RAPPORT – Loket6

Renderade bild på Loket 6

Fig 1 - Rendered images of Corona-free hand-sanitizer train. Own work. Note all removable parts. Pump not to be printed. Rendered in Autodesk Fusion 360.

Fusionlänk

https://a360.co/32JoXqq

Foton på utskrivet Loket 6

Fig 2 - Printed Lok filling all assignment requirements. Note pump not printed but salvaged from a PET bottle. Own work.

Printing Parameters

Table 1 - Slicer settings and printer details.

Printer	Ultimaker 2+
Type	FFF (Fused Filament Fabrication)
Bed surface	Glass
Nozzle	0.4 mm
Material	add:north X-PLA Black
Slicer	Ultimaker Cura 4.9.0
Hot end temperature	196 °C
Bed temperature	66 °C
Ultimaker print profile	Extra Fine (plus changes listed below)
Layer height	0.25 mm
Wall thickness	1.05 mm
Infill density	15%
Infill Pattern	Cubic
Speed	50 mm/s
Support	Touching bed only, 10mm distance between supports, 100% interface
Build plate adhesion	Brim, 10 lines, Purple glue stick

Överblick & Planering

Loket 6 is the final redesign of the original Loket model. We are given relative freedom to redesign the model with a few design restrictions. The locomotive is to be printed fully assembled using Fused Filament Fabrication (FFF) avoiding internal support and minimizing or eliminating the need for external support. The final volume of the printed locomotive should be within twenty percent of the original and maintain similar design features like four spinning wheels and a removable cabin.

In planning this redesign, we take all design restrictions into account and consider our options. It is important to have an understanding of one's workflow and project timeline in order to not bite off more than we can chew. Some designers first create hand drawn sketches of one's ideas before doing any sort of CAD modeling. This can be a very useful technique to hash out design ideas quickly, as I have had experience with this in the past for large projects. Since we have been working with the original locomotive design in Fusion 360 for over six months, I have become extremely familiar with it within the CAD environment. I attempted the sketching technique and quickly realized that I am much faster making my rough sketch ideas directly on a CAD model. This way I can save many copies and play around with my ideas in a similar style as a sculptor with clay or kid with Legos.

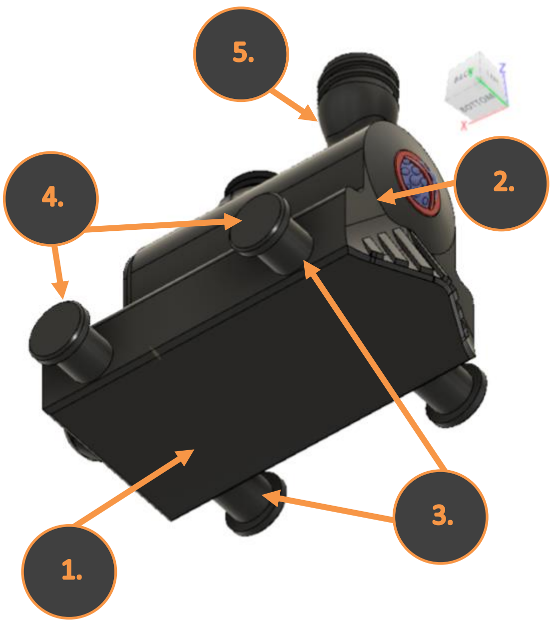

Fig 3 - Combined central body. Own work. Screenshot from Fusion 360 workspace.

Anpassningar

Combined central body

This design feature encapsulates many changes in one:

1. Chassis constructed as a rectangular box, *(same overall dimensions as designed)*.
2. Cylindrical boiler *(same overall dimensions as designed)* combined with chassis via vertical tangent. Design inspiration from **early aero steam locomotives.**
3. Axels *(same diameter as designed)* combined with chassis.
4. Hubs redesigned recessed within outer face of wheel, maintaining same diameter as original Lok design.
5. Smokestack redesigned and combined with boiler.

Wheels

The wheels maintain the same overall dimensions as the original design. Changes were made for both aesthetics and printability on the ornery Ultimaker 2+.

6. For aesthetics, a hollow is created both inboard and outboard face of the wheel.
7. Small, single filament string paths, are created to ensure the hub and wheel stay separated, maintain their roundness, and print without curling.

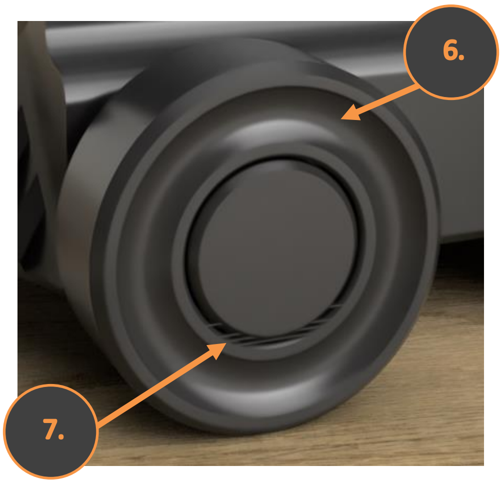

Fig 4 - Wheel design render. Own work. Rendered in Fusion.

Unfortunately, the Ultimaker 2+ I am using has poor part cooling, which results in less than desirable overhangs that curl as the part is being printed *(fig 5, a.)*. This curling looks bad and interferes with the nozzle, potentially leading to failed print. I have tried tweaking overhang settings with unpredictable results. I am assuming this is due to the way the slicer mathematically decides what it considers overhangs. I have tried to adjust print settings in certain areas with support blockers, but this also leads to mixed results and is time consuming to set up for each print. If the model is to be shared publicly, or with other printers, these settings will need to be repeated each time someone slices the STL. It becomes simpler, faster and more robust to add the small strands directly into the model *(fig 4)*. A potential issue could be realized if one decides to have a much greater layer height than 0.25 mm. The small paths would potentially disappear on larger layer heights and widths. These single-layer strands are easily clipped away with a small cutter or broken free by twisting the wheel.

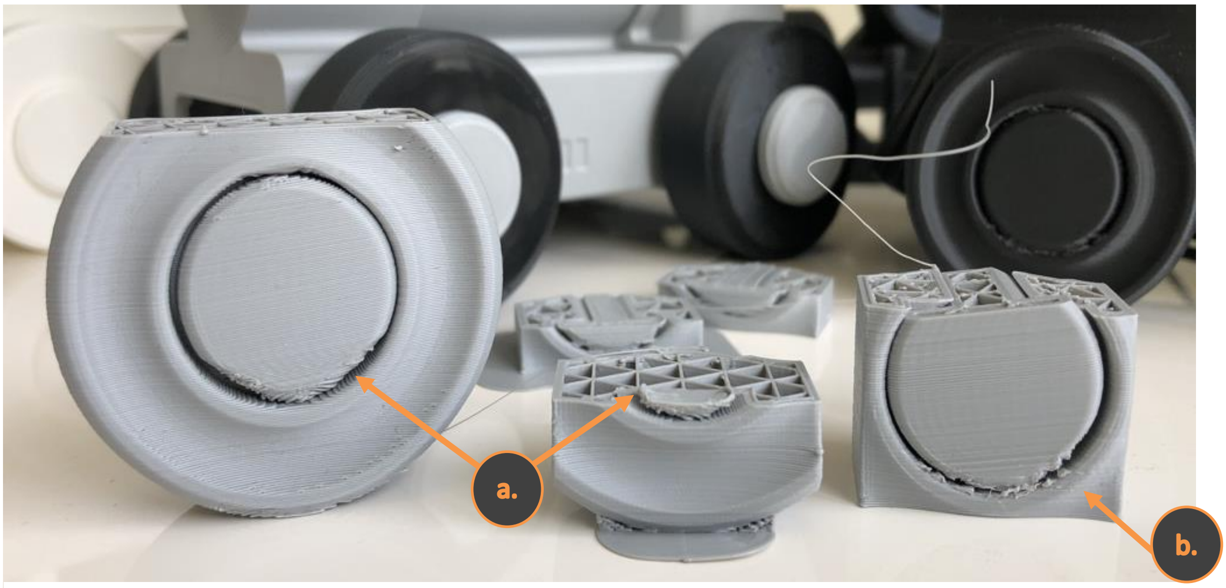

Fig 5 - Wheel axel design and clearance tests. Note ugly looking overhangs to left (a.) and acceptable last print on the right (b.). Iterative adjustments and changes between. The curling is most noticeable on the center print (a.). Own work.

Internal Fluid Chamber

Fig 6 - Overengineered sanitizer stand. Photo by CJ Grevby.

The inspiration for this Lok design is based on an image *(fig 7)* sent to me by CJ Grevby suggesting an overengineered design of a hand sanitizer bottle. I simply cannot think of a better way to make an un-useful Lok useful than to make a disinfection extruder for our class. Thus, the anti-corona train with internal disinfection chamber is born.

After the combined body, chassis, axel, hub and smokestack, the body is completely shelled to make it hollow. From there it is required to adjust the overhanging areas by either adding chamfers or extruding a 45-degree sketch to ensure the overhangs print successfully without support. Ribs have been added at the aft section below the cab to aid in successful bridging. This increases the chamber capacity without sacrificing print quality. An extra fill point with a threaded cap and boss is added with respect to the water fill point on the steam boilers in the good old days. *(see fig 8)*

I have a bottle with a pump which I could take measurements to be sure the pump will fit the design. The pump model used in my design is simply a placeholder to represent the pump I will be using. It is loosely based on a Grabcad model by Edward M Barnes[1].

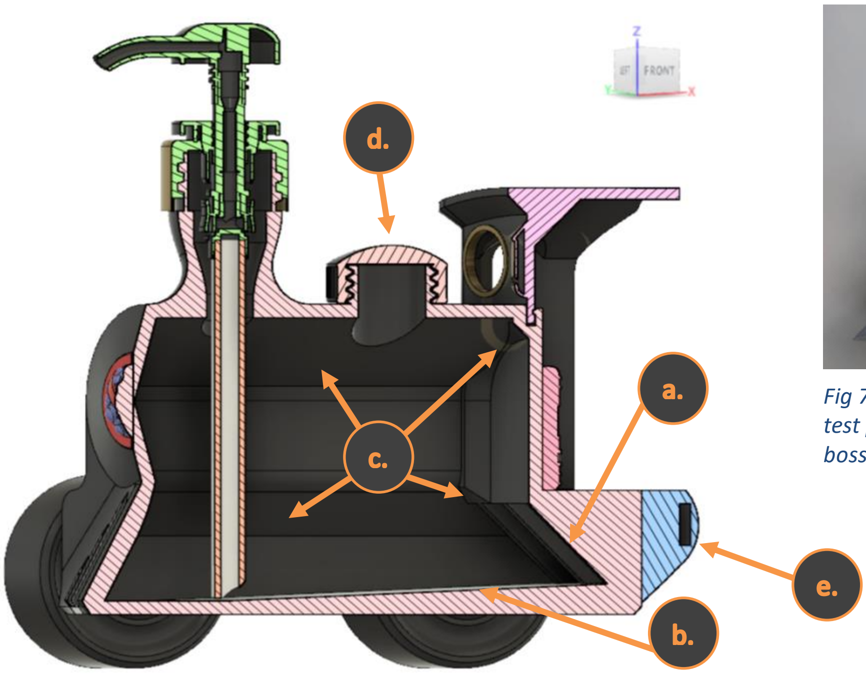

Fig 8 - Section analysis through the center of Loket 6. Note the support ribs on the right (a.) angled chamber bottom (b.) allowing every last drop of disinfectant to be sucked up by the ump, angled chamber overhangs (c.) and extra fill cap with matching threaded boss (d.) Own work. Screenshot from workspace in Fusion 360.

Fig 7 – Successful and unsuccessful test prints of extra fill caps and thread bosses. Own work.

[1] Square Bottle Shapes Shampoo Bottle. Edward M Barnes. https://grabcad.com/library/square-bottle-shapes-shampoo-bottle-1 retrieved 24 April 2021.

Removable Cab

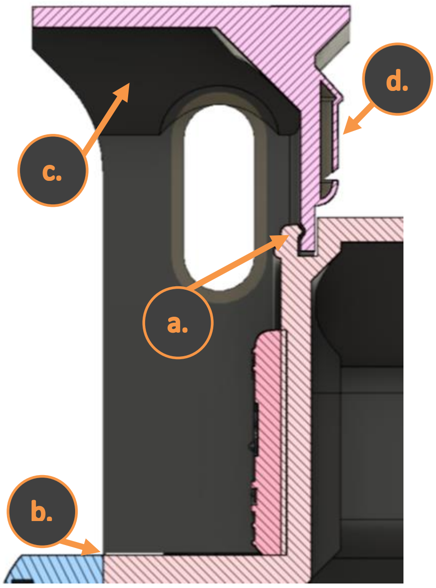

Fig 9 - Removable cab details. Own work. Section analysis screenshot from workspace in Fusion 360.

By design requirement, the cab is printed in place but removable and can be seen removed in the rendering in figure 1 and the picture in figure 2. The joint is a simple sliding joint with an embossed bump *(fig 9a)* to prevent the cabin from falling off in the unfortunate event of a derailment and capsize. This joint was given the usual extra 0.5 mm clearance required by the Ultimaker 2+.

A single filament was modeled at the bottom aft end of the cab to ensure a clean corner and separation from the chassis *(fig 9b)*.

This joint should have printed very easily as the test print was completely successful, however upon completion I noticed some strange layer shifting. The cabin had fused in places near this layer shift and was very difficult to remove initially. Superglue was required to fix the cab.

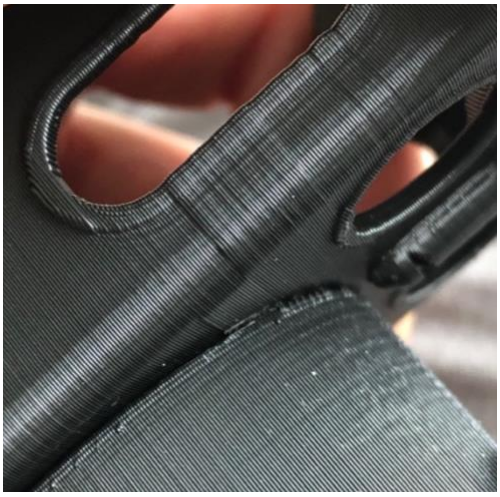

Fig 10 - Layer shift which resulted in fusing the cab to the boiler. Own work.

Cabin Features

We are told that complexity is free with additive manufacturing, so I have added some complexity to the cab in the form of aesthetic features. Design rules are followed so these features pop out in high quality.

Whistle

A whistle has been added to the front of the cabin with a sketch, revolve and extrude cut. It is also hollow, because why not?

Embossed Windows

Window frames have been extruded adding depth the otherwise boring cabin.

Cabin roof

Fig 11 - Overhangs to make cabin roof printable. Note bridging and curling curling artifacts.

I like the look of outboard overhangs. To prevent support material, 45-degree overhangs were designed into the roof outboard and inboard *(fig 9c)*. There is some bridging required between the overhangs, but it is minimized.

Once again due to the ornery nature of the Ultimaker 2+, or my incompetence to tame the beast, some curling on the relatively benign 45-degree overhangs has persisted *(fig 11)*.

Chassis features

The pump connection details, and more "free" design complexity is added to the chassis.

Pump threads on smokestack

In order to fit the salvaged pump onto the smokestack, we need to figure out the thread details. Roughly measuring the threads gives a general idea of the details to choose a thread type. Based on my research there were guidelines but no precise standards for plastic threads, so I modeled various thread patterns available in Fusion 360 and measured for the closest potential fitment. The ISO trapezoidal threads were the closest in measurement and adjusting the faces via offsets gave a good feel. Since it's not exactly precision work with a plastic cap I go with what will simply hold and send off a test to the slicer.

Fig 12 - Thread test, pump and stack extension.

Say no to Covid-19

A cute mega-magnified Corona virus with a "No" sign over it, is modeled as a separate component and attached to the front of the boiler *(fig 2 and 13)*. Let it be a warning to all those little viruses to stay away or meet their doom via 99% alcohol gel about to be squeezed on their little heads. They can't tell us we didn't warn them!

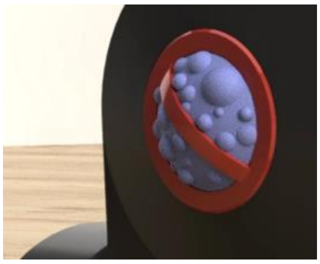

Fig 13 - Just say NO to Covid-19.

Magnetic coupler

Fig 14 - Furnace hatch and magnetic coupler. Own work. Rendered in Fusion 360.

Similar to those little wooden train toys I have modeled a magnetic coupler to the stern of this fine locomotive. The magnet is completely enclosed in the print *(fig 8e)*. I have added a script in the slicer to pause at layer 164. Beep and hold the steppers in place until I drop in the magnet and tell it to begin again. This has been something I have wanted to do since the first Lok assignment and completed successfully.

Furnace hatch

Purely ornamental the boiler furnace hatch has details of a trident, piping around the hatch, a handle, hinge and fire vent. *(fig 14)*

Other designs

I just can't help myself. While my Loket 6 is printing, I continue to let my creative juices flow and keep on designing more features. These features do not make it onto the print but are all capable of being printed in place, further improving and complexifying my Loket design.

Fig 15 - Cap with smoke. Own work. Rendered in Fusion 360.

Cap with smoke

Fig 16 - Cap with smoke test print. Own work.

If we don't want to fight corona with a hand sanitizer pump, we can light the boiler and run as fast as we can from it! Just replace the pump with this stack cap with smoke billowing from it and you are good to go far, far away from that nasty virus. Capable of being printed in place with the Lok. Test prints have been completed.

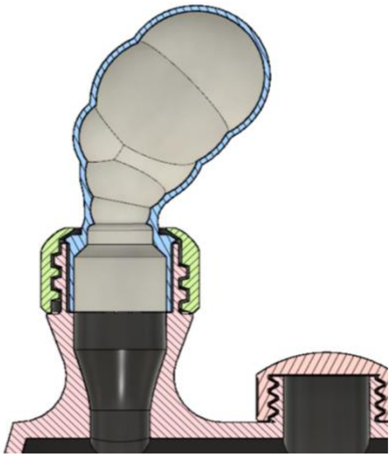

Fig 17 - Cap with smoke section analysis. Note possible to be printed in place. Own work. Screenshot from workspace in Fusion 360.

Edward Wheel

Fusion link to Edward wheel and Cap with smoke model:
https://a360.co/3sNP9KX

The Edward wheel is designed to solve the current problem of support requirement under the chassis. The current wheels hold the base of the chassis 14 mm above the build platform, as we cannot print n thin air (yet), it requires support to be printed. The under-chassis section of support is 99% of the support material required of this print. The last 1% is a small area under the round wheels which prevents sagging of the filament when printing the extreme overhangs required of circular shapes. The Edward wheel eliminates the need for all support in this print.

This wheel is designed to deploy post print in a shear fashion. The test print of this wheel is hot off the printer and functions well. It requires four small cuts with a small side cutter, but the pins are pushed free with some persuasion by pliers and attach again with a satisfying tolerance. I really would like this to be part of the design.

Fig 18 - Edward wheel CAD views closed, open and analysis, test and final prints. Own work. Photos and screen capture from Fusion 360 workspace.

Kalkyl LOKET 6 Verklig kostnad FDM

Table 2 - Actual costs. Numbers pulled from spreadsheet. Own work.

Typ av kostnad	Totalpris
Kostnad operatör + maskiner	1 517 kr
Kostnad material	72,00 kr
Ändringar anpassningar	6 500 kr
Tests Operator + machine	1 765 kr
Test materials	21 kr
Totalt	**9 875 kr**

Kalkyl Loket 6 Uppskattad kostnad för FDM

Table 3 - Estimated costs. Numbers pulled from spreadsheet. Own work.

Typ av kostnad	Totalpris
Kostnad operatör + maskiner	1 088 kr
Kostnad material	294 kr
Ändringar anpassningar	4 000 kr
Tests Operator + machine	2 225 kr
Test materials	38 kr
Unknown costs 10% of final	764 kr
Totalt	**8 409 kr**

SLS

We are asked to discuss what the differences could be if we were to design and print our locomotive using the selective laser sintering (SLS) process.

Printing Loket 6 with an SLS process would save me many headaches. The filament deposition process deposits 0.4 by 0.25 mm path of filament at, in this case, a speed under 55 mm/s. Building up layer by layer means strict design rules must be adhered to in order to improve the quality of the final print. Quality meaning resolution, part clearance for print in place parts, overhangs, etc. Design freedom is simply limited to a bottom-up build with FDM, or a ton of support will be required. Design freedom is further limited to the nature of how the filament can be dragged around decreasing circumferences accidentally, or parts fusing together completely due to inadequate support material or clearances between printed parts.

SLS as a process is the selective melting of a powdered polymer by a laser. It allows for vastly more design freedom than filament deposition as there is usually no need for added support material. The printed part is completely encased within the polymer powder which, in theory, supplies all of the support required. With no support required we could remove all of the forty-five-degree overhangs in our locomotive design and even re-think and add more design features.

While the filament deposition process can be quite granular, SLS typically has finer layer heights, 0.1 to 0.06 mm, leading to a finer resolution and arguably better-looking prints. According to the documentation in *A Practical Guide to Design for Additive Manufacturing*, clearances between parts when printing with SLS[2] seem to be very similar to what I have already designed into my locomotive, so all of the clearances in my design are sufficient to transfer over to SLS.

Kalkyl LOKET 5 Verklig kostnad FDM.

Table 4 - Reflection on the actual costs of printing Loket 5. Own work.

Typ av kostnad	**Totalpris**
Kostnad operatör + maskiner	kr 1 881
Kostnad material	kr 135
Ändringar anpassningar	kr 5 575
Tests Operator + machine	kr 572
Test materials	kr 3
Totalt	**kr 8 166**

Fig 19 - Loket 6 and 5. Own work.

Jämförelse Loket 5 / Loket 6

Considering the differences in design and printing style between Loket 5 and 6, it is surprising that the costs compare so closely. It is clear that the majority of costs associated with additive manufacturing these locomotives is directly proportional to the number of human hours of work put into designing, and preparing, rather than the machine time and material.

In the Loket 5 report, we have compared the advanced Loket 5 as seen in *fig 19*, to a simpler redesign that makes a simple combination of the cabin, chassis and boiler. That comparison reveals a cost differential of over 3 000 SEK. This extra cost is due entirely to the number of human hours required for a more advanced CAD design.

If we think in terms of cost efficiency, we can see that such a large number of hours required for the design, creating STLs and slicing, is a one-time cost. This means more locomotives of the same design printed reduces the individual price. The costs that will not reduce, however, are those associated with post processing, printer, and materials. The latter two being negligible. It is important to design for reducing or removing the need for any post processing when considering time and cost efficiency.

Övriga reflektioner

Complexity of design

It is often quoted that complexity is free in additive manufacturing, but that is not entirely accurate. What I assume people are trying to say with this is design complexity is possible beyond what we have been able to produce by traditional manufacturing. For example, additive allows for us to manufacture strange disinfectant gel chambers within our locomotives or print-in-place Edward-scissor-wheels that freely spin but are unremovable from the axels. This would be impossible with traditional manufacturing techniques. What is not free, or not often said, is the amount of time

[2] Diegel, Olof. "Designing for Polymer Powder Bed Fusion." *A Practical Guide to Design for Additive Manufacturing.* Also by Axel Nordin and Damien Motte, Springer Nature Singapore Pte. Ltd., 2020, e-book pp. 110-116

required to iterate through designing, simulating and testing. Design complexity takes time and is often not intuitive, but it is fun.

CAD vs Hand drawn sketches

I have opted to use CAD as my sketchpad. Perhaps a decade ago CAD was a difficult beast to tame and made hand sketches much easier to iterate through initial design concepts. CAD still has some limitations as a sketchpad, but there are some interesting benefits.

We are very familiar with this locomotive now especially in the Fusion 360 design environment. Knowing the design well and having such experience allows me to quickly and easily design and adjust that design within CAD. When I rest on a design this way, I immediately know it's dimensions, including volume, and have the freedom to rotate it around almost as if I am holding it in my hands. Sketching in CAD allows me to see angular relations between objects, helping me put my imagination to work when creating more complex relationships for parts that I might want to function together.

Adding and removing design ideas is as simple as offsetting a face or hitting the delete key. I can even have multiple design components in separate files and add them all to the same central design to try out different fits and aesthetics. When I am content with the design, I can easily take measurements and re-model it parametrically or be content with the design as-is if no changes are expected in the future. Fusion 360 is very powerful in this way. I understand that our locomotive model is relatively computationally simple, so this CAD-as-sketchpad technique might not be optimum for more intricate, computationally expensive, models. For me, this was the right choice.

Limitations

The potential of additive manufacturing is clear. Fused deposition is a very accessible technology. The machines and materials are inexpensive and readily available. Creating things bit by bit, only what we need, wasting nothing, utilizing multi-materials, but the truth of the matter is that it is currently limited. Our design ideas cannot come true without first considering the limitations of the machines that will print our designs.

I have the opportunity to test two FDM machines, the Creality Ender 3 and the Ultimaker 2+. During this report I used only the Ultimaker as it was the same used for Loket 4 and 5, same machine, materials and printer settings. For Loket 1, I printed using the Ender 3. Both are fused deposition Cartesian types with some minor differences. The Ultimaker has some benefits of higher speed printing, sometimes twice as fast, but suffers with tolerances and clearances between parts when printing in place, or all in one print, like Loket 6. With the Ender 3 I was able to have clearances between printed-in-place parts of 0.2 mm, on the Ultimaker I must design an extra wide berth of at least 0.5 mm. With all other print settings being the same, I have yet to uncover what is actually happening here that results in an order of magnitude less resolution.

There are limitations with the assignment. It is a fun exercise to think about designing the entire Lok to print in place with minimal support and still have a removeable cab and rolling wheels. I would be more interested in designing the Lok to print best with the specific machine and completely eliminating post processing, including support. Post processing of the parts takes me more time than printing pieces separately and assembling them later. With printed-in-place parts being difficult for the Ultimaker, it makes post processing difficult and time consuming. Having multiple pieces that can be joined together later also allows the design to be changed or added to later without the need to consume another 24 hours of print time.

The future of additive needs to be focused on removing limitations in the manufacturing process. So far, additive does this well by increasing the ability for complexity at less cost than traditional manufacturing, but there is much to be gained from more technologies and machine capabilities. I look forward to hopefully being a small part of helping additive grow and improve.

Fig 20 - The plastic that gave its life to the cause plus the family of Locomotives. Adieu dear Loket, Adieu.