to upload an object on the website out of a total of 20 people that were approached.

These were all people with a certain affinity to repair and making, including the volunteers from Repair Café Delft, students, friends and family.

The participants were asked to post an object they deemed suitable for replicating with a 3D printer. They were also instructed to follow the tutorial on the website as a guide on how to do it.

Some responses came in very quickly and without help whereas others took longer to respond and needed extra guidance. Some participants were helped with the uploading process when something went wrong with the collage making.

Insight list

The responses from the participants were ordered into an insight list where the most important insights are listed together with the accompanying evidence or quotes from the respondents. The colours are an indication of the implications of the insight on the validity or usability of the concept.

The insight list was made based on a modified version of an observation log from Valsplat, a Dutch UX research firm: https://valsplat.nl/resources/observation-log

- positive: green,
- neutral: blue
- negative (low impact): yellow
- negative (medium impact): orange
- negative (high impact): red

User test insights		CyberCaliper Website online tests		20-04-2020		
General context	Specific context	[1]	Insight description	Quotes/evidence	Recommendations	Evidence links
3D viewer	3D viewer in comment section		People found the 3D viewer in the comment section useful.	*"Sorry, my sketch may be unclear.. The hole is better if its a through hole than a blind one. Is this still possible? Thanks. Great 3d pic"*	The 3D model viewer needs to be embedded and improved so that it can be made larger. It allows people without CAD software to view and inspect a part that makers draw for them.	https://cybercaliper.com/item.php?item=46
Attracting users	Barrier to entry		Barrier to entry still too high for some repairers.	*8 respondents in total out of approximately 20 that were asked.*	Make the sign up flow effortless and inspire the user with examples and tutorials.	
CAD modelling	Redesigning the part		When the maker gets no explicit instructions next to the images he doesn't know exactly what the repairer wants or how much room there is for creativity or redesign.	*"I made a simplified version which is easier for printing."*	This can be extra challenging and fun for makers, however sometimes clarity is needed. This could be done via commenting and guiding repairers to write a clear description of what they expect.	
Creating a collage	Creating a collage in an external tool		Creating a collage was a problem for some users	*"Het uploaden als PDF lukte wel maar ik zie de compilatie niet staan. Je kunt hem wel ophalen volgens mij."*	Enable the user to upload a selection of images and automatically create a collage for them.	
Describing an object	Description technique		Description techniques vary wildly among users.		Clearly guide users through the tutorial so that everyone understands the 'intended' description technique.	https://cybercaliper.com/item.php?item=46 https://cybercaliper.com/item.php?item=51
Measuring an object	Measuring technique		Most participants were very capable of using the caliper and taking all the necessary measurements.		This shows that the caliper is easy to use and people the right choice to go forward.	https://cybercaliper.com/item.php?item=52
Measuring an object	Measuring technique		Some participants perfectly followed the tutorial and created a collage with all the measurements.		This shows that the current tutorial works if participants can find it and when they are dedicated enough. Embedding it in the uploading workflow will help more users to learn how to do it.	https://cybercaliper.com/item.php?item=51 https://cybercaliper.com/item.php?item=45
Measuring an object	Measuring technique		Measuring techniques vary wildly among users.		Clearly guide users through the tutorial so that they understand the intended measuring technique.	
Measuring an object	Measuring technique		Incomplete measurements were observed.		Guide users and remind them that ALL the measurements are needed to create the part.	
Measuring an object	Caliper		Not every participant owns a vernier caliper.	*"I don't have a caliper, can I use Lego as a reference instead?" "You could place a ruler next to the object and take an image."*	Clearly state why calipers are important, but leave the option for people without a caliper to post something because sometimes accuracy is not needed. Make calipers available for sale or advise on where to buy them cheaply.	https://www.instructables.com/id/How-to-Make-a-Manual-3D-Scan-With-Calipers/#discuss
Measuring an object	Caliper		Almost no participants own a digital caliper.		State why digital calipers are better than vernier calipers for this application and sell them or advise on where to buy them.	
Measuring an object	Taking photos		Making photos of a caliper is a hassle without a setup.	*"Nice concept, but it would be wildly easier to simply put the phone in video mode. Let it run the entire time, and sound out (speak) the measurements as you make them. This will give the viewer both visual and audio confirmation of the dimensions."*	Further research should be done into hands free options such as triggering the shutter with sound or recording video with vocal measurements that are automatically interpreted.	https://www.instructables.com/id/How-to-Make-a-Manual-3D-Scan-With-Calipers/#discuss
Notifications	Upload and comment notifications		The users are not notified when a new comment is made on their post.		Send email notifications to the users with new comments or replies on their posts or comments.	
Notifications	Account verification		Users don't get an email verification which leaves them wondering if their account is successfully registered.		Send a verification email to new users.	
Notifications	Maker committed		When a maker decides to help someone he can't see if other makers are already working on it.		Give makers the option to send a 'commit' or 'I'm working on it' emoji.	
Part request	Feasibility of requests		Infeasible requests were done.	*"Deze ring zit bovenop de mantel van de kachel. Door de warmte is hij broos geworden en brokkelt af."*	Implement a filter that advises repairers on the printability of their request. This can eliminate infeasible requests before they are posted.	https://cybercaliper.com/item.php?item=45
Print finishing	Filing/sanding the final part		A print that was made through the system had to be filed before it fit into place.	*"I had to file the mounting square a bit because of printer tolerances, but the hood prop now fits very securely."*	Post processing is needed in almost all prints and therefore repairers need to be warned that that is the case. Also it can be made easier by providing them with the special hand tools such as miniature files and a deburring tool.	https://cybercaliper.com/item.php?item=48
Purpose of the post	Purpose other than 3D printing		A participant posted a repair with no intention of 3D printing it, it was just a call for advice on a repair.	*"I have this desk light holder that doesn't fit my desk because it is too thick, I can't physically modify my desk or the holder, what could I do?"*	This could bring extra traffic to the platform, however it may distract from the core goal of making 3D printing easier. These extra use cases need to be reconsidered.	https://cybercaliper.com/item.php?item=43
Uploading images	Uploading caliper images		The option of uploading 3 images is not sufficient.	*"I wanted to post one more pic, so here goes:"*	Create an upload button that accepts multiple images.	

Figure 53: Insight list from the user test

S. Creating the wireframes

The validation resulted in a number of recommendations and insights which were translated into a final design, this design is presented by creating wireframes and a wire flow of the envisioned website.

The goal of the wireframes was to go through the process from the perspective of the repairer and implement the findings from the validation. Finally presenting the envisioned design in a clear overview.

The UX workshop to create wireframes and wireflow was based on this article: https://uxdesign.cc/when-to-use-user-flows-guide-8b26ca9aa36a

Steps of the UX workshop to create wireframes

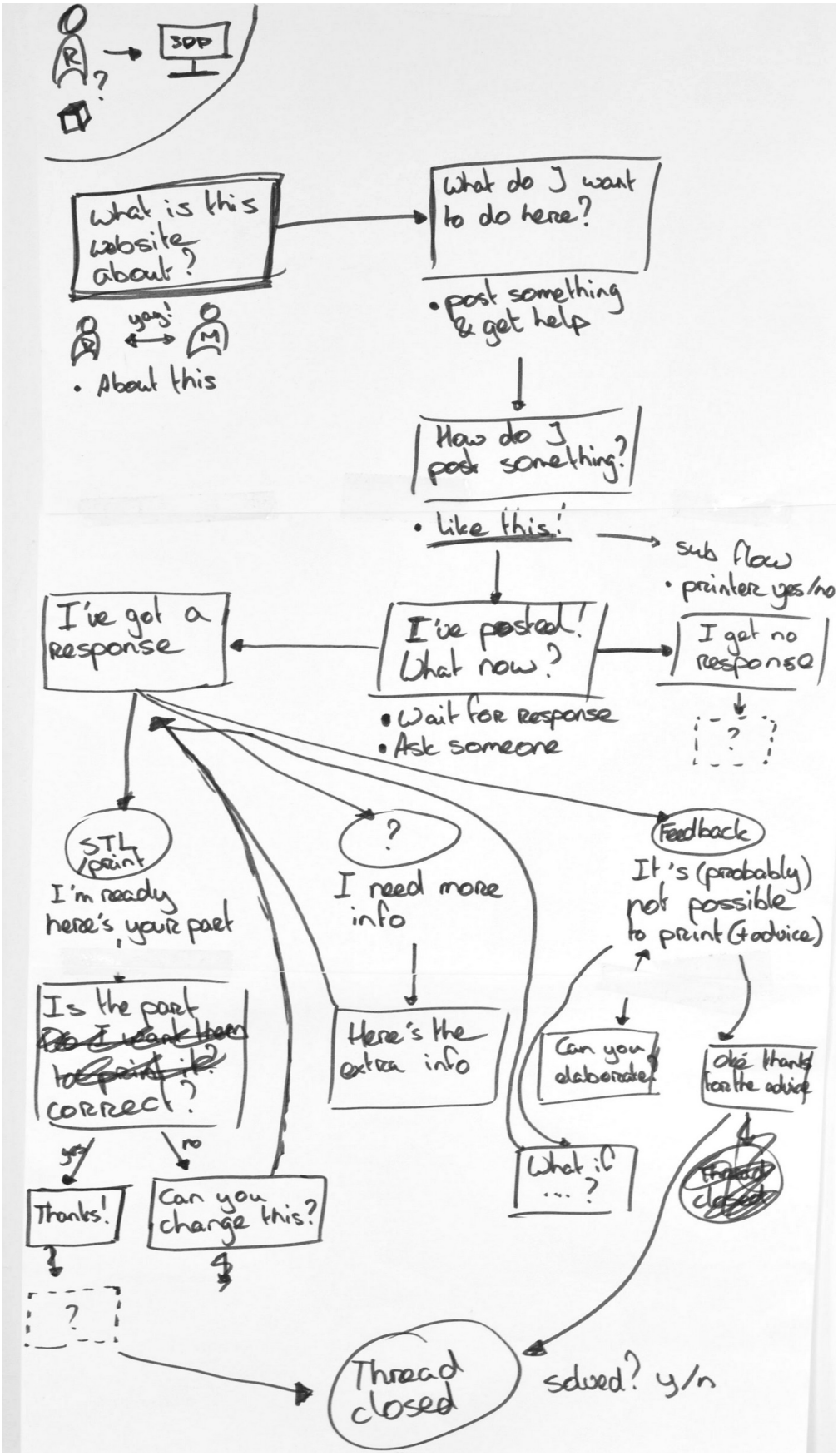
- Wrote down the user goals
- Mapped out the task flow of a repairer, with entering the website as a starting point
- Created low-fi paper wireframes of the 'post a repair'-flow
- Digitised those wireframes using Sketch (https://www.sketch.com/) and Form, a wireframe kit from InVision (https://www.invisionapp.com/inside-design/design-resources/free-wireframe-kit-form/)
- Made the wireframes into a wireflow

User goals

- As a repairer, I want to help people by repairing something for them. Therefore, I sometimes want to get help with 3D printable parts.
- As a maker, I am searching for fun and challenging projects to do and maybe help people and share my knowledge and skills in the meantime.

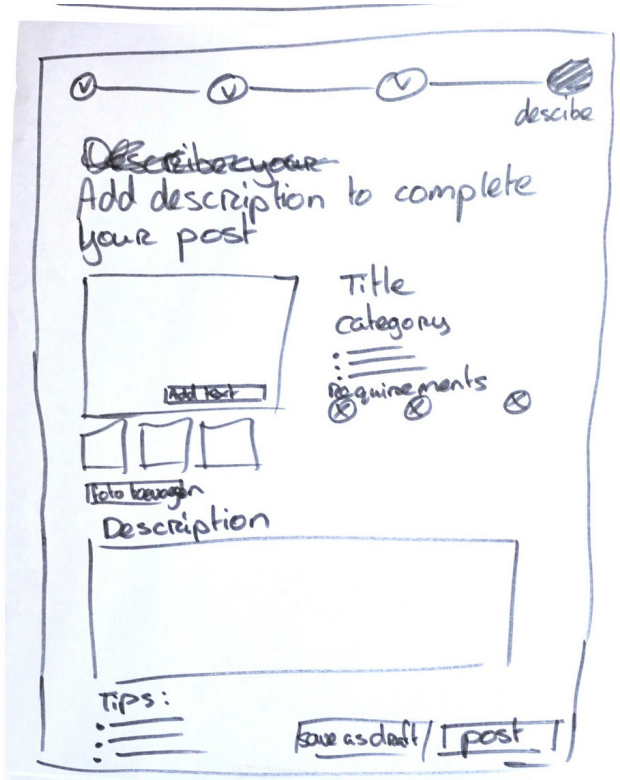
Figure 54: Creating the wireframes with UX researcher Maartje de Rond

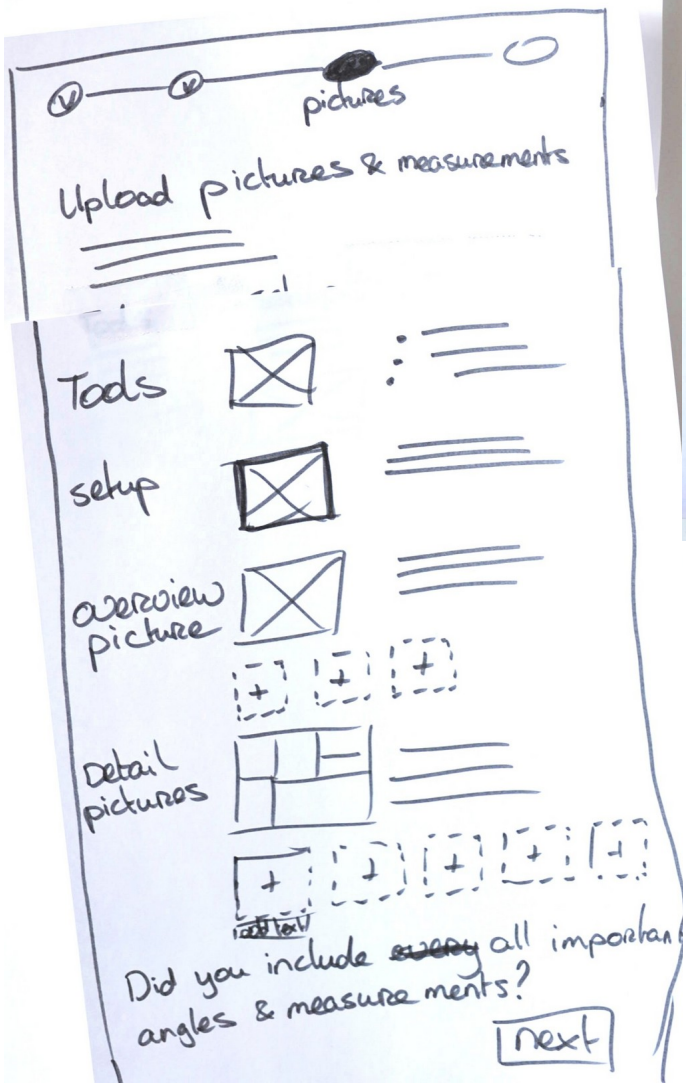
Mapping the task flow of a repairer



Paper wireframes


options
check
categorize
Product category
to help you best
Brand
Model serial nr. of product
part nr.
omschrijf in steekwoorden
ex.
previous
next

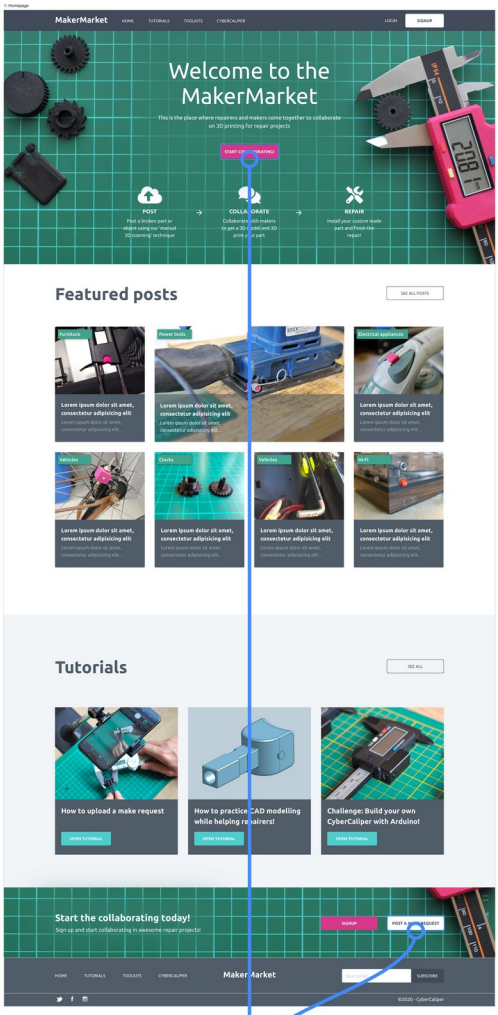

describe
Add description to complete your post
Title
category
requirements
Description
Tips:
save as draft
post


pictures
Upload pictures & measurements
Tools
setup
overview picture
Detail pictures
Did you include all important angles & measurements?
next


Yay! success!

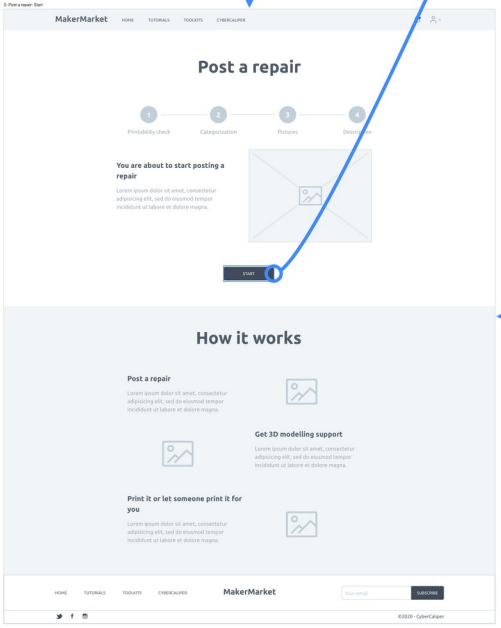
T. Wireflow

Homepage

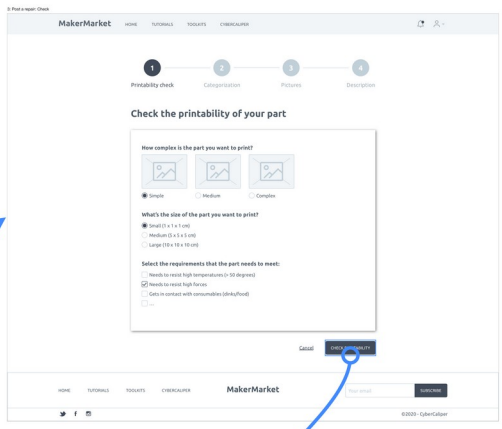


If user is logged in

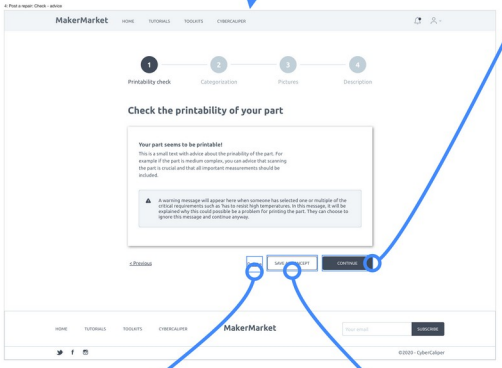
Introduction: Start a post



Step 1a: Printability check



Step 1b: Get printability advice



Are you sure that you want to delete your post?

- Yes, delete my post
- No, I want to continue posting
- No, save it as a concept

Are you sure you want to pause posting and save your post as a concept?

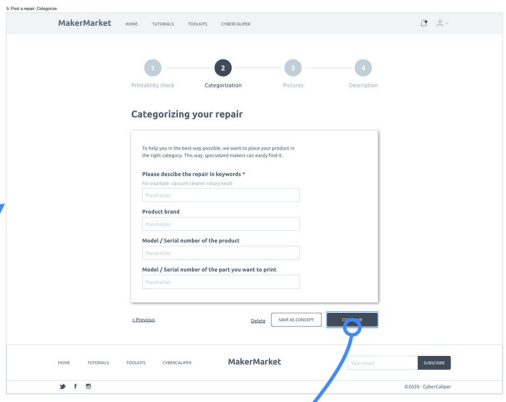
- Yes, save my post as a concept
- No, I want to continue posting

Go to profile page where you have an overview of your live and concept posts

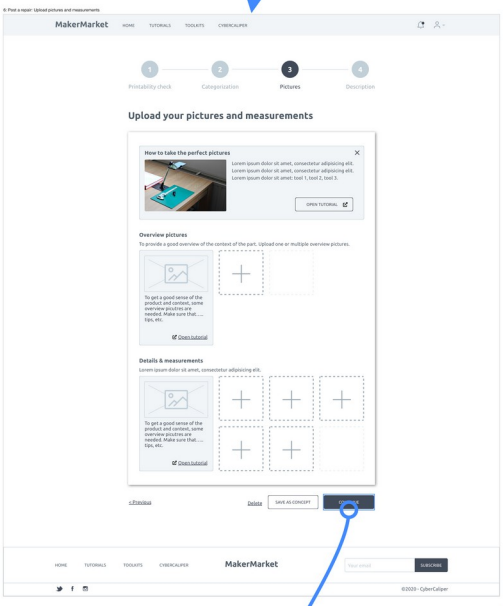
Wireflow

This wireflow illustrates the flow of a first user through the posting process.

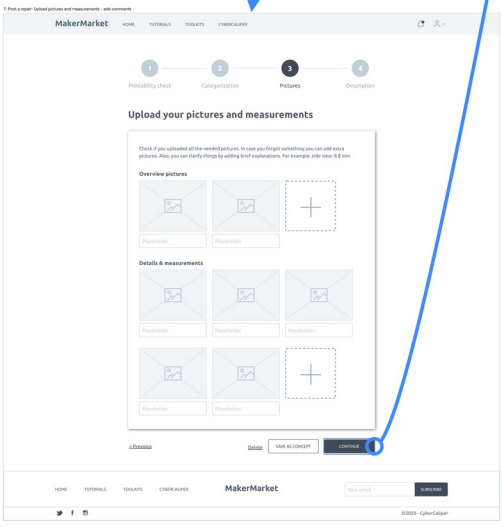
Step 2: Categorization



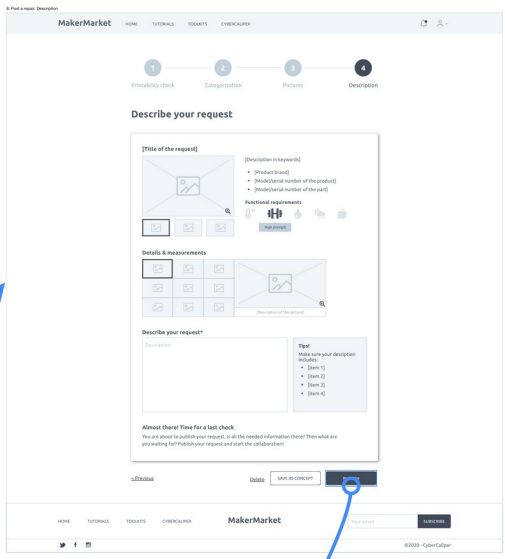
Step 3a: Upload pictures & measures



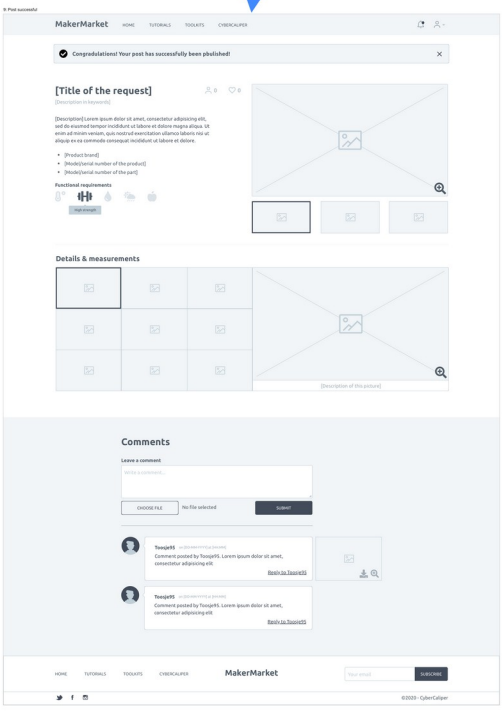
Step 3b: Check pictures & add comments



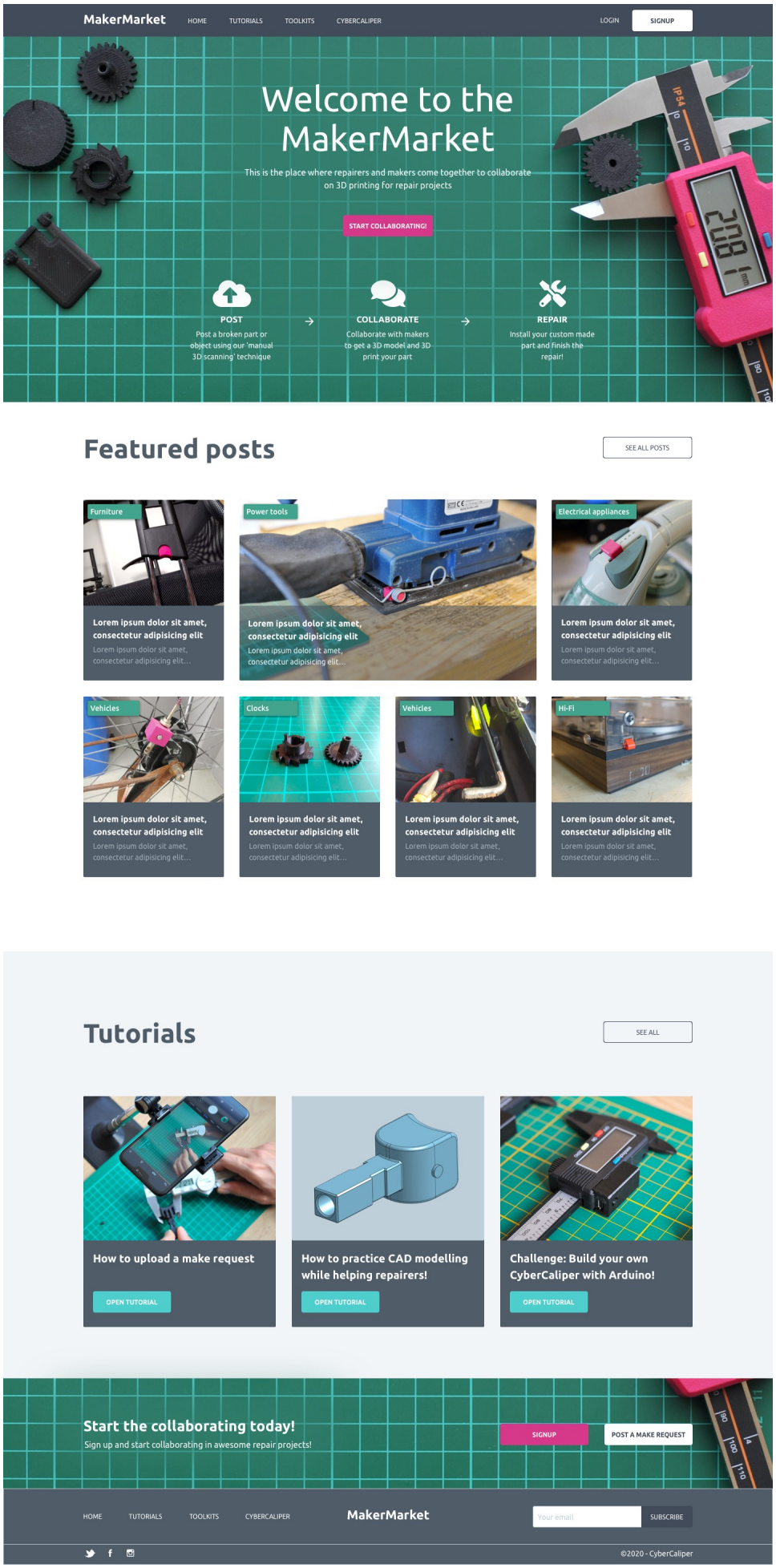
Step 4: Add description & final check



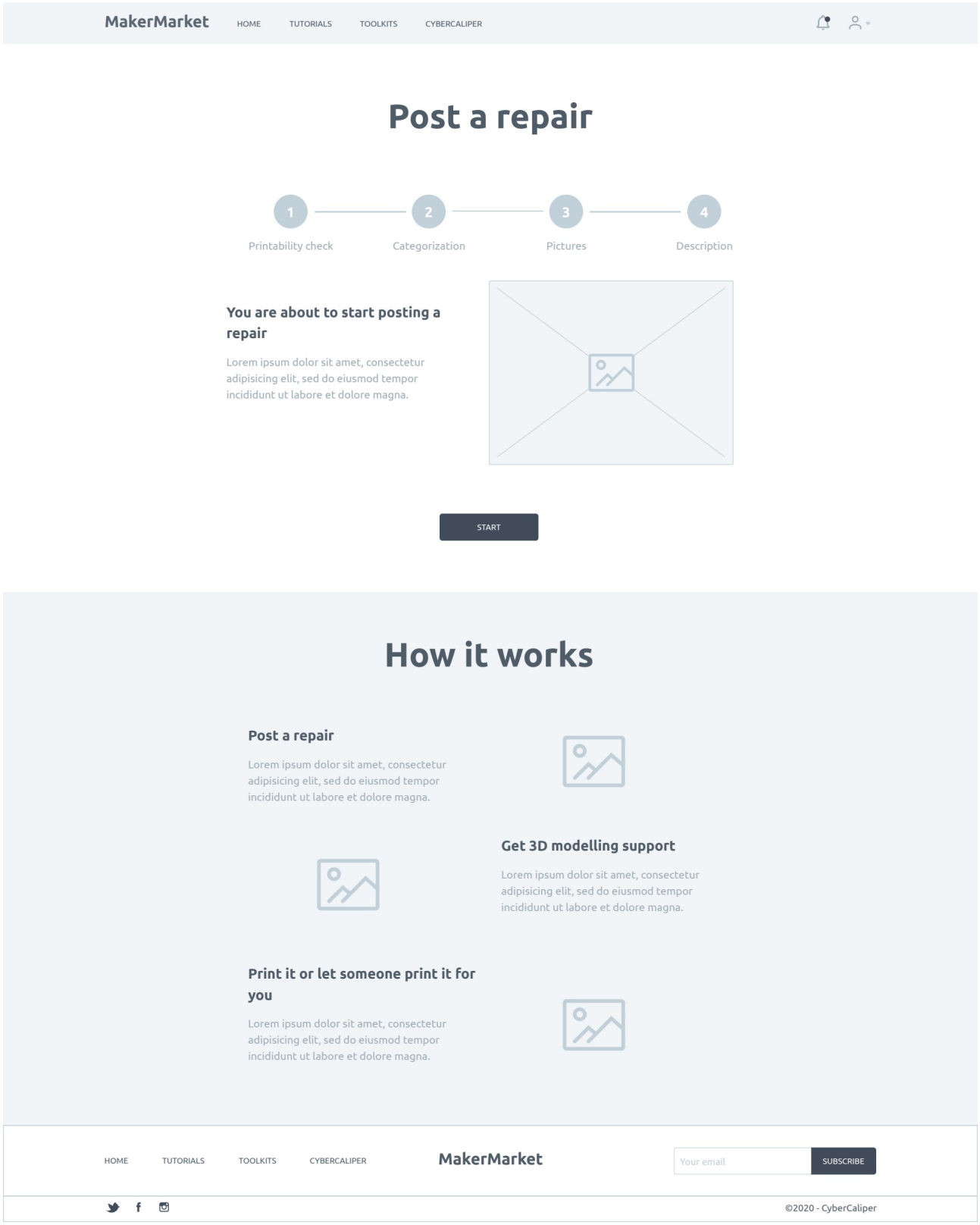
Request is posted!



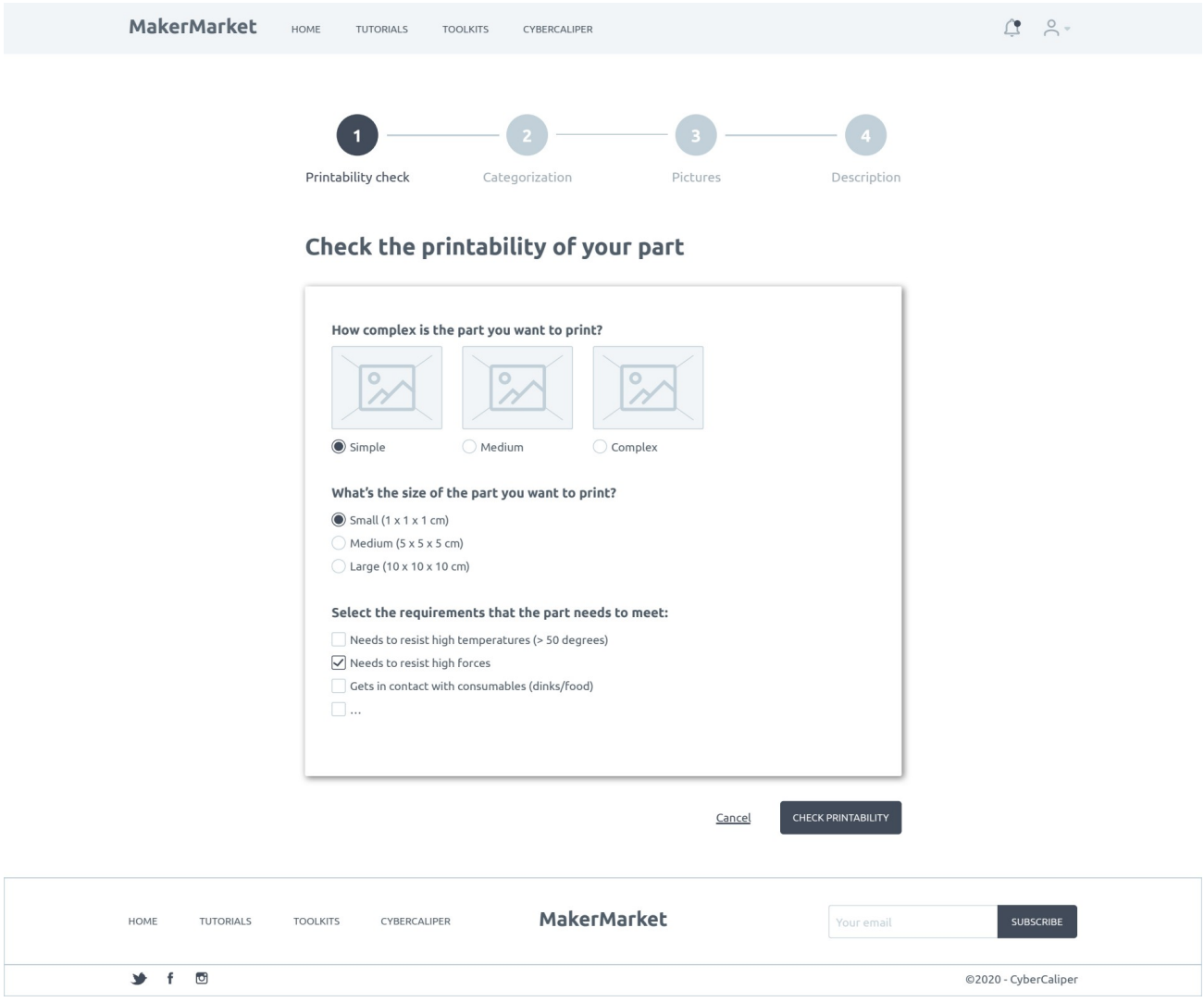
Homepage


MakerMarket
HOME
TUTORIALS
TOOLKITS
CYBERCALIPER
LOGIN
SIGNUP
Welcome to the MakerMarket
This is the place where repairers and makers come together to collaborate on 3D printing for repair projects
START COLLABORATING!
POST
Post a broken part or object using our 'manual 3D scanning' technique
COLLABORATE
Collaborate with makers to get a 3D model and 3D print your part
REPAIR
Install your custom made part and finish the repair!
Featured posts
SEE ALL POSTS
Furniture
Power tools
Electrical appliances
Vehicles
Clocks
Vehicles
Hi-Fi
Lorem ipsum dolor sit amet, consectetur adipisicing elit
Lorem ipsum dolor sit amet, consectetur adipisicing elit...
Tutorials
SEE ALL
How to upload a make request
OPEN TUTORIAL
How to practice CAD modelling while helping repairers!
OPEN TUTORIAL
Challenge: Build your own CyberCaliper with Arduino!
OPEN TUTORIAL
Start the collaborating today!
Sign up and start collaborating in awesome repair projects!
SIGNUP
POST A MAKE REQUEST
HOME
TUTORIALS
TOOLKITS
CYBERCALIPER
MakerMarket
Your email
SUBSCRIBE
©2020 - CyberCaliper

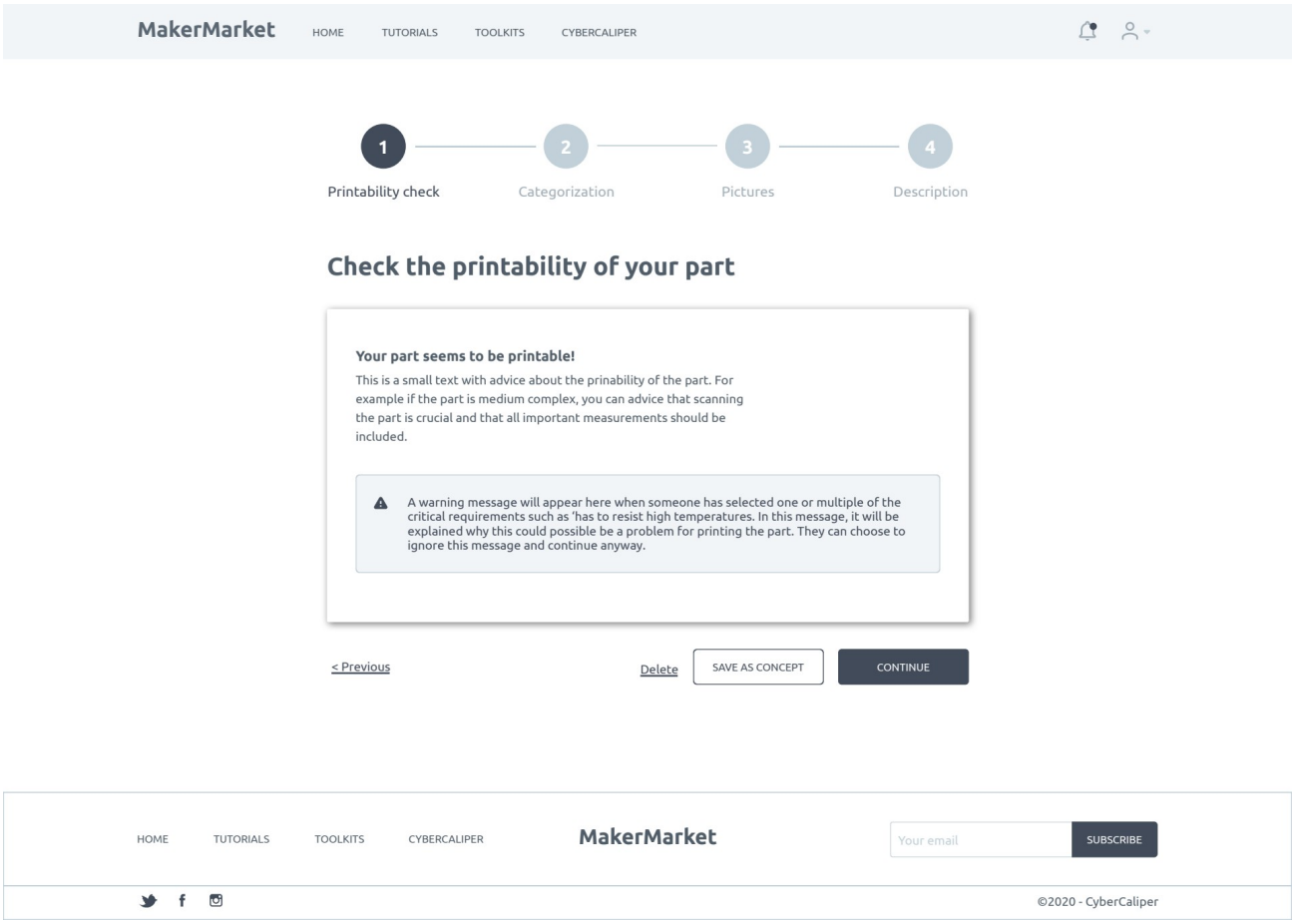
Introduction: Start a post



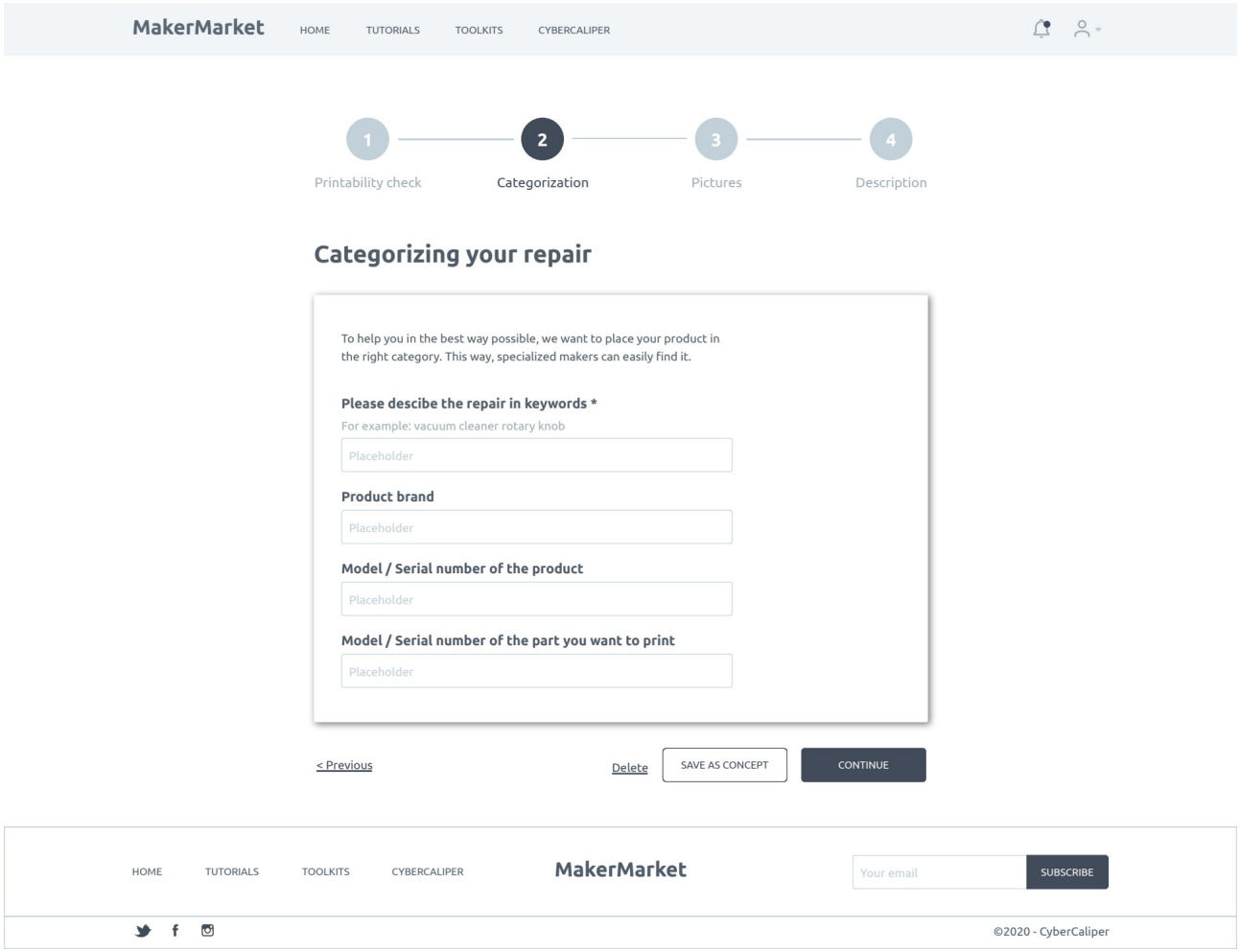
Step 1a. Printability check



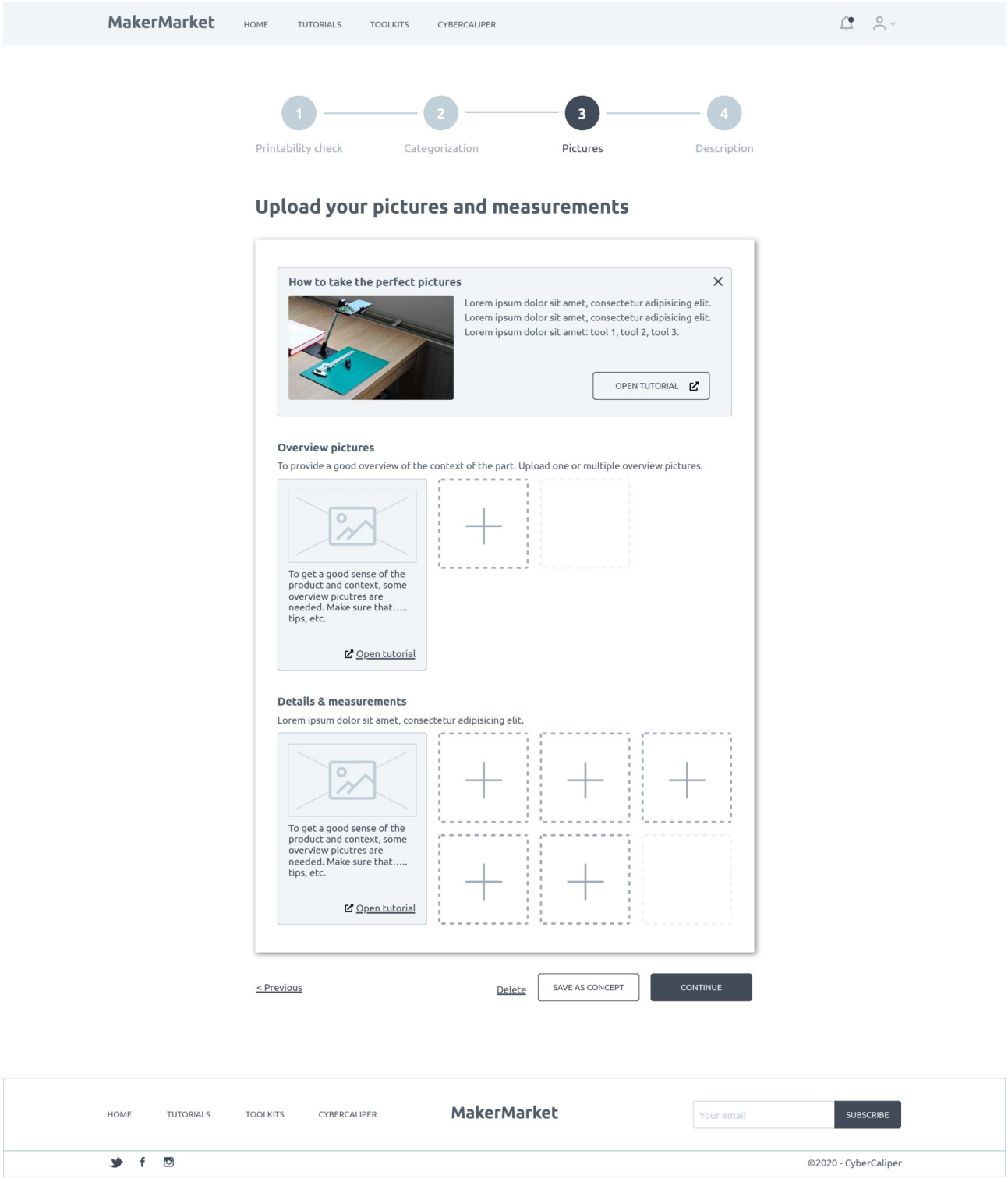
Step 1b. Printability advice



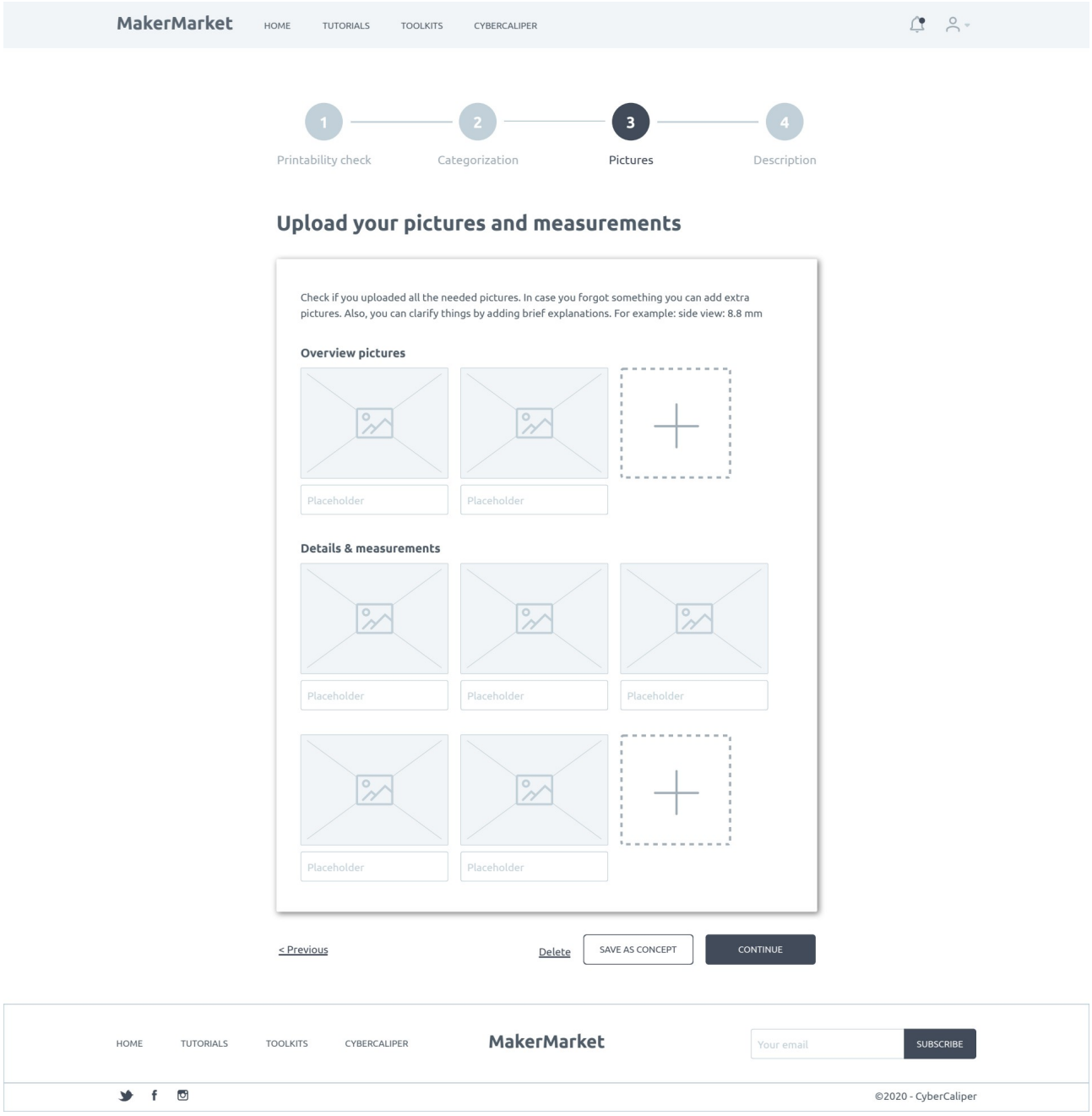
Step 2. Categorisation



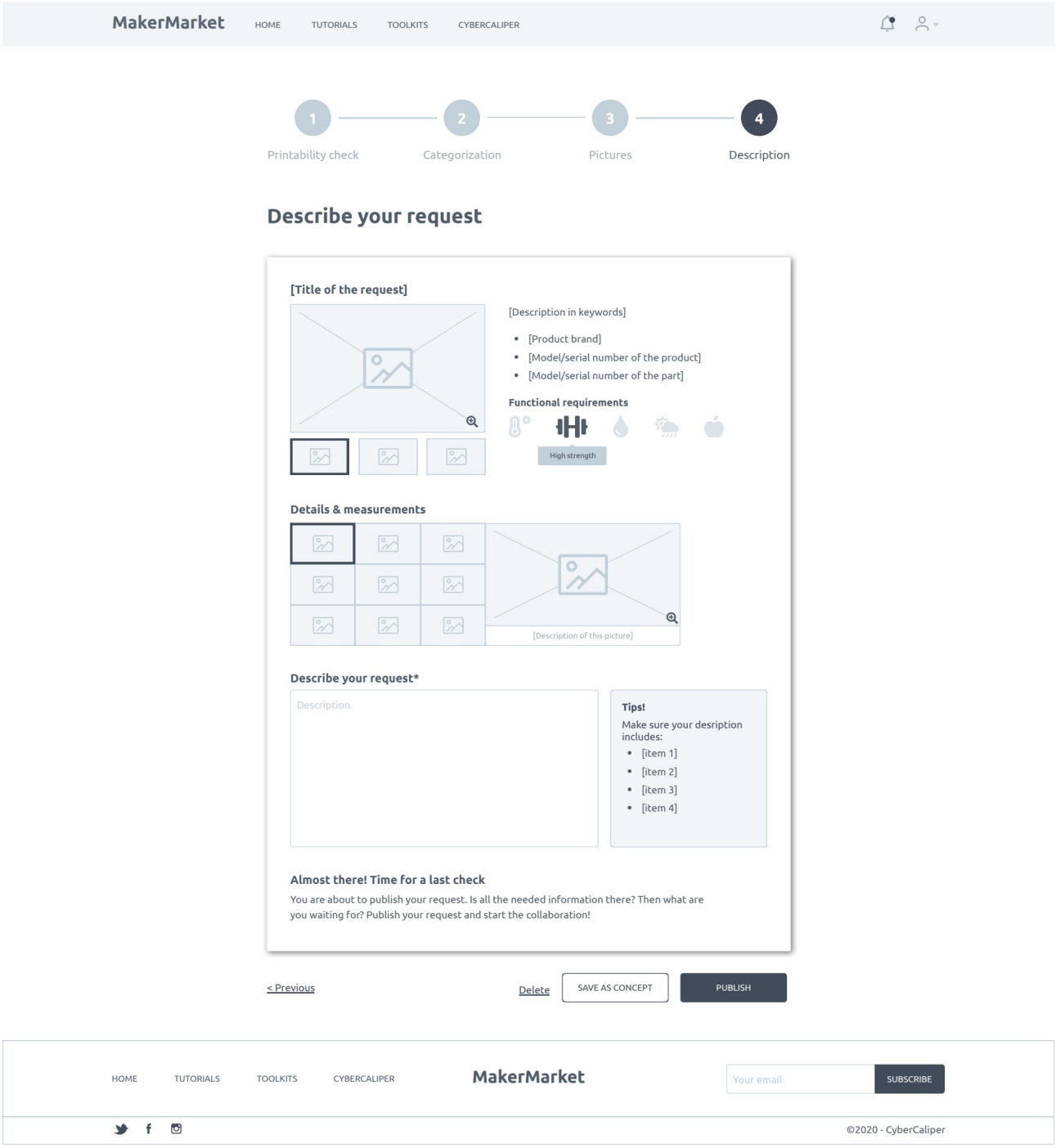
Step 3a. Upload pictures and measurements



Step 3b. Check pictures and add comments



Step 4. Add description and final check



Request is posted!