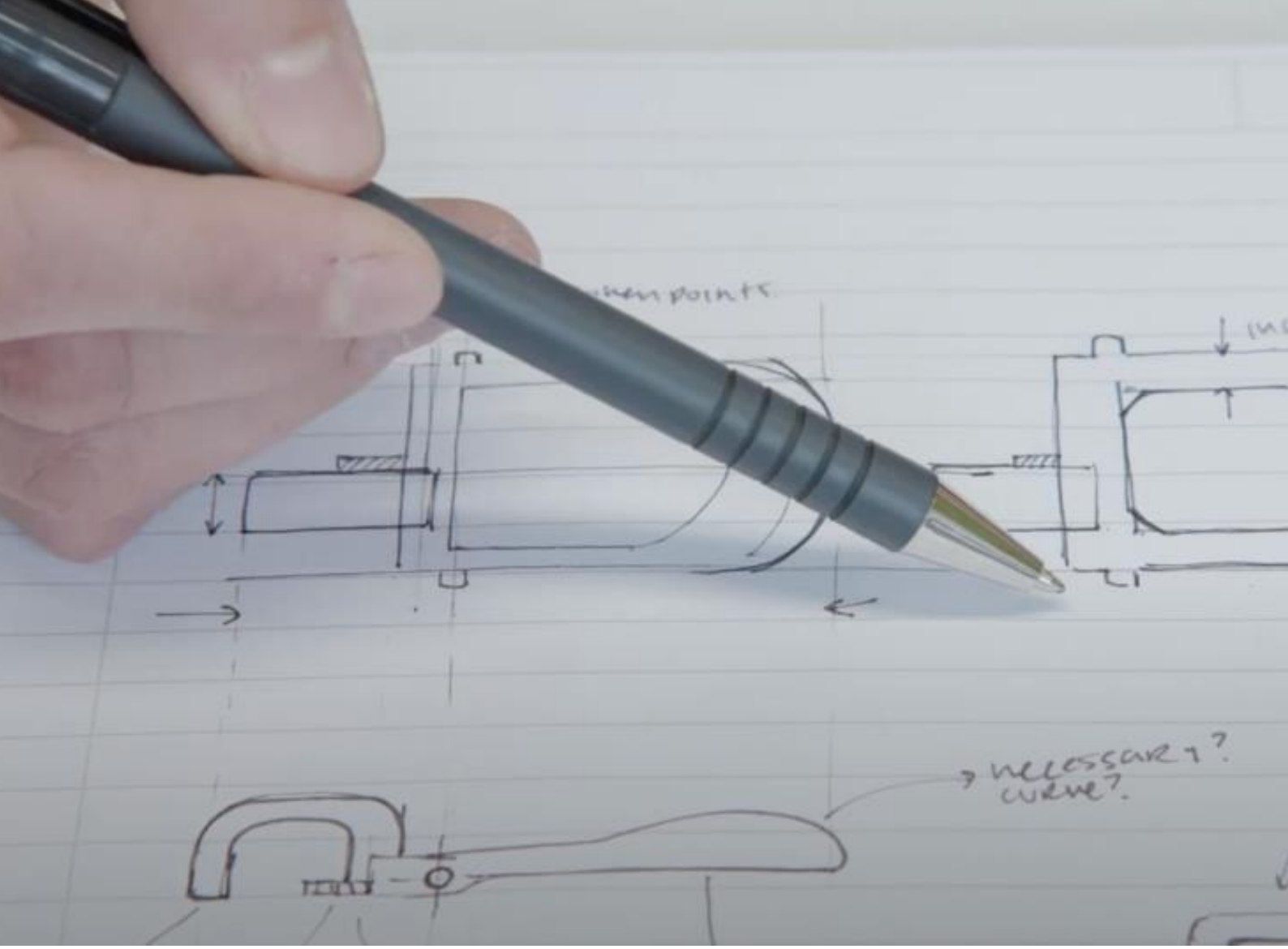

3D PRINTING FOR REPAIR WORKBOOK

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TU Delft

Interreg North-West Europe SHAREPAIR

3DP4R WORKBOOK

In this self-paced workbook, you will go through the 3D Printing for Repair process as shown in Figure 1. It consists out of five modules with videos and exercises. Make sure to watch the videos before making the exercises as the videos will explain the process.

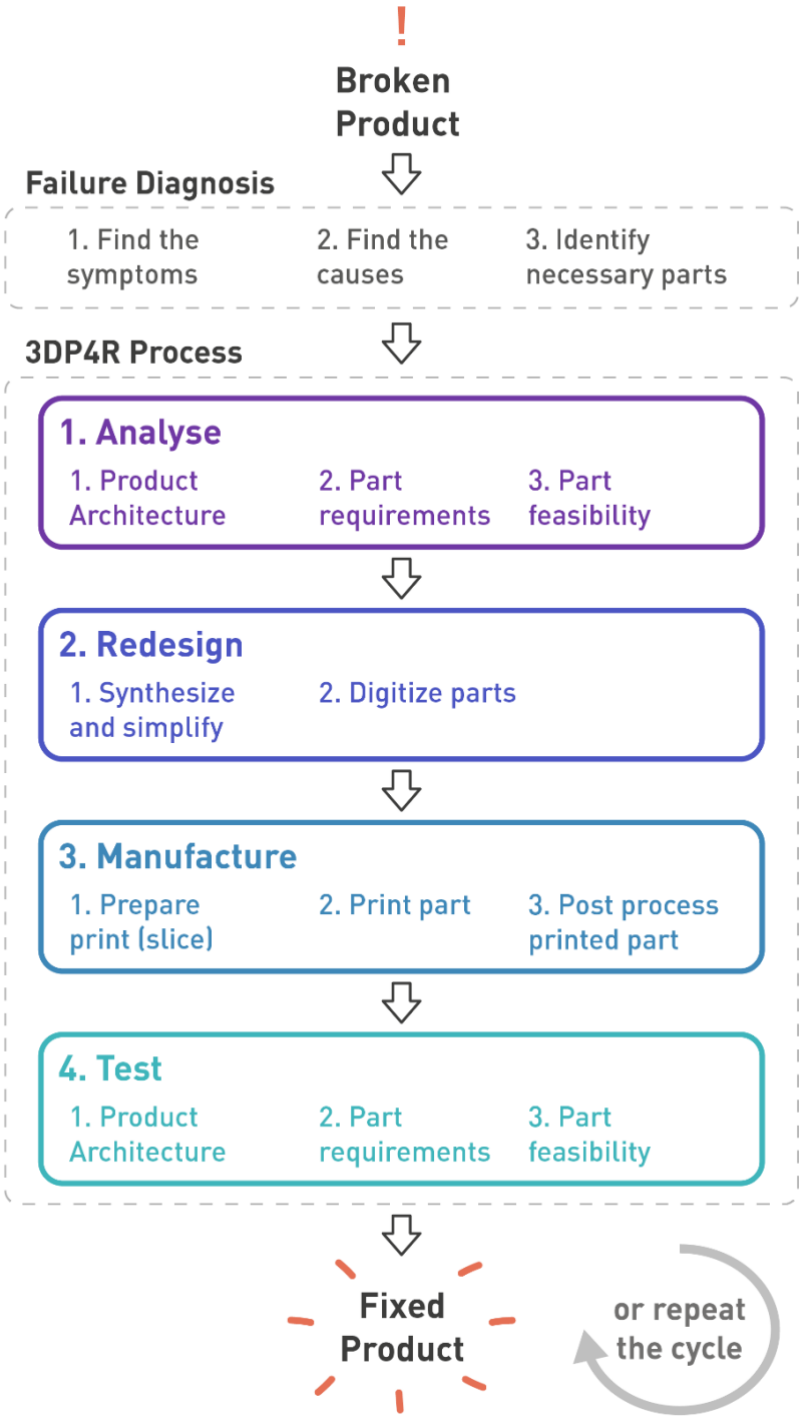

Figure 1 - 3DP4R process.

DISCLAIMER

A. This guide involves tinkering with commercially sold appliances. Doing so may void warranties and can be hazardous if not done with care and appropriate safety measures.

B. Every 3D printed “copy” you make could infringe on copyright or Intellectual property (IP) of the Original Equipment Manufacturer (OEM). Before you share your result to an open online database, be aware of possible infringements.

C. **Unplug all devices from power sources before disassembly**. Be aware of products that could contain heating elements or boiling water and let them cool down before any procedure.

D. Beware of the disassembly steps and keep a record to properly reassemble the product at the end of a repair process. A bad reassembly could cause accidents such as short circuits, fires, and leakage, among others.

E. 3D printed spare parts do not comply with the OEM’s quality standards and testing, and therefore are not guaranteed to function appropriately. Be especially careful with parts that need to withstand high forces, are spring-loaded, encounter electronics, need to withstand high temperatures, or contact water and/or food. Keep in mind that 3D printed parts are in general of lower quality than its original.

F. This guide is provided for information purposes only. The authors of this guide and any referenced sources are not responsible for anything done in relation to this guide and the collection of guidance videos. The reader/viewer should understand and accept that the processes described in this guide (and videos) and resulting 3D printed parts may pose a high risk of injury to the end user, as well as risk of injury to the individual repairing the device.

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INTRODUCTION

Before you go through the process in Figure 1, it is good to write down for yourself what product and part you are working on. This will help you to find information on the product, such as repair manuals. It is also good to double-check whether (3D printable) spare parts are already available online.

Video 1: Intro 3DP4R process - click here

After this video you will understand what 3D printing for Repair is. Also, you will be able to decide whether 3D printing could help you to repair your product.

Exercise 1: Product and part documentation

Fill in the table below for the product and part you are working on.

Tip: Don't forget to check if your needed part is already available for purchase or as a 3D model!

1.1 GENERAL INFORMATION

Product category *Example: headphone, bike light*	
Product brand *Example: Sony, Philips*	
Product model *Example: Senseo HD7820/60*	
Part name *Example: hinge, bracket, button*	

2.1 YOUR REPAIR CASE

Part completeness

Circle the part completeness type that applies to your part in .

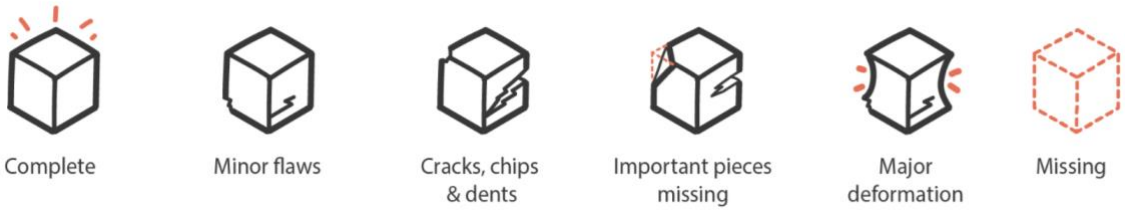


Figure 2 - Part completeness, based on Repair Using 3D printing by Thijs Beerkens [1].

Pictures of your product and part

Add pictures of your product and part below for future reference for yourself and others.

Insert pictures of your product

Insert pictures of your part

PHASE 1: ANALYSE

The analyse phase is the first phase of the 3D Printing for Repair process. To find what is needed to replace your broken part, it is helpful to first make an analysis of your part.

VIDEO 2: The analysis phase – click here

After this video, you will know how to identify the most important characteristics of your part to be able to make a 3D printable version of it. You will also be able to decide if your part is feasible for 3d printing.

Exercise 2: Analyse your part

You will analyse the product architecture, part configuration, and part feasibility of your repair case to find what the requirements are for your repair.

2.1 PRODUCT ARCHITECTURE

Part function

Describe what the part does in the product.

For example: "The mounting bracket holds the heater in place"

Tip: Take a look at how to define a part function using Functional Analysis [2]

Tolerance and fit

Circle the right assembly type and fit in Figure 3. The gap size is what you should keep in mind when modelling your part.

Tip: getting tight fits right most likely requires experimentation and/or post processing.

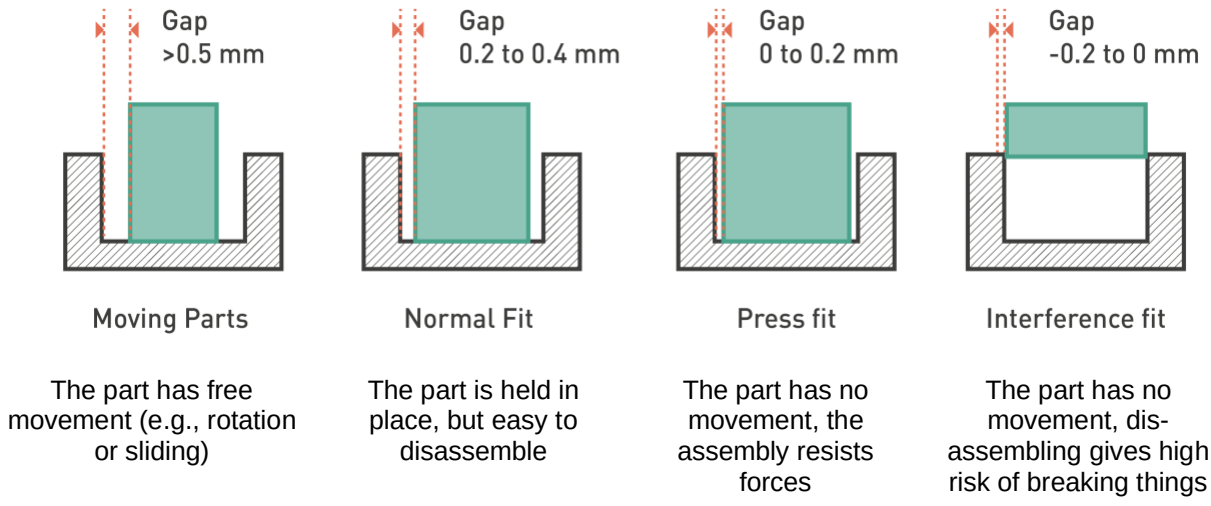


Figure 3 - Types of fit.

Part reference points

Describe where and how the part meets other parts in the product. For this, you can use the part reference types shown in Figure 4.

For example: "The mounting bracket connects to the heater via a form fit with the same contours"

Tip: look at all the parts that you interacted with during the disassembly.

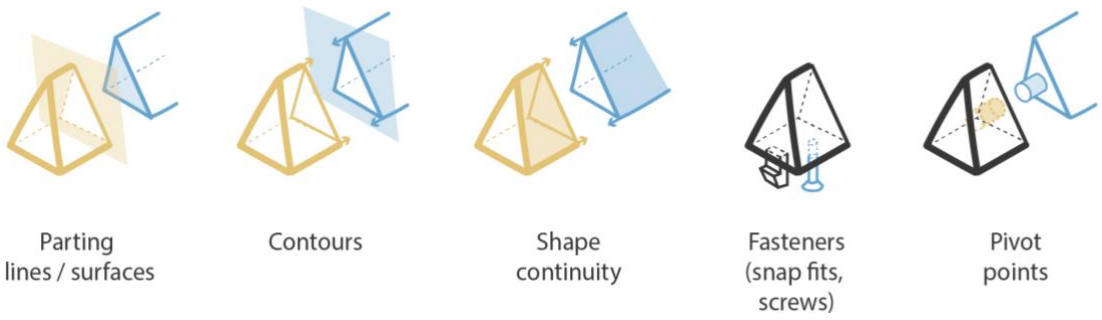


Figure 4 - Part relations, based on Repair Using 3D printing by Thijs Beerkens [1].

Insert pictures of important part reference points

2.2 PART CONFIGURATION

Geometry class

Circle the geometry class that best fits with your part in Figure 5.

Figure 5 - Geometry class, based on Repair Using 3D printing by Thijs Beerkens [1].

Complexity

Circle the complexity type that best fits with your part in Figure 6.

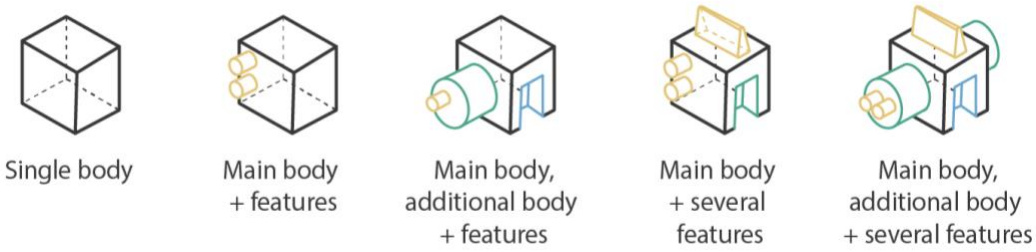
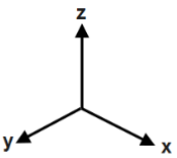


Figure 6 - Part complexity type, based on Repair Using 3D printing by Thijs Beerkens [1].

General dimensions

Sketch the general dimensions of your part.



Part features

Describe what features the part has.

For example: ridges, drainage holes, non-slip texture…
Tip: if you take a basic shape, what shapes would you have to add to make your part?

Insert pictures of part features

Original manufacturing method & material

Describe (or make an educated guess) on what manufacturing methods and materials were used to create the part, and why. This will help you to select a replacement material later on.

For example: “The part is most likely made out of PP because it needs to be food safe.”

Tip: you can try to see if there are any recycling symbols on plastic parts and look those up.

Part requirements

Indicate which requirements are applicable to your part, and note down relevant values or details.

For example: High temperatures: 100 °C (boiling water)

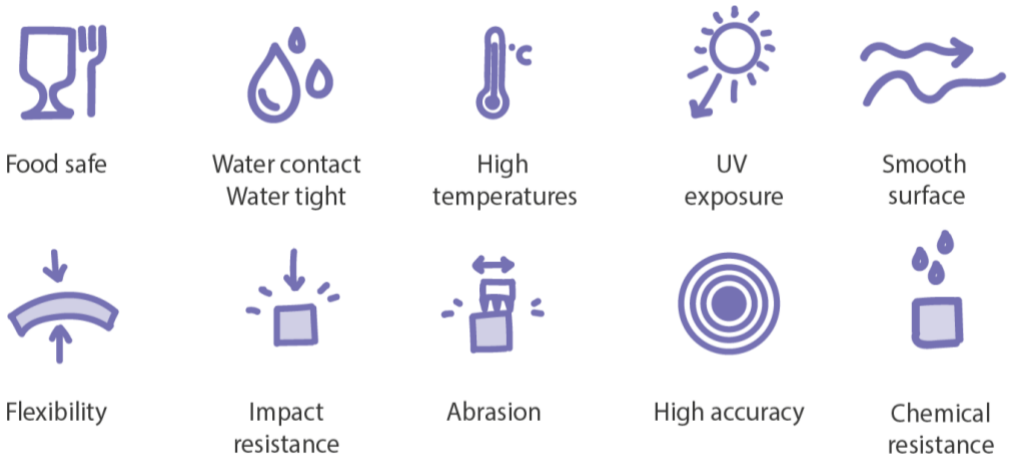


Figure 7 - Part requirements, based on Repair Using 3D printing by Thijs Beerkens [1].

	Not applicable		Somewhat applicable		Very applicable	Relevant values
Food safe	☐	☐	☐	☐	☐	
Water contact/water tight	☐	☐	☐	☐	☐	
High temperatures	☐	☐	☐	☐	☐	
UV exposure	☐	☐	☐	☐	☐	
Smooth surface	☐	☐	☐	☐	☐	
Flexibility	☐	☐	☐	☐	☐	
Impact resistance	☐	☐	☐	☐	☐	
Abrasion	☐	☐	☐	☐	☐	
High accuracy/detail	☐	☐	☐	☐	☐	
Chemical resistance	☐	☐	☐	☐	☐	

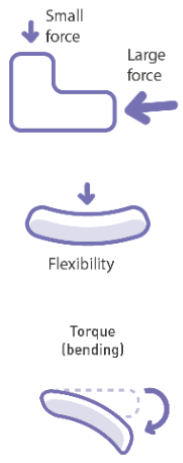
Force distributions

Identify and map the forces applied to your part.

For example: see the forces drawn in the example on the right side.

Tip: think about how you push/pull/bend/flex the product when you use it or (dis)assemble it

Insert a picture or sketch of your part and map the applied forces



Essential elements

Look back at part function, reference points, features, requirements, etc. Select the part features are **essential** for the part to function and describe these below (or add a picture).

For example: pivot points, snap fits, drainage holes, non-slip textures…

Tip: if you doubt if something is essential or not, try to think how the product would work without it.

	Indicate the essential elements in your part

2.3 CONCLUSION PHASE 1: PART FEASIBILITY

Indicate whether you agree with the statement below.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think this part is feasible for 3D printing	☐	☐	☐	☐	☐

What are the most important things that you want to consider in the next stage?

For example: important elements, things you can simplify

PHASE 2: (RE)DESIGN

The (re)design phase is the second phase of the 3D Printing for Repair process. A direct copy of the original part will almost never work. Therefore, you will have to redesign your part to fit with the functional and manufacturing requirements.

Video 3: (Re)design phase - click here

After this video, you will understand what the basic differences between injection moulding and 3D printing are. Also, you will know how to design your part for 3D printing.

Exercise 3: Redesign your part

You will think of possible solutions for 3D printing challenges in your part, and ideate a new and simplified design that is 3D printable.

3.1 RETHINK

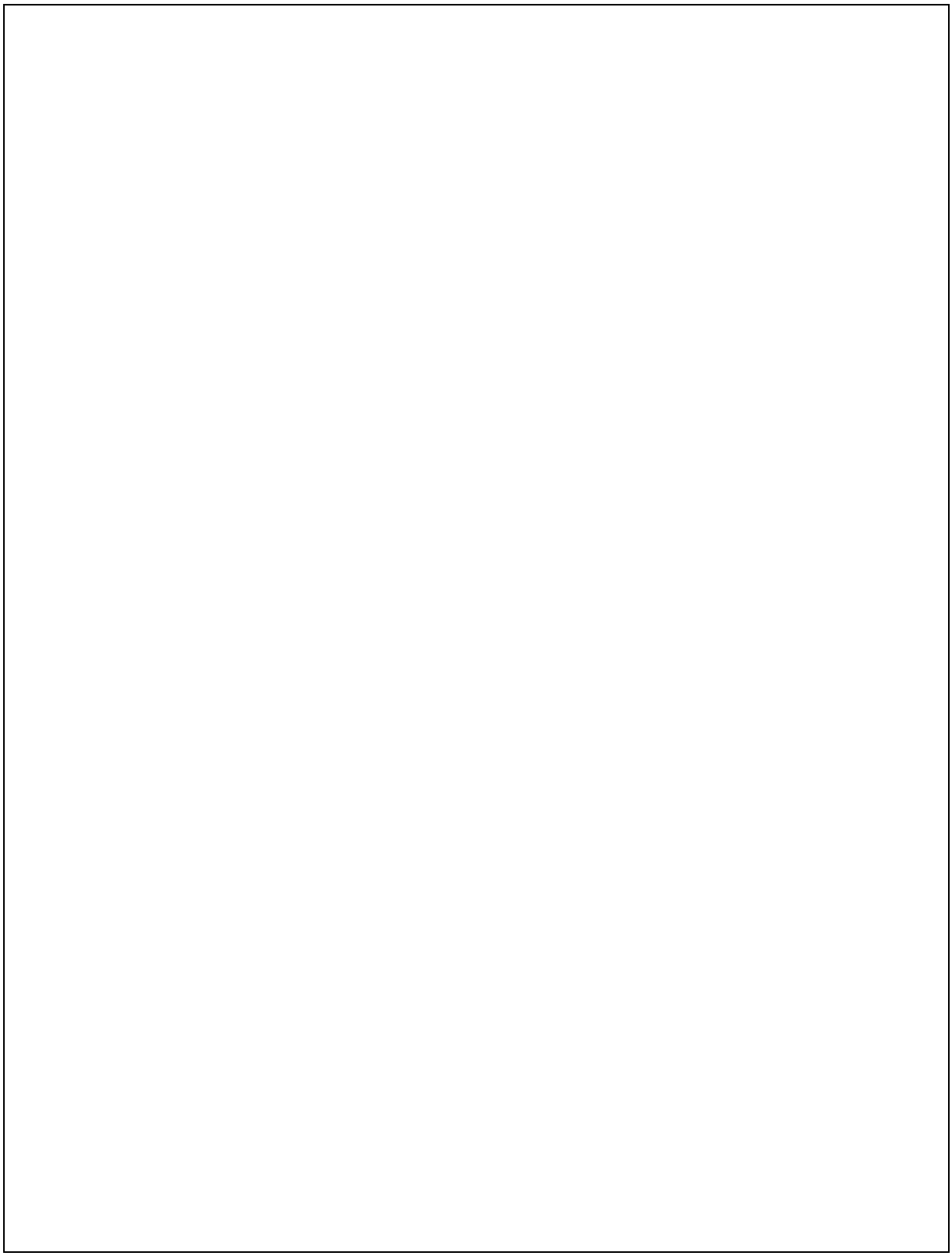
Take a look back at your part reference points, essential elements and part requirements and look for things that might be a challenge when 3D printing the original part. Try to find at least 3 challenges, and try to think of solutions for these challenges.

Challenge Describe what could be a challenge when 3D printing the original part	**Possible solutions** Think of how you change this part aspect to make it easier to 3D print.
Example: "This part has a large overhang, which is difficult to 3D print"	Example: "I can adjust the overhang angle, I can use support, ..."

3.2 IDEATE AND SIMPLIFY

Sketch out how you could redesign the original part and indicate important measurements. Keep the problems and possible solutions of the previous exercise in mind, and don't forget to simplify where possible.

Tip: this step might feel redundant, but it will make the modelling process easier and quicker!



Video 4: Digitizing - click here

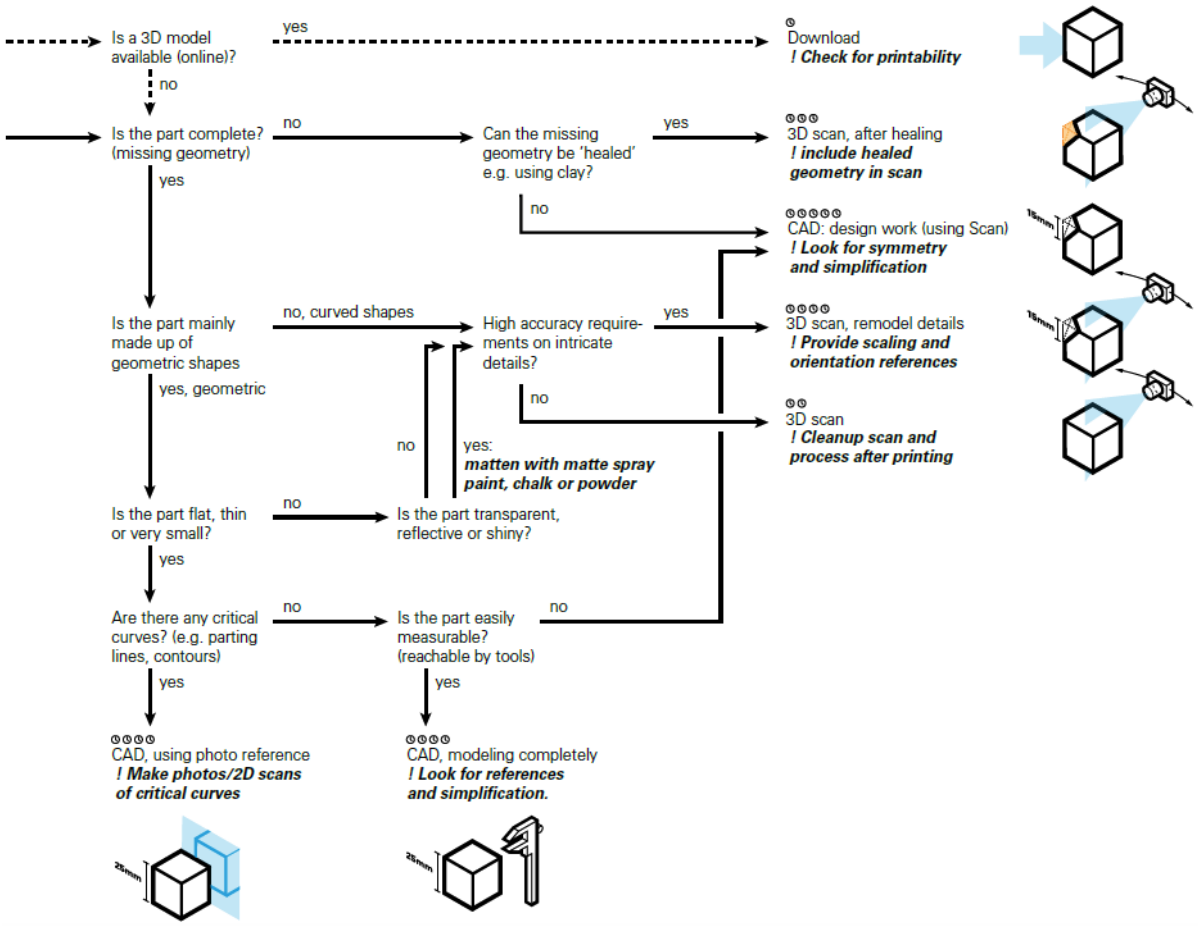
After this video you will understand how to go from a physical to a digital design. Also, you will know what methods and tools you can use to digitize the geometry of your part.

Exercise 4: Digitizing your part

In this exercise you will decide which digitizing approach you will take.

4.1 DIGITIZING APPROACH

Go through the flowchart below, and note the recommended approach.



Recommended approach

If you are unfamiliar with the recommended approach, read up on it and decide if it suits your experience level and part shape. You can find more information on the recommended approaches in the 3D printing for repair guide!

Video 5: CAD modelling - click here

After this video you will understand what is 3D modelling is. Also, you will know more about the basics on how to build your part in 3D modelling software.

Exercise 5: Model your part

In this exercise you will create the 3D model for your part in the CAD modelling software of your choice.

5.1 MAKE YOUR MODEL

Design your part in CAD modelling software and put a picture down below for future reference.

Tip: Use the 'Key design considerations for 3D printing' from 3DHubs here. [3]

Insert pictures of your final CAD model

5.2 PARTIAL PRINT (OPTIONAL)

Sometimes, it can be a good idea to print a tricky section of your part separately. This can help you to determine whether the part will print successfully, and to double-check things such as fit and performance. State below whether you want to make use of partial prints, and if so, what you want to print and test.

5.3 MODELING CHECKLIST

Tick off the points on this checklist. This will help you to create a better CAD model.

- ☐ I have considered the difference between the original manufacturing method and 3D printing
- ☐ I looked at the 'Key design considerations for 3D printing'
- ☐ I have recreated all the essential elements in my part
- ☐ I have simplified the non-essential elements in my part
- ☐ I have considered the printing direction of my part elements
- ☐ I have used the right tolerances to get the right fit
- ☐ I have considered all the performance requirements in my part design
- ☐ I have checked if the measurements and scale of my part are correct
- ☐ I have reinforced weak sections of the part if needed
- ☐ I have checked that my model is a solid and not separate surfaces

5.4 CONCLUSION PHASE 2: PART REDESIGN

Indicate whether you agree with the statements below.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
My redesigned part is suitable for 3D printing	☐	☐	☐	☐	☐
I think it was easy to redesign my part for 3D printing	☐	☐	☐	☐	☐
I understand why you need to redesign the part for 3D printing.	☐	☐	☐	☐	☐

PHASE 3: MANUFACTURE

The manufacture phase is the third phase of the 3D Printing for Repair process. It is important to understand how the manufacturing process influences the previous two phases. To get a part that meets the part requirements found in the analysis phase, it might be necessary to move back and forth between manufacture and redesign.

Video 6: From Redesign to Manufacturing - click here

After this video, you will understand how the 3D printing process works. You will also know what is important when you design your part for 3D printing.

Exercise 6: Manufacture your part

In these exercises you will 3D print the final design of your part. Try to keep in mind how the manufacturing decisions will influence the part performance.

6.1 SELECT MATERIAL

Look at the material comparison table in Figure 8, and write down what material would best fit your part. If needed, take a look back at the part requirements you wrote down in Exercise 2.

Material choice

Material	1. Aesthetics		2. Strength and wear				4. Operating environment			6. Post. pros.	Cost	Printing difficulty
	1.a Aesthetic quality	1.b Colors	2.b Elasticity	2.b Strength	2.b Impact resistance	2.c Wear resistance	4.a Moisture sensitiveness	4.b Chemicals resistance	4.c Temperature resistance	6.b Workability		
PLA											$$	
Tough PLA											$$	
ABS							Store in Polibox				$$$	
Nylon							Store in Polibox				$$$	
TPU 95A							Store in Polibox				$$$$	
PC											$$$	
PP							Store in Polibox				$$$$	
Recycled PLA											$	
Recycled ABS							Store in Polibox				$	
Recycled PET							Possibly store in Polibox				$$	

Figure 8 - Filament material selection guidance. Used with approval of F. DeFazio.
(You can find a larger version in the 3D printing for Repair guide)

6.2 SLICE YOUR PART

Export your CAD file as a .STL file and load it into your slicer software (Cura is the most common slicer software, but there are also other alternatives out there). Before printing your part, you will first need to determine the printing orientation and printing settings.

Printing orientation

First, you need to decide what the ideal printing orientation of your part is. Keep in mind that the printing orientation influences part strength, as well as printing time and material use.

Insert a picture of/sketch the printing orientation of your part in your slicer software

Printing settings

Fill in the most important settings here:

Print accuracy (layer height) *Example: Standard – 0.15 mm*	
Shell thickness *Example: 3 layers/*	
Infill type & percentage *Example: Cubic, 15% infill*	
Support *Example: yes, standard support*	
Build plate adhesion *Example: brim*	
Material specific settings *Example: nozzle/bed temperature*	

6.3 PRINT & POST-PROCESS

Slice your part, upload your GCODE in the 3D printer, and print it/have it printed. Don't forget to check the first few layers to see if the print is sticking to the build plate.

The next step is post-processing your part, such as removing support or possibly gluing sections together. Put your pictures below, and write down how the post-processing went.

Important: don't forget to weigh your part before you move any material or support! You will need this data in exercise 7.2.

BEFORE	***AFTER***
Insert a picture of your part before post-processing	*Insert a picture of your part after post-processing*

Write down how the post-processing went, and if you would change anything next time to make the process easier.

6.4 CONCLUSION PHASE 3: PART MANUFACTURING

Indicate whether you agree with the statements below.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
It was easy to find the right printing settings	☐	☐	☐	☐	☐
I am confident my 3D printed part will work	☐	☐	☐	☐	☐

PHASE 4: TEST

The test phase is the fourth phase of the 3D printing for Repair process. It will help you to determine whether your part meets the requirements of the Analysis phase, or whether further improvement is needed.

Video 7: Testing phase - click here

After this video, you will understand why testing is important. You will also know what you can test in your part and how you can do this.

Exercise 7: Test your part

In this exercise, you will test the printing quality and performance of your part. Before you start testing, it is good to make a test plan. In this test plan you write down what you want to test in your part and how you will do this. You will then conduct these tests to see whether the part was printed successfully and whether it performs correctly.

7.1 PRINT QUALITY – TEST PLAN

To check if the part has been printed successfully, you can use the tests as described in the guide. Use the checklist down below to prepare for these tests.

A. Visual test

- ☐ I have an idea of what surface finish I need (smooth/rough/…)
- ☐ I have an idea of what common 3D printer faults look like

You can find common 3D printer faults in the Print Quality Troubleshooting Guide by Simplify3D [4].

B. Dimensional test

- ☐ I have written down the values of the important dimensions I want to test (you can directly note them down in the table in Exercise 7.2).
- ☐ I have arranged measuring tools such as calipers.

C. Weight test

- ☐ I have looked up the estimated part weight in Cura.
- ☐ I have arranged a (kitchen) scale to weigh my printed part.

7.2 PRINT QUALITY – RESULTS

Note down the results of your tests.

A. Visual test

☐ The part has the required surface finish (after post-processing).

☐ There are no printer defaults that affect part performance (after post-processing).

Visual test outcome

☐ The part has the **right surface finish** and **no 3D printer defaults**, so the test is **successful**

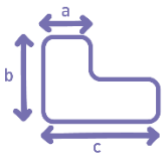
☐ The part has the **wrong surface finish** and/or **3D printer defaults**, so the test is **unsuccessful**

B. Dimensional test

Insert a picture in which you indicate the measurements you are comparing. Then note down the values for these measurements in the original part, CAD model, and printed part.

Tip: you can check your general part dimensions in Exercise 2.2.

Insert a picture of your part and indicate which measurements you are testing



Measurement	a	b	c	d	e	f
Original part						
CAD model						
Printed part						

Dimensional test outcome

☐ The part has the **right measurements**, so the test is **successful**

☐ The part has the **wrong measurements**, so the test is **unsuccessful**

C. Weight test

Compare the estimated weight with the actual weight. If your difference is larger than 10%, it is recommended to check your printer and maybe reprint your part.

If you already removed your support, don't worry, you can still do this test. To get a better estimate, you can look up the estimated weight in Cura by slicing the part again without support.

Estimated weight part in Cura *Example: 9 g with support*	
Actual weight printed part *Example: 8.5 g with support*	
Difference *Example: 0.5 g difference = 5.5%*	

West outcome

☐ The difference is **smaller than** 10 %, so the test is **successful**

☐ The difference is **larger than** 10 %, so the test is **unsuccessful**

7.3 PART PERFORMANCE – TEST PLAN

Take a look back at your part requirements in Exercise 2.2. Then, decide how you will test these requirements, and which result they should achieve in order to be considered successful. Keep in mind that you can also test parts separately before you install them in the product.

Measurement & value Describe what requirement you want to measure in your part, and what minimum/maximum value is needed to succeed	**Test method** Describe what method you will use to measure your part. Try to be as specific as possible!	**Tools** Describe what you learned: does your part meet the requirements?
Example: "Temperature resistance, at least 100 °C for 30 minutes."	*Example: "Submerge the part in a pot of boiling water and let it sit for 30 minutes."*	*Example: "water cooker or stove, thermometer, pan, timer."*

7.4 PART PERFORMANCE – RESULTS

Take a look back at your part requirements in Exercise 2.2. Then, decide how you will test these requirements, and which result they should achieve in order to be considered successful.

Measurement & value Copy the measurement & value cells from your test plan.	**Test result** Describe what the result was of your test.	**Conclusion** Describe what you learned: does your part meet the requirements?
Example: "Temperature resistance, at least 100 °C for 30 minutes."	*Example: "The part deformed after 3 minutes."*	*Example: "The part deformed very quickly so it does not meet the temperature requirements."*

If all the tests were successful, you can install your part in the product. However, you should always be careful when using 3D printed parts in your product – see the Disclaimer.

Insert pictures of your final part, and how it is installed in the product

7.5 CONCLUSION PHASE 4: PART TESTING

Indicate whether you agree with the statement below.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think my part was successful	☐	☐	☐	☐	☐

If your part was unsuccessful, what (do you think) was the reason?

If you (would) do a second iteration, what would you change?

SHARING YOUR RESULTS

If you are satisfied with your part and printer settings, you can decide to share your results with Sharepair and other repairers. This can help others to repair their product as well!

You can share your results with Sharepair in the following way:

A. Collect the pictures of your printed part: both outside the product and installed in the product.

B. Fill in the Spare part manufacturing recommendations form in Appendix A.

C. Upload your STL file and manufacturing recommendations form online, for example on MyMiniFactory [5] using the tag sharepair.

REFERENCES

[1] T. Beerkens, “Repair Using 3D Printing,” Instructables, 2017. [Online]. Available: https://www.instructables.com/Repair-Using-3D-Printing/. [Accessed 15 December 2021].

[2] TU Delft, “Function Analysis,” TU Delft, [Online]. Available: http://homepage.tudelft.nl/6c92j/Functieleer/FunctionAnalysis-wv-190515.pdf. [Accessed 17 January 2022].

[3] R. Brockotter, “Design Guidelines - Key design considerations for 3D printing,” 3D Hubs, 2021. [Online]. Available: https://www.hubs.com/knowledge-base/key-design-considerations-3d-printing/. [Accessed 15 December 2021].

[4] Simplify3D, “Print Quality Troubleshooting Guide,” Simplify3D, 2022. [Online]. Available: https://www.simplify3d.com/support/print-quality-troubleshooting/ . [Accessed 24 January 2022].

[5] MyMiniFactory, “Filtering with tags: sharepair,” MyMiniFactory, 2022. [Online]. Available: https://www.myminifactory.com/search/?tags=sharepair. [Accessed 24 January 2022].

APPENDIX A

Spare part manufacturing recommendations – FDM printing

General information	
Product Brand	
Product category	
Product model(s), Number(s), Name(s)	
Part description	
File type	.STL
File name *Example: brand_product_part.STL*	
Images	*Insert image*
General dimensions L/W/H* (in CM)	

*Outer dimensions to be used as a reference in case of scaling.

Recommended settings for manufacturing **	
Recommended printing technology	FDM
Recommended printing material	
Nozzle temperature (degrees in Celsius)	
Bed temperature (degrees in Celsius)	
Infill %	
Layer height	
Orientation	*Insert image*
Support	
Bed adhesion	

**Settings recommended for Ultimaker Cura, for different slicing software these settings will have to be adjusted.

Additional information	