YRKESHÖGSKOLAN NOVIA

Industrial Management for 3D Printing

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DEGREE THESIS

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Abstract

This thesis project covers the process of developing a management system for the client of this thesis, Wärtsilä's Additive manufacturing department, and their BigRep "bigrep ONE" FDM 3D printer.

The goal of the system created and covered in this thesis is to both log the prints that are made on the printer as well as to create a Power BI report with the help of the data that's logged from each print.

The theoretical parts of this thesis cover subject like basic information about 3D printing like a brief overview of the history of 3D printing, different types of FDM printers and the advantages and disadvantages, most common materials and their strengths and weaknesses, existing management software's for 3D printing that includes both open source and paid software as well as a basic overview of IT and OT.

Other than just the theoretical part of the subject this thesis goes over as well in detail how the created system works, including the Ui-path program, Excel files and the formulas used in them, and the Power BI report.

Language: English
Key Words: 3D-printing, Ui-Path, management system, Power BI

EXAMENSARBETE

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Utbildning och ort: Produktionsekonomi, Vasa

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Abstrakt

Detta examensarbete går över processen av att utveckla ett ledningssystem för Wärtsiläs Additive manufacturing avdelning BigRep ”bigrep ONE” FDM 3D Printer.

Målet med systemet som utvecklades och som detta arbete går över var att logga varje print som görs på printern samt att skapa en Power Bi rapport med hjälp av den data som man får från varje slutförd printarbete.

Den teoretiska delen av arbetet går över ämnen så som grundläggande information om 3D-printning så som en snabb övergång om teknologisk historia, olika typer av FDM printrar och deras för och nackdelar, de vanligaste materialen och deras styrkor och svagheter, existerande ledningssystem för 3D-printning samt en enkel översikt om och hur IT och OT skiljer sig från varan.

Förutom den teoretiska delen så gås det noggrant igenom hur det utvecklade ledningssystemet fungerar, hur Ui-path programmet, Excel filerna och formlerna som används i dem samt Power BI reportern fungerar.

Språk:

Nyckelord: 3D-printing, Ui-Path, Ledningssystem, Power BI

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Tiivistelmä

Tämä opinnäytetyö kattaa prosessin, jossa hallintajärjestelmää kehitetään opinnäytetyön asiakkaalle, Wärtsilän Additive Manufactuirng osastolle ja heidän BigRep "bigrep ONE" FDM 3D-tulostimelleen.

Tämän opinnäytetyössä luodun ja käsitellyn järjestelmän tavoitteena on sekä kirjata tulostimen tekemät tulosteet että luoda Power Bi -raportti kunkin tulosteen kirjatuista tiedoista.

Tämän opinnäytetyön teoreettinen osuus kattaa aiheita, kuten 3D-tulostuksen perustiedot, lyhyt katsaus 3D-tulostuksen historiaan, erilaiset FDM-tulostintyypit ja niiden edut ja haitat, yleisimmät materiaalit ja niiden vahvuudet ja heikkoudet sekä olemassa olevat hallintaohjelmistot 3D-tulostukseen, mukaan lukien sekä avoimen lähdekoodin että maksulliset ohjelmistot, sekä peruskatsaus IT:hen ja OT:hen.

Teorian lisäksi opinnäytetyö käsittelee yksityiskohtaisesti, miten luotu järjestelmä toimii, mukaan lukien UiPath-ohjelma, Excel-tiedostot ja niissä käytetyt kaavat sekä Power BI-raportti.

Kieli:
Avainsanat: 3D-printing, Ui-Path, Hallintajärjestelmä, Power BI

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List of Abbreviations

AM: Additive manufacturing.

FDM: Fused deposit molding.

SLA: Stereolithography.

PLA: Polylactic acid.

ABS: Acrylonitrile Butadiene Styrene.

PETG: Polyethylene terephthalate glycol.

TPU: Thermoplastic Polyurethane.

BVOH: Butenediol vinyl alcohol copolymer.

IT: Information Technology.

OT: Operational Technology.

RPA: Robotic Process Automation.

1 Introduction

Ever since 2011, 3D printing has seen a huge explosion in popularity as well as the development of technology, so it is no surprise that 3D printing technology has been adapted into many industries, be it for manufacturing or rapid prototyping. Even with the minimal material spill and with the complexity of parts that can be made with the manufacturing method there are still costs that have to be taken into consideration when making decisions.

Here is where the project of this thesis comes in, creating a management system for Wärtsiläs Additive Manufacturing department that tracks and collects data of prints that are performed and uses the collected data to create a Power BI report to showcase the collected data.

2 3D Printing

As 3D printing is part of this thesis, specifically FDM 3D printing, the following chapters are going to be an overview of it, both the technology and its history.

Regarding the term "3D printing" and what it refers to, it's something that most people nowadays are aware of and at least have a basic idea of what it entails. A manufacturing process of creating a three-dimensional object based on a digital model that's created by printing it layer by layer, most commonly out of plastic but metal 3D printers do exist as well.

2.1 3D printing as a manufacturing method

This chapter is going to have a look at how 3D printing as a technology has impacted the world of manufacturing as the technology has matured and become more widespread around the world.

How 3D printing as a manufacturing method differs from traditional manufacturing methods is in the name itself, Additive manufacturing. Traditional manufacturing methods like milling, turning, and grinding work by subtracting material to shape the raw material into the desired shape while generating waste. 3D printing on the other works by adding material to create the shape of the object being printed thus not generating any waste, the only amount of waste generated from 3D printing comes in the case support materials are needed or a print fails, though even so the amount of waste generated is usually minimal. (PROTOLABS NETWORK by hubs, 2023)

Other than waste material how does 3D printing compare with traditional manufacturing methods when comparing the two methods through other aspects?

2.1.1 Design Flexibility

If we look at design flexibility, it's an aspect where 3D printing beats traditional manufacturing due to its ability to easily create complex shapes by building the object layer by layer, thus being able to create complex shapes that would be impossible or difficult to create with traditional manufacturing methods. Traditional manufacturing is also limited by the constraints of the tooling that's available to use. (PROTOLABS NETWORK by hubs, 2023)

2.1.2 Production time

Production time is another aspect where 3D printing has an advantage over traditional manufacturing, this comes primarily from the lack of extra steps in the production or the minimal amount of setup that's needed before starting the print. In traditional manufacturing, the setup can take from a couple of minutes to days depending on everything that's required to do before the production can begin, especially if molds are needed to be created or custom tooling is needed to be made. Comparing that to 3D printing where a part can be made in just a couple of hours or even minutes, the only major setup needed is ensuring that the right material is loaded into the printer. (Sam, 2022)

2.1.3 Low-volume production

When it comes to producing batches in low volumes that's where 3D printing can be a better option due to the lack of needed setup, which reduces the cost of the setup compared to traditional manufacturing where both tooling and setup will affect the cost. Due to this 3D printing is a great option for low-volume batch production or production of customized parts. (Michael Schloder, 2023)

2.1.4 High-volume production

While 3D printing is more cost-effective for low-volume batch production, traditional manufacturing, on the other hand, is more cost-effective for high-volume batch production. While the cost for the tooling, setup, and possible molds might be much higher compared to if the production was made with 3D printing instead, in the long run, the startup cost is going to be recuperated from the amount of time that it takes for the part to be made, especially if compared to making the same part and amount with 3D printing. This especially applies if the parts being produced are simple and don't have a complex geometry. (Michael Schloder, 2023)

2.2 The sudden growth of 3D printing /History of 3D printing

Additive manufacturing has experienced a boom in both popularity and advancement of the technology during the past 15ish years, but the technology is much older than what most people think.

2.2.1 The early days of 3D Printing, 1940s to 1970s

As an idea 3D printing can be dated back as far as 1945 where a process in a short Sci-Fi story written by Murray Leinster “Things Pass By” describes a machine that’s quite similar to that of modern 3D printers, the machine described in the story feeds “magentronic plastics” into a moving arm making drawings in the air with plastic coming out of the end of the arm and hardening as it comes out. (Turney, 2021)

In the 50s another Sci-Fi story “Tools of the Trade” written by Raymond F. Jones introduces the idea of a so-called “molecular spray” that’s used in his story to create items. The first patent that was filed that had to do with 3D printing and was granted in 1971 was by Johannes F. Gottwald, his patent described a continuous inkjet technology that uses metal powder that’s used to make metal fabrication with the powder able to be formed and remelted. His innovation became a precursor to how additive manufacturing works today with material being added layer by layer (Raise 3D)

2.2.2 The technology starts to develop, the 1980s to 1999s.

In 1981 the first patent for a new manufacturing system called “Rapid Prototyping” was filed by Dr. Hideo Kodama, a lawyer working for a research institute in the city of Nagoya, Japan. His patent described a process where a machine created a three-dimensional model layer by layer using resin that’s hardened when exposed to UV light, while his research was published in several papers the patent ended up not going anywhere due to lack of interest. (Turney, 2021)

While Dr. Hideo Kodama was unable to patent his invention it’s still considered one of the first forms of what would nowadays be called a Stereolithographic (SLA) printer. The first person to patent the SLA 3D printing technology was Chuck “Chuck” Hull in 1984, his patent included a way to use design files to control the 3D printer. He is credited as the inventor of the SLA printing method and the “.STL" file type. 1986 he co-founded 3D Systems which produced 3D printers, and the same year launched their first printer “SLA-1”. (Ikonen, 2023)

In 1988 a student at the University of Texas, Carl Deckard licensed another 3D printing technology, Selective Laser Sintering (SLS) where a laser is used to selectively sinter material that's in powder form into a solid structure. A year later Scott Crump patented Fused Deposition Modeling (FDM also known as Fused Filament Fabrication, FFF) and founded Stratsey, which is to this day one of the biggest players in the 3D printing industry. (Ultimaker, u.d.)

The 90s consisted of many new companies being founded for the new 3D printing industry, with SLA and SLS technology starting to be commercialized by companies and thus leading to the technology starting to be adopted by many sectors. (Team Xometry, 2024)

2.2.3 RepRap and first low-cost printers, 2000-2009

The early 2000s is when 3D printing as a technology started to become more widely known, this is partly due to the first commercially available 3D printers aimed towards hobbyists starting to pop up as well as the founding and launch of the RepRap project and community. (Turney, 2021)

Replicating Rapid-prototyping, RepRap was invented by Adrian Bowyer in 2005 with the idea of creating a self-replicating 3D printer, capable of replicating a majority of the parts needed to build an identical 3D printer. When RepRap was founded the cheapest commercially available printer would have cost about 30,000€ and the printer wasn't designed to replicate itself, the goal of the RepRap team was to create a printer that cost about 350€ and was capable of replicating itself, thus providing easy access to 3D printing. All the files and software were distributed for free under the open-source license to follow the Free Software Movement. (RepRap Org, 2024)

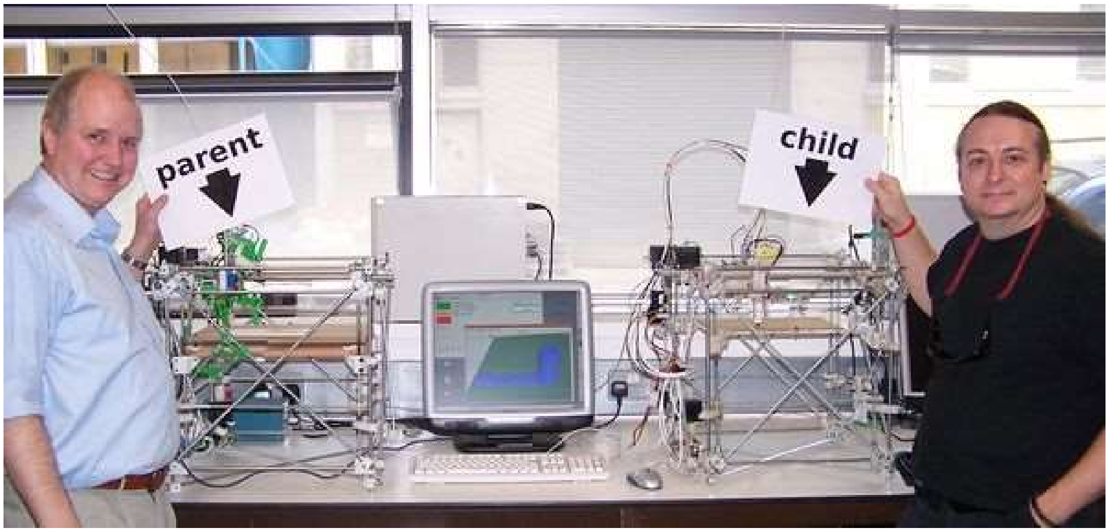


Figure 1 Adrian Bowyer (left) and Vik Olliver (right). Bowyer next to the parent 1.0 Darwin, Olliver next to the child 1.0 Darwin created from parts printed by the parent. The child creating its first "grandchild" part only a couple of minutes after it was assembled. (RepRap Org, 2024)

RepRap's 1.0 Darwin was the first practical application of the RepRap Philosophy, this gave everyone the possibility to create whatever they wanted, and right around the corner was the launch of Kickstart. It provided a source of funding in the form of crowdfunding for all kinds of projects. In 2006 the first commercially available desktop 3D printers started to arrive from "Object" nowadays owned by Stratasys. As the interest in 3D printing started to grow around 2009 MakerBot arrived on the scene with DIY kits to build your own 3D printer, providing an even bigger boost to the technology like that of the Internet and social media. (Turney, 2021)

Another thing that helped to bring 3D printing into the mainstream was the launch of online file repositories like "Thingiverse" that housed hundreds of thousands (and counting) ".STL" files available for free for anyone to download and print. (Ultimaker, u.d.)

2.2.4 The wide adoption of the technology, 2009 to the present

3D printing technology has since 2009 seen a huge advancement and adaptation both industrially and also among hobbyists. A major reason for the growth was that many of the patents that launched the technology expiring, including Chuck Hull's SLA patent and Stratasys´ patent for FDM technology (though still holding the trademark on the term FDM, thus causing competitors to make a deal with them or to use the less popular term FFF) in 2009. With the patent expired many competitors were quickly out on the market with their own kits for a far lower price and aiming for the growing hobbyist community that congregated around online places like Thingiverse, Object and RepRap. MakerBot and Rapman introduced their own FDM products quickly after the patent ended. SLA printers didn’t become as popular among hobbyists until 2012 when Formlab came out with the first affordable SLA printer for hobbyists, many of the remaining patents expired in 2014 when the patent for SLS expired thus meaning that the three major forms of 3D printing became public domain. (Haines, 2024)

Since then, the technology has kept on growing, advancement has been made from the creation of multi-material printers that are capable of printing with multiple materials, and advancement in SLM printing allows for the possibility of printing complex and strong parts out of metal. Alongside these technologies bioprinting has also seen a huge advancement since the 90s, making it possible to print new skin tissue for burn victims or even print brand-new organs. (Raise 3D)

2.3 FDM 3D Printers

Fused Deposition Modeling or FDM (trademarked by Stratasys), also known by the acronym FFF (Fused Filament Fabrication, open source) refers to all 3D printers that work by extruding polymers through a heated nozzle and onto a Build plate. The material used for printing comes in the form of a spool of filament, the filament usually has a diameter of 1.75 mm, but some printers use 2.85 mm filament. (Prusa Reserach, 2024)

When it comes to FDM Printers there are many different variants, these usually differ in how the printer moves and extrudes. The following is going to be an brief overlook of the four most common ways FDM printers might differ from each other.

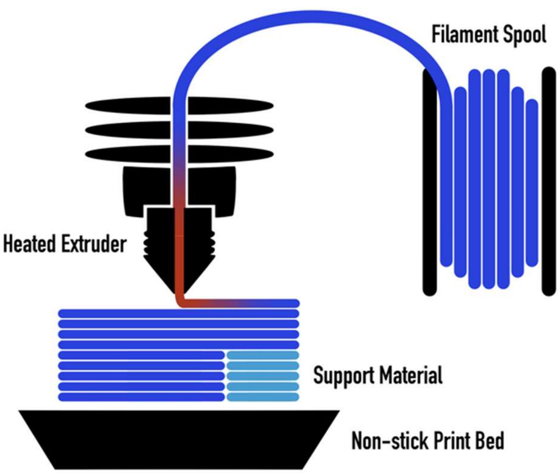


Figure 2 The layer-by-layer printing process of FDM Printing (Dozuki System, 2022).

2.3.1 Bowden Extruder

Bowden extruder also known as Bowden Tube extrusion is an extrusion method where the filament is fed through a PTFE tube, the so-called Bowden tube. The tube guides the filament to the toolhead as it's being pushed further into the tube by the extruder that's mounted to the frame of the printer. (Tess Boissonneault, 2023)

The general advantage of Bowden tube extrusion is the smaller size of the toolhead which means that there is a larger print area than if Direct drive was used, less weight is also put on the toolhead which allows for higher print speed, smoother movement, and less vibration. The main disadvantage of Bowden tube extrusion is the slow retraction speed that's due to the friction that occurs when the filament is pushed inside of the PTFE tube, thus causing a delay in response time that leads to a longer but faster retraction being needed to avoid tension. Another disadvantage with Bowden tube is the need for a stronger extruder motor with high torque to push the filament through the PTFE tube and into the heatsink and nozzle, material compatibility is also a disadvantage with Bowden extrusion when it comes to flexible and abrasive filaments like TPU and Nylon as it might lead to clogs or filament coil depending on the length of the Bowden tube. (Kingroon 3D, 2022)

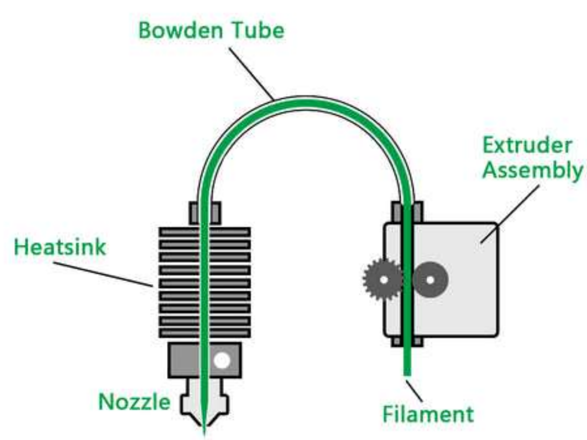


Figure 3 Bowden tube extruder (Kingroon 3D, 2022).

2.3.2 Direct drive extruder

As an extrusion method direct drive works by the extruder being mounted right above the heatsink and feeding the filament directly into the heatsink and the nozzle, thus neglecting the need for a PTFE tube to guide the filament. (Michael, 2023)

When it comes to the advantages of direct drive, they all come down to the shortened distance between the extruder and the nozzle and better control of the retraction and extrusion. To put it simply the advantages of direct drive are that they are better and more reliable extrusion, quicker and easier retraction due to the shortened distance, suitable for use with flexible and abrasive filaments as well able to use a smaller motor for the extruder. The disadvantages, on the other hand, come from the extra weight added onto the toolhead, these are limitations in the print speed limit and possible more vibrations and wobbles happening that might lead to accuracy loss in the X and Y-axis. (Kingroon 3D, 2022)

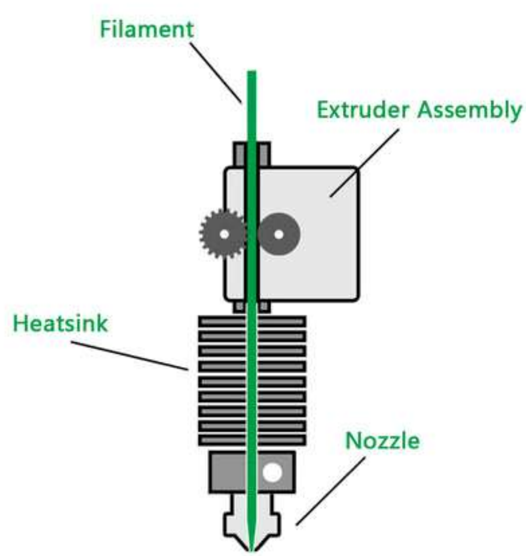


Figure 4 Direct drive extruder (Kingroon 3D, 2022)

2.3.3 Cartesian printers

Cartesian printers are printers where three stepper motors are used to control each of the three axes, usually either by leadscrews or belts that are attached to the stepper motor and used to convert the rotational movement of the motor into linear motion. Cartesian printers can be divided into two types of printers: Standard Cartesian System and H-Bot System. (Radaviciute, 2022)

Standard Cartesian System, also known as XZ-head printers are printers where the toolhead of the printer moves in the X and Z-axis while the print bed moves in the Y-axis and due to the movement of the print bed in the Y-axis, these kinds of printers are usually referred to as "bedslingers". The movement of the bed does introduce a couple of problems with these types of printers, these can be summarized as the need for more space for the printer due to the movement of the bed as well as the impact on the final quality or loss of accuracy due to the vibrations or instabilities that are caused by the movement of the bed. (Billington, 2024)

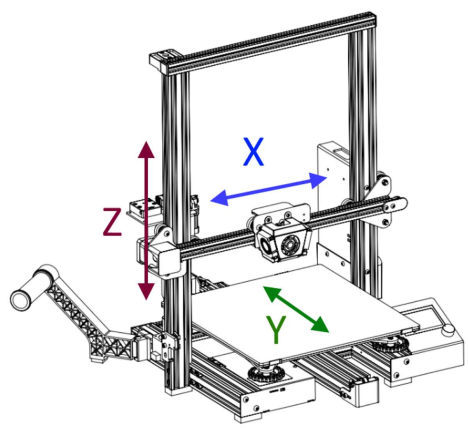


Figure 5 Standard Cartesian system printer and its axis (Billington, 2024).

H-bot systems also known as XY-head printers on the other hand work by the toolhead moving in the X and Y-axis and the bed being moved up and down in the Z-axis. The movement of the toolhead in the X-axis is achieved by it moving along a rod in the specific axis, while movement in the Y-axis is achieved by moving the toolhead and X-axis rod in the Y-axis direction. The movement of the toolhead is usually done by using one of the two options. (Billington, 2024)

The first option is where the X and Y-axis motions are achieved by a single belt that's routed in the shape of an "H" and pulled by two stepper motors to move the toolhead. Movement of the toolhead in the X-axis is achieved by driving both motors in the same direction while moving it in the Y-axis is achieved by driving both motors in opposite directions. (Galil)

The secondary option is one where instead of using only one belt and two motors to move the toolhead in both directions, three belts and two motors are used instead. Here one motor and one belt move the toolhead in the X-axis while the other motor and the two belts are used to move the toolhead and the X-axis gantry in the Y-axis direction. (Team Xometry, 2023)

While the system is in general more expensive compared to the Standard Cartesian system due to the complexity of the system and the additional components, it has advantages when it comes to higher precision and print speed as well as the printer requiring less space due to the bed not moving in the Y-axis. Tough even with the advantages the system is quite complex to maintain compared to a Standard Cartesian system. (Billington, 2024)

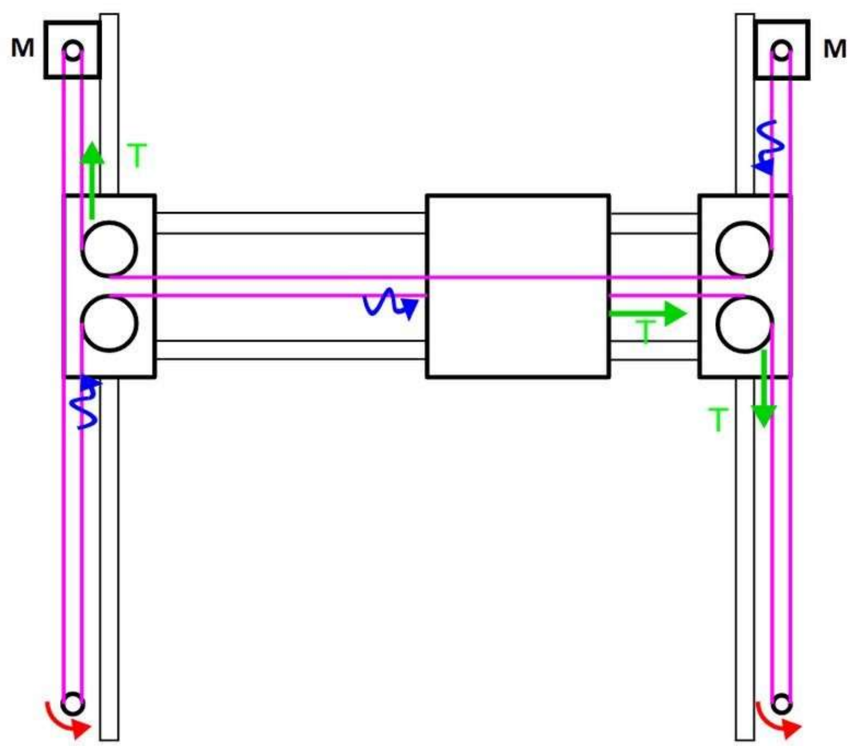


Figure 6 Diagram of the H-Bot system using a single belt (TOP 3D MEDIA, 2019)

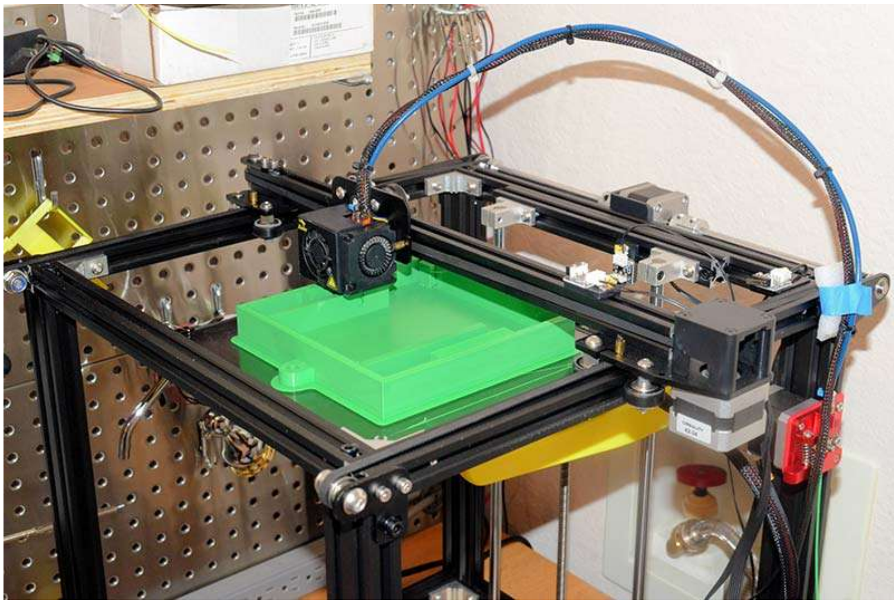


Figure 7 An Creality Ender 5-Pro showcashing the H-bot system using the three belts to move the toolhead and X-axis gantry. (Wierenga, 2020)

2.3.4 CoreXY system

The CoreXY system is quite like that of the H-bot system, both systems work by moving the toolhead by using a system of belts and motors, the main difference between them is the use of two belts instead of one in the CoreXY system.

The movement of the toolhead in the different directions is achieved by the different directions that the stepper motor turns into, movements in the X-axis are achieved by the motors spinning in either clock or counterclockwise, while movement in the Y-axis is achieved by the motors spinning towards or against each other (one spinning clockwise while the other spinning counterclockwise). Movement in the Z-axis is achieved by the build plate being raised or lowered. (Roslind, 2018)

The CoreXY system's advantages are for the most part the same as with the H-bot, the printer takes less space and has faster print speed and precision. The main advantage that the CoreXY system has over the H-bot system is that twisting of the axes is minimal due to how the belts are arranged. (Hakulinen, 2021)

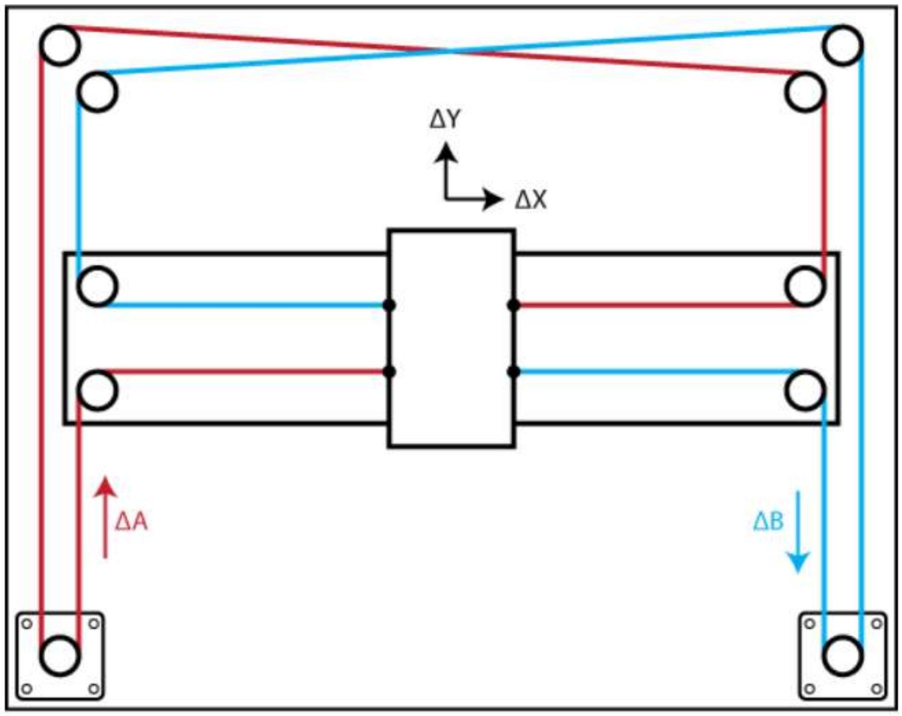


Figure 8 Diagram of the CoreXY system (Prusa Reserach, 2024)

2.4 Common material

The following is a short description of the most common materials used in FDM 3D printing, going over the material properties, advantages, and disadvantages as well as what to keep in mind when printing with them.

2.4.1 PLA

PLA (Polylactic acid) a plant-based polyester, is the most common and easiest-to-use material used in FDM 3D printing. Its popularity comes from the ease of printing with it and that it does not require high temperatures to print with, with the recommended temperature for the nozzle being 210°C (its melting point being around 175°C) and the need for a heated print bed not being required but recommended (60°C being recommended for the bed) and the fact it’s not prone to warping making it quite easy to print with. (Prusa Research, 2024)

As a material, it’s suitable for quite a lot of use cases, everything from making models, prototyping, toys, statues, etc., and it is capable of being used for printing both small and large prints. But with any material, it has its disadvantages, the biggest being it not the best for use outdoors due to the material starting to deform at above 60°C (PLA glass transitioning temperature) and degrading from being exposed to UV light. The material’s mechanical resistance is also quite poor, usually breaking by the layer lines or shattering into pieces when impacted. A common misconception about PLA is it is biodegradable, while technically being so due to the material being made from corn and sugar cane it will only decompose in special composting facilities where the temperature exceeds 80°C. (O'Connell, 2023)

2.4.2 ABS

ABS (Acrylonitrile Butadiene Styrene) is a common material in 3D printing as well as a popular material for injection molding where it is used for many real-world applications such as toys, LEGO bricks, housing for electronics, automotive parts, household applications, and much more. The chances are quite high that if you get something made from plastic and look into what kind of material it is made out of, you’ll find that it's made from ABS. When it comes to material characteristics of ABS it has a high tenacity and temperature resistance, making it suitable for use in creating mechanical parts or parts that need to be able to endure higher temperatures with its glass transition temperature at 105°C and melting point at 200°C. (Protolabs Network by hubs).

When it comes to printing with ABS it requires high temperatures, nozzle temperature should be about 255°C and bed at around 80-100°C depending on the size of the object that's being printed (larger object requires higher temp). What makes printing with ABS challenging are the fumes released from it during printing and the fact that the material is prone to warping, the fumes that are released during printing are the biggest challenge when it comes to printing with ABS as the fumes are toxic and thus require that the prints are done in a well-ventilated room but it's also important that the ventilation doesn't create draft around the print as it might cause warping to occur due to the change in temperature around the print. Due to the toxic fumes and sensitivity to changes in temperature around the print, it's highly advised that the print with ABS is performed in an enclosure with the fumes vented, if possible, directly outside. (Prusa Research, 2024)

2.4.3 PETG

PETG (Polyethylene terephthalate modified with Glycol) is the third most used material alongside PLA and ABS, the plastic being a modification of PET (Polyethylene terephthalate) with the Glycol being added to make it easier to print with, less brittle and clearer than its base form. Plastic PET is most used in water bottles, clothing fibers, and food containers. PETG material characteristics are in general a good all-round filament due to its flexibility, strength, and resistance to high temperatures and impacts which makes it ideal when printing functional parts that might be exposed to sustainable and sudden stress. (All3DP, 2023)

Printing with PETG is a bit special compared to ABS with which it shares similar material properties with the temperature for the bed and nozzle being lower with the nozzle at around 240°C and the bed at 90°C. The two biggest differences between ABS and PETG are that no toxic fumes are released and that the material is not prone to warping at all, making it a great option in case venting the fumes from ABS isn't an option but needing to print something from a material that can endure both UV-light and high temperatures. (Prusa Research, 2024)

2.4.4 TPE, TPU TPC (Flexible filaments)

TPE (thermoplastic elastomers) is a broad class of co-polymers used in 3D printing that shares in general the same kind of characteristics in being soft, stretchable, and able to withstand punishment that neither PLA nor ABS can endure. TPU (Thermoplastic polyurethane) is a variant of TPE, that is more rigid, durable, and able to retain its elasticity even in the cold. Due to it being more rigid, it's easier to print with compared to TPE. TPC

(Thermoplastic Copolyester) on the other hand is more or less similar to that of TPE, with the main difference being that TPC has a higher resistance towards chemicals and UV-light as well able to handle temperatures up to 150°C. TPE and TPU are both great choices in case the printed parts need to be able to bend, stretch, endure a lot of wear, or even compress. Making both great for making toys, phone cases, wearable stuff, or even tires for RC cars. TPC on the other hand can be used for similar stuff but does especially well in harsher environments like outdoors or in places where it might be exposed to higher temperatures like inside of a car. (All3DP, 2023)

When it comes to printing with flexible filaments, they tend to be among the most difficult filaments to print with (the softer the harder it is), this is due to flexible filaments tending to cause clogs or get entangled with the extrusion gears. Temperature vice the temperature for the nozzle should be around 230-240°C and the bed between 60-75°C, the temperature for the nozzle depends on the hardness and brand of the filament while the bed temperature depends on the size of the object that's being printed. Print speed is recommended to keep around 20 mm/s to minimize the risk of clogging occurring and if printing on a smooth print surface use a glue stick or something similar to create a separation layer between the filament and bed to make it easier to remove the finished print, a separation layer is thought not needed if a textured print surface is used. It's also important to note that flexible filament is hygroscopic, absorbing moisture easily which can cause problems when printing. (Prusa Research, 2023)

2.4.5 Water soluble BVOH & PVA

BVOH (Butanediol vinyl alcohol copolymer) and PVA (Polyvinyl alcohol) are water-soluble materials used for support materials in multi-material printers (printers that can print with more than one material at a time), the model itself is printed from another material. Once the print is completed the support material is easily dissolved or washed off (both are also biodegradable and non-toxic), making water-soluble supports great when supports are needed in a hard-to-reach spot. The main difference between the two materials is that PVA tends to be cheaper but also prone to clogging and BVOH tends to stick better than PVA. The temperature vice the nozzle is around 195°C when printing with PVA and 215°C when printing with BVOH, the recommended temperature for the bed is 60°C making both materials great support when using PLA due to the similar printing temperatures. The biggest disadvantage with both materials is that they are hygroscopic, meaning that they must be kept as dry as possible and stored in a dry box when not in use. (Prusa Research, 2024)

3 IT and OT

IT and OT are two technologies where the line between the two can be quite blurry, especially as technology keeps on advancing and they become more and more entangled. This chapter is going to give a quick overview of the two, try and explain how they differ from each other, and what kind of tasks each is used for.

3.1 IT

Information Technology (IT), refers to any device that's capable of Processing, creating, storing, exchanging, and retrieval of both data and information. IT devices consist of everything from computers, smartphones, servers, and IoT (Internet of Things) that's part of IT infrastructure, IT infrastructure in itself consists of Hardware, Software, networks, and services that are needed to support the earlier mentioned devices. (Rich Castagna, Stephen J. Bigelow, u.d.)

As a system IT plays an important role in today's business landscape, its capability to retrieve, store, and create data means it's a big part of the daily running of a company and important to ensure everything goes smoothly. IT ensures that the system in charge of everything from payment of the staff and subcontractors to billing, project planning, or revenue collection works as it should and ensures that the company can stay competitive. (Prema Srinivasan, 2020)

3.2 OT

Operational Technology (OT) is the use of software and hardware to control and manage industrial equipment that's primarily used for physical tasks or processes. OT is commonly used to supervise processes in industries like manufacturing, energy, medicine, and building management to mention a few. (Red Hat, 2022)

As with IT, OT applies to a lot of devices such as Programmable logic controllers, Human-machine interfaces, and regular as well as industrial IoT. OT is simply the hardware and software that's used to keep things running in factories, power plants, etc. Below is a definition from Gartner that describes OT the best. (i-scoop, u.d.)

“Operational technology (OT) is hardware and software that detects or causes a change, through the direct monitoring and/or control of industrial equipment, assets, processes, and events”. (Gartner, u.d.)

4 bigrep ONE

As the project of this thesis is regarding the creation of a management system to collect data from Wärtsiläs “bigrep ONE” printer the following is going to be a brief overview of the printer. The information about the printer has been gathered from BigReps own site and page where they give an overview of the printer. (BigRep, u.d.)

Bigrep ONE is an award-winning large format 3D printer with over 350 systems installed around the world. The build volume of the printer is one cubic meter making it capable of handling all sorts of large prints and the open design of the printer ensures that monitoring of the print is easy.

The printer’s extrusion system is a direct drive extrusion, with the possibility of printing with only one or using two printheads in the case you want to use water-soluble filament like BVOH for support material or use the printers “TWIN MODE” which enables the printer to print two copies of the same print as the same time, one printhead per item being printed. The max speed of the printer is 500 mm/s with max acceleration at 400 mm/s and can use both third-party filament and BigReps own brand of filament.

The motion system used by the printer is the H-bot system, with a similar setup as that of the Ender 5 where instead of using belts in a H shape to move the toolhead it uses motors to move the X-axis gantry in the Y-axis and a motor to move the X-axis gantry is used to move the toolhead in the X-axis direction.

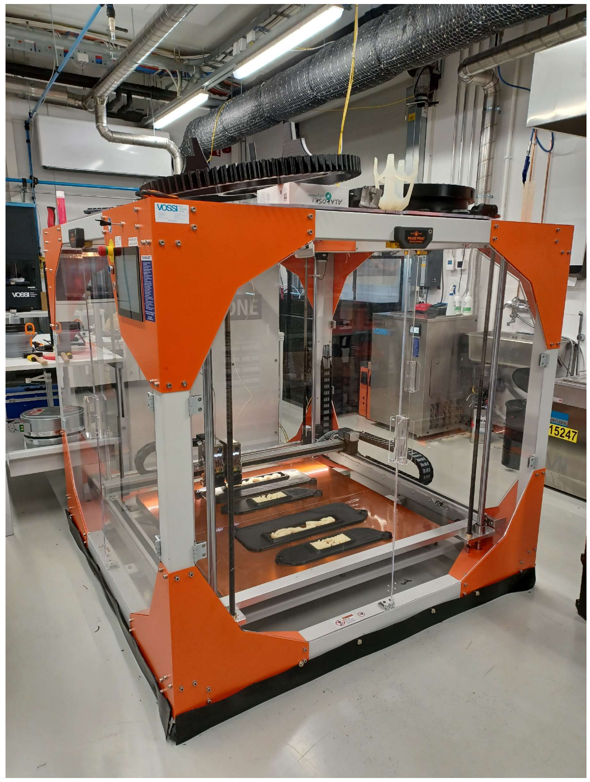


Figure 9 Picture take of Wärtsiläs BigRep ONE

5 Existing management software's for 3D printers

When it comes to gathering data from 3D printers, be it just to log each print or to make a report out of the collected data, there are plenty of both commercial and open-source software that are capable of this. The following is going to be an overview of software's that was investigated and considered for the possibility in the use of collecting data from the BigRep ONE Printer.

5.1 OctoPrint Open-source software option

Open source has long been and still is a big part of the 3D printing community, originally primarily regarding data and software needed to build your own printer but has nowadays grown to incorporate all kinds of aspects of the technology. When it comes to open-source software used in the 3D printing community, OcotPrint is probably the most well-known and most utilized one.

5.1.1 What is OctoPrint?

OctoPrint is a software that makes it possible for the user to control and monitor a printer through a browser. The software is most commonly run on a Raspberry Pi single-board computer as it's the easiest way to install it, but the software can be installed on most other devices. (Radaviciute, 2022)

When it comes to the functions that the software provides there are a bunch, and all of these can be accessed and activated through the browser. Monitoring the print while it's going on is possible from the embedded webcam feed and constant feedback about the progress of the print is provided by the software in the form of live updates about the temperature of the nozzle and bed, the integrated g-code visualizer provides the ability to see a rendition of the g-code that's currently being printed. It offers the ability to control your printer as well, in the form of the ability to send commands to the printer to move the toolhead in the different axis, extruder or retract or other custom controls that can be made for it, the ability to start a print, stop or pause an ongoing print whenever you want is also possible. But these are just a few of the many features that OctoPrint has, there is nearly an endless amount of freely available plugins for the software that adds to the features of the software. (Häußge, 2024)

5.2 BigRep Connect, the Commercially available software option

When it came to commercially available management software that would work with the printer it was quite limited as most of the software focuses on a specific printer or brand. Due to this only one Software was investigated, and the software was BigReps own software in the form of the services provided by BigRep Connect.

5.2.1 BigRep Connect

BigRep Connect is a web platform available for free to the majority of users with a BigRep printer with the latest firmware installed and an internet connection, the only printers not compatible with the service are the “ONE.2” and “STUDIO.1” models.

The services provided by the site are the ability to remotely monitor the printer and its status, create analytics based on archived prints as well as the option to upload g-codes for prints remotely and create print queues, and the ability to create accounts for team members and manage the access and right each account got are to mention a few of the many services that are offered by the site.

Regarding the security of stored data on the site, only those with access to the data can see it and to do so a manager with access to the data must create an account for the user or grant access for the user to see the data. All the data is encrypted and the only data that BigRep uses is anonymously aggregated data that’s used to improve the printing process with their printers.

The source for the data about BigRep Connect was gathered from BigReps own site and page regarding BigRep Connect. (BigRep, u.d.)

6 The solution

After looking over the different solutions on how to get the data from the printer, log the data somewhere and make a Power BI report out if the decision was made using the following solution.

6.1 Source of data

First and foremost a source for the data must be chosen, for this, there was only one real option from where the data could be gathered, and this was BigRep Connect.

The reasons why there is no real other option for gathering data regarding the prints are mostly due to two reasons that come down to warranty. To put it simply BigRep stated in an email that was an answer to one sent out to them regarding questions about the printer that any modifications made to the printer, or its software nulls the warranty, meaning that trying to use any software like Octorprint or any custom software that you connect to the printer directly to gather the data from it and would require modifications to be made to the software so it could run would void the warranty.

This makes BigRep Connect the only real option to get the data in a way that won't risk losing the warranty on the printer.

6.2 Data retrieval

Now that a source for the data is chosen a way to collect it is needed. The best and most practical way to do this is by using a bot, meaning that the process also could be automated. For this Ui-path Studio was chosen as it's already used internally at Wärtsilä meaning that there will be a minimal number of permissions, specifically related to security, that will have to be granted before the whole system can be set up to run.

6.3 Logging the data

Lastly, the data needs to be stored somewhere, while Power BI can retrieve data straight from another webpage like BigRep Connect the problem is that Connect only stores data for up to 12 months after which it will be deleted. This is why Connect is not an option to use as both a log and as a source for Power BI, due to this the decision was made to use Excel as both log the data and as a source for Power BI.

7 Excel logs files

The following is going to be an in-depth explanation of the Excel files used to get the data collected from BigRep Connect logged and formatted so that Power BI can read the data. This will include a general overview of what each file does and how the formulas used in them work.

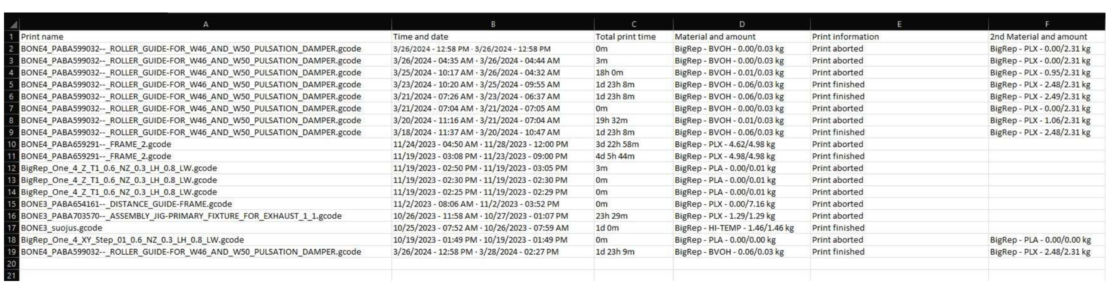
7.1 BigRep log

The Excel file “BigRep log” (BigRep log recovered.xlsx) has two specific purposes, first to work as a log for all the prints, this is due to BigRep Connect only storing print logs for up to 12 months, after which they are deleted. Thus, there is a need to store old data to ensure that it’s possible to compare new data to old data from multiple previous years or months. The file consists of two sheets, “Collected data” and “Processed data”.

7.1.1 The collected data

The collected data sheets are where the data collected by Ui-path S§tudio is pasted into, the sheet contains data like Print name, Time and date, Total print time, Material and amount, Print information as well as Second Material and amount. Each of these contains data that is needed, be it to log each print or to get data that is needed for the Power Bi presentation.

The data regarding the second material is added lastly due to at the point when the the system was first being developed it wasn’t available, this was due to BigRep Connect not updating the print history and thus not providing any data of prints being done where a second material was used. Instead of waiting for it to be fixed, the decision was made to add it at the end once the problem with Connect was fixed.



	A	B	C	D	E	F
1	Print name	Time and date	Total print time	Material and amount	Print information	2nd Material and amount
2	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/26/2024 - 12:58 PM · 3/26/2024 - 12:58 PM	0m	BigRep - BVOH - 0.00/0.03 kg	Print aborted	BigRep - PLX - 0.00/2.31 kg
3	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/26/2024 - 04:35 AM · 3/26/2024 - 04:44 AM	3m	BigRep - BVOH - 0.00/0.03 kg	Print aborted	BigRep - PLX - 0.00/2.31 kg
4	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/25/2024 - 10:17 AM · 3/26/2024 - 04:32 AM	18h 0m	BigRep - BVOH - 0.01/0.03 kg	Print aborted	BigRep - PLX - 0.95/2.31 kg
5	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/23/2024 - 10:20 AM · 3/25/2024 - 09:55 AM	1d 23h 8m	BigRep - BVOH - 0.06/0.03 kg	Print finished	BigRep - PLX - 2.48/2.31 kg
6	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/21/2024 - 07:26 AM · 3/23/2024 - 06:37 AM	1d 23h 8m	BigRep - BVOH - 0.06/0.03 kg	Print finished	BigRep - PLX - 2.49/2.31 kg
7	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/21/2024 - 07:04 AM · 3/21/2024 - 07:05 AM	0m	BigRep - BVOH - 0.00/0.03 kg	Print aborted	BigRep - PLX - 0.00/2.31 kg
8	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/20/2024 - 11:16 AM · 3/21/2024 - 07:04 AM	19h 32m	BigRep - BVOH - 0.01/0.03 kg	Print aborted	BigRep - PLX - 1.06/2.31 kg
9	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/18/2024 - 11:37 AM · 3/20/2024 - 10:47 AM	1d 23h 8m	BigRep - BVOH - 0.06/0.03 kg	Print finished	BigRep - PLX - 2.48/2.31 kg
10	BONE4_PABA659291--_FRAME_2.gcode	11/24/2023 - 04:50 AM · 11/28/2023 - 12:00 PM	3d 22h 58m	BigRep - PLX - 4.62/4.98 kg	Print aborted	
11	BONE4_PABA659291--_FRAME_2.gcode	11/19/2023 - 03:08 PM · 11/23/2023 - 09:00 PM	4d 5h 44m	BigRep - PLX - 4.98/4.98 kg	Print finished	
12	BigRep_One_4_Z_T1_0.6_NZ_0.3_LH_0.8_LW.gcode	11/19/2023 - 02:50 PM · 11/19/2023 - 03:05 PM	3m	BigRep - PLA - 0.00/0.01 kg	Print aborted	
13	BigRep_One_4_Z_T1_0.6_NZ_0.3_LH_0.8_LW.gcode	11/19/2023 - 02:30 PM · 11/19/2023 - 02:30 PM	0m	BigRep - PLA - 0.00/0.01 kg	Print aborted	
14	BigRep_One_4_Z_T1_0.6_NZ_0.3_LH_0.8_LW.gcode	11/19/2023 - 02:25 PM · 11/19/2023 - 02:29 PM	0m	BigRep - PLA - 0.00/0.01 kg	Print aborted	
15	BONE3_PABA654161--_DISTANCE_GUIDE-FRAME.gcode	11/2/2023 - 08:06 AM · 11/2/2023 - 03:52 PM	0m	BigRep - PLX - 0.00/7.16 kg	Print aborted	
16	BONE3_PABA703570--_ASSEMBLY_JIG-PRIMARY_FIXTURE_FOR_EXHAUST_1_1.gcode	10/26/2023 - 11:58 AM · 10/27/2023 - 01:07 PM	23h 29m	BigRep - PLX - 1.29/1.29 kg	Print aborted	
17	BONE3_suojus.gcode	10/25/2023 - 07:52 AM · 10/26/2023 - 07:59 AM	1d 0m	BigRep - HI-TEMP - 1.46/1.46 kg	Print finished	
18	BigRep_One_4_XY_Step_01_0.6_NZ_0.3_LH_0.8_LW.gcode	10/19/2023 - 01:49 PM · 10/19/2023 - 01:49 PM	0m	BigRep - PLA - 0.00/0.00 kg	Print aborted	BigRep - PLA - 0.00/0.00 kg
19	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/26/2024 - 12:58 PM · 3/28/2024 - 02:27 PM	1d 23h 9m	BigRep - BVOH - 0.06/0.03 kg	Print finished	BigRep - PLX - 2.48/2.31 kg
20						
21						

Figure 10 Screenshot of the Collected data sheet.

7.1.2 Processing the data

The "Processed data" sheet is where the collected data is processed into a readable format that Excel and Power BI can read, this is needed as the data that's collected from BigRep Connect is in a format that neither Excel or Power BI can't read or is read by both as being a text.

	A	B	C	D	E	F	G	H
1	Start date	Start time	time Day, Ho	Days	Hours	Minutes	Total print time (Hours)	Raw material data
2	3/26/2024	12:58 PM	0m	0	0	0	0,00	BigRep - BVOH - 0.00/0.03 kg
3	3/26/2024	04:35 AM	3m	0	0	3	0,05	BigRep - BVOH - 0.00/0.03 kg
4	3/25/2024	10:17 AM	18h 0m	0	18	0	18,00	BigRep - BVOH - 0.01/0.03 kg
5	3/23/2024	10:20 AM	1d 23h 8m	1	23	8	47,13	BigRep - BVOH - 0.06/0.03 kg
6	3/21/2024	07:26 AM	1d 23h 8m	1	23	8	47,13	BigRep - BVOH - 0.06/0.03 kg
7	3/21/2024	07:04 AM	0m	0	0	0	0,00	BigRep - BVOH - 0.00/0.03 kg
8	3/20/2024	11:16 AM	19h 32m	0	19	32	19,53	BigRep - BVOH - 0.01/0.03 kg
9	3/18/2024	11:37 AM	1d 23h 8m	1	23	8	47,13	BigRep - BVOH - 0.06/0.03 kg
10	11/24/2023	04:50 AM	3d 22h 58m	3	22	58	94,97	BigRep - PLX - 4.62/4.98 kg
11	11/19/2023	03:08 PM	4d 5h 44m	4	5	44	101,73	BigRep - PLX - 4.98/4.98 kg
12	11/19/2023	02:50 PM	3m	0	0	3	0,05	BigRep - PLA - 0.00/0.01 kg
13	11/19/2023	02:30 PM	0m	0	0	0	0,00	BigRep - PLA - 0.00/0.01 kg
14	11/19/2023	02:25 PM	0m	0	0	0	0,00	BigRep - PLA - 0.00/0.01 kg
15	11/2/2023	08:06 AM	0m	0	0	0	0,00	BigRep - PLX - 0.00/7.16 kg
16	10/26/2023	11:58 AM	23h 29m	0	23	29	23,48	BigRep - PLX - 1.29/1.29 kg
17	10/25/2023	07:52 AM	1d 0m	1	0	0	24,00	BigRep - HI-TEMP - 1.46/1.46 kg
18	10/19/2023	01:49 PM	0m	0	0	0	0,00	BigRep - PLA - 0.00/0.00 kg
19	3/26/2024	12:58 PM	1d 23h 9m	1	23	9	47,15	BigRep - BVOH - 0.06/0.03 kg
20								0
21								0
22								0
23								0

	I	J	K	L	M	N	O
1	Type of material used	actually used / simulated use	Amount of material used (Kg	2nd Raw material data	2nd Type of material use	2nd actually used / simulated us	2nd Amounbt of material used (Kg)
2	BVOH	0.00/0.03 kg	0,00	BigRep - PLX - 0.00/2.31 kg	PLX	0.00/2.31 kg	0,00
3	BVOH	0.00/0.03 kg	0,00	BigRep - PLX - 0.00/2.31 kg	PLX	0.00/2.31 kg	0,00
4	BVOH	0.01/0.03 kg	0,01	BigRep - PLX - 0.95/2.31 kg	PLX	0.95/2.31 kg	0,95
5	BVOH	0.06/0.03 kg	0,06	BigRep - PLX - 2.48/2.31 kg	PLX	2.48/2.31 kg	2,48
6	BVOH	0.06/0.03 kg	0,06	BigRep - PLX - 2.49/2.31 kg	PLX	2.49/2.31 kg	2,49
7	BVOH	0.00/0.03 kg	0,00	BigRep - PLX - 0.00/2.31 kg	PLX	0.00/2.31 kg	0,00
8	BVOH	0.01/0.03 kg	0,01	BigRep - PLX - 1.06/2.31 kg	PLX	1.06/2.31 kg	1,06
9	BVOH	0.06/0.03 kg	0,06	BigRep - PLX - 2.48/2.31 kg	PLX	2.48/2.31 kg	2,48
10	PLX	4.62/4.98 kg	4,62	0		0	
11	PLX	4.98/4.98 kg	4,98	0		0	
12	PLA	0.00/0.01 kg	0,00	0		0	
13	PLA	0.00/0.01 kg	0,00	0		0	
14	PLA	0.00/0.01 kg	0,00	0		0	
15	PLX	0.00/7.16 kg	0,00	0		0	
16	PLX	1.29/1.29 kg	1,29	0		0	
17	HI-TEMP	1.46/1.46 kg	1,46	0		0	
18	PLA	0.00/0.00 kg	0,00	BigRep - PLA - 0.00/0.00 kg	PLA	0.00/0.00 kg	0,00
19	BVOH	0.06/0.03 kg	0,06	BigRep - PLX - 2.48/2.31 kg	PLX	2.48/2.31 kg	2,48
20		0		0		0	
21		0		0		0	
22		0		0		0	
23		0		0		0	

Figure 11 Screenshot of the Processed data sheet.

The first set of collected data that is processed is the "Time and date" data, this is done to extract the start date and time from a text that contains the start date, time, and end date and time. The start date and time are the only data that is needed from that set of collected data. To extract the start, date the formula below is used.

```
=LEFT('Collected data'!B2:INDEX('Collected data'!B:B; MATCH("ZZZ"; 'Collected data'!B:B)); 10)
```

This formula works by using the LEFT function to extract a specific number of characters from the beginning of a string of text, in this case, ten characters starting from cell B2 to the last non-empty cell in column B in the "Collected data" sheet.

```
=MID('Collected data'!B2:INDEX('Collected data'!B:B; MATCH("ZZZ"; 'Collected data'!B:B)); 13; 9)
```

The formula above extracts the start time from the time and date value from the previous sheet. The formula works similarly to the previous formula, the only big difference is that instead of using the LEFT function the MID function is used to extract the string of characters. The MID function works similarly to that of the LEFT function, the only difference is that a starting position is given alongside the number of characters that need to be extracted, here the extraction starts at the 13th character and extracts the next nine characters.

	A	B
1	Start date	Start time
2	11/24/2023	04:50 AM
3	11/19/2023	03:08 PM
4	11/19/2023	02:50 PM
5	11/19/2023	02:30 PM
6	11/19/2023	02:25 PM
7	11/2/2023	08:06 AM
8	10/26/2023	11:58 AM
9	10/25/2023	07:52 AM
10	10/19/2023	01:49 PM
11		

Figure 12 Screenshot of the formatted Start date and time in the Processed data sheet.

Calculating the total print time in hours is a bit more complicated as making the formula too complicated could lead to the formula failing easily, as the way the data is written varies quite a bit.

Sometimes it is displayed as days, hours, minutes or hours, and minutes or even only minutes. This means that the formula must take into consideration the different ways the print time can be written, that it might find the number of days missing or that the time is given as days and minutes or only hours and minutes.

Each formula below is used to calculate the total print time in hours and each one is followed by a brief explanation of how each formula works.

```
='Collected data'!C2:INDEX('Collected data'!C:C; MATCH("ZZZ"; 'Collected data'!C:C))
```

The formula above brings the total print time data from the “Collected data” sheet over, it is primarily done to cut down on the length of the formulas that are going to be needed to calculate the total print time in hours. The formula works similarly to the ones used in the process of extracting the start date and time, the only difference is the cell that’s referred to and that the data is not processed.

```
=IF(C2=""; ""; IF(ISNUMBER(SEARCH("d"; C2)); VALUE(LEFT(C2; SEARCH("d"; C2)-1)); 0))
```

The formula above is used to extract the value of days spent printing and works by first looking at the cell to check if the cell is empty or not, if empty the value is returned as blank and if not empty it moves onto the next step. Next, it looks for the letter “d” and if the letter is found the value in front of it is extracted using the LEFT function, and the value of characters to extract is set to -1, if the letter “d” is not found in the cell the value is returned as a zero.

```
=IF(OR(ISBLANK(C2);C2="");"";IFERROR(VALUE(MID(C2;SEARCH("d";C2)+2;SEARCH("h";C2)
-SEARCH("d";C2)-2));IF(ISNUMBER(SEARCH("h";C2));VALUE(LEFT(C2;SEARCH("h";C2)-
1));0)))
```

The formula above is used to extract the hour value and works in a similar way as the day value formula but a couple of extra steps are needed to consider the possibility that the letter “d” is missing.

First and foremost, it checks as the previous formula if the cell is empty or not, if not empty it moves on to the next step where it looks for “d” and “h” and extracts the string of characters between it using the MID function, the extracted characters is then converted into a number using the VALUE function. IFERROR is used to handle the case that this step isn’t successful, and the combination of “d” and “h” isn’t found in the cell, if so, it moves on to the next step.

In case the combination of “d” and “h” is not found in the cell it moves on to the next steps where it only looks for the letter “h”. These steps work in the same way as the previous formula, using the LEFT function and the value -1 to extract the character and then using the VALUE function to convert the character into a number.

In case none of the previous steps are successful it returns the value as zero.

```
=IF(OR(ISBLANK(C2);C2="");"";IFERROR(VALUE(MID(C2;SEARCH("h";C2)+2;IFERROR(SEARCH("m";C2);LEN(C2)+1)-SEARCH("h";C2)-2));IF(ISNUMBER(SEARCH("m";C2));IFERROR(VALUE(LEFT(C2;SEARCH("m";C2)-1));0);0)))
```

The formula above extracts the minutes and works in similar ways as the previous formula, the only difference is the possible combination of characters that can be found. Instead of looking for a possible combination of "d" and "h" it looks for "h" and "m", in case a combination of "h" and "m" isn't found it moves on to the next step where it looks for "m" only and if found extracts the number in the same way as in the previous formulas.

```
=IF(ISBLANK(C2); ""; IFERROR(D2*24; 0) + IFERROR(E2; 0) + IFERROR(F2/60; 0))
```

To calculate the total print time value in hours the formula above is used to calculate the sum of the three previous formulas.

The formula starts by checking if the cell is empty or not, if empty it returns the value as blank and if it's not empty it moves on to the next step. In the step the formula converts the value in a cell in column "D" into hours by taking the value times 24, IFFERROR here and in the following steps handles the case that the cell is empty, or the calculation is not successful and if so moves onto the next step and returns the value for that calculation as zero. The third step is just taking the value straight from a cell in column "E" while the fourth step takes the value in the cell and divides it by 60. Lastly, all the values are added up to get the total print time in hours.

C	D	E	F	G
time Day, Ho	Days	Hours	Minutes	Total print time (Hours)
3d 22h 58m	3	22	58	94,97
4d 5h 44m	4	5	44	101,73
3m	0	0	3	0,05
0m	0	0	0	0,00
0m	0	0	0	0,00
0m	0	0	0	0,00
23h 29m	0	23	29	23,48
1d 0m	1	0	0	24,00
0m	0	0	0	0,00

Figure 13 Screenshot of the calculated values in the Excel file.

To get the values for the amount and type of material that is used requires a couple of steps to get both of these values.

```
=+'Collected data'!D2
```

The first formula above brings the “Material and amount” value that was on the “Collected data” sheet over to the “Processed data” sheet.

```
=IFERROR(MID(H2; SEARCH(" - "; H2) + 3; SEARCH(" - "; H2; SEARCH(" - "; H2) + 3) -
SEARCH(" - "; H2) - 3); "")
```

The formula above extracts the type of material used from the “Raw material data” cell. This formula works by first using the SEARCH function to look for the two “-“ that appear in the “Raw material data” cell, the first “-“ being the start position for the extraction and using 3 to move the starting position to where the first character of the materials name should be. The second “-“ indicates where the extraction should end.

The two following formulas are used to extract the amount of material that is used, they are split into two formulas to cut down on the length of the formulas as well to minimize the chance of the formulas failing due to differences in how the values in the cell are written.

```
=TRIM(RIGHT(SUBSTITUTE(H2;"-";REPT(" ";LEN(H2)));LEN(H2)))
```

The first step in extracting the value for the amount of used material is to extract the actually used and simulated used amount of material from the “Raw material data”, this is done with the formula above.

The formula works by first replacing all the hyphens “-“ in the text with blank spaces, this is then followed by the right function that extracts all the data starting from the right side until the last hyphen in the text. Lastly, the Trim function is used to remove any trailing spaces at the end or start of the extracted text.

It is important to note here that the two values displayed are actually used amount of material and simulated used material. The usually lower value to the left is always the actually used amount while the amount on the right is the simulated used material given by the slicer.

```
=IF(ISBLANK(J2); ""; IFERROR(SUBSTITUTE(LEFT(J2; SEARCH("/"; J2) - 1); "."; ","); ""))
```

The formula above extracts the actually used amount of material (kg) from the “actually used/simulated used material” cell.

This formula works in two steps. First, it checks if the cell in column “J” is empty or not, if empty it returns the value as blank, and if not empty moves on to the next step. Next, it uses the SEARCH function to look for a “/”, if none is found it returns the value as blank. If a slash is found it uses the LEFT function to extract the value from the beginning of the text until the slash before using the SUBSTITUTE function the replace the “,” with “.”.

H	I	J	K
Raw material data	Type of material used	actually used / simulated use	Amount of material used (Kg)
BigRep - PLX - 4.62/4.98 kg	PLX	4.62/4.98 kg	4,62
BigRep - PLX - 4.98/4.98 kg	PLX	4.98/4.98 kg	4,98
BigRep - PLA - 0.00/0.01 kg	PLA	0.00/0.01 kg	0,00
BigRep - PLA - 0.00/0.01 kg	PLA	0.00/0.01 kg	0,00
BigRep - PLA - 0.00/0.01 kg	PLA	0.00/0.01 kg	0,00
BigRep - PLX - 0.00/7.16 kg	PLX	0.00/7.16 kg	0,00
BigRep - PLX - 1.29/1.29 kg	PLX	1.29/1.29 kg	1,29
BigRep - HI-TEMP - 1.46/1.46 kg	HI-TEMP	1.46/1.46 kg	1,46
BigRep - PLA - 0.00/0.00 kg	PLA	0.00/0.00 kg	0,00
0		0	
0		0	

Figure 14 Screenshot of the processed material data and all the four steps.

7.2 PB data

"PB data" or Power Bi data is the Excel file where the processed data from the BigRep log is extracted into, the reason why two separate Excel files are used is to prevent or at least minimize the chance of Excel crashing due to many calculations being done all at once in one big file.

7.2.1 Importing the data

The first step is to import the formatted data from the "BigRep Log" that is going to be needed for the Power Bi report.

The data that are imported are the following: Print name, Start date, Start time, Total print time, Type of material used, Amount of material used (kg), 2nd Type of material used, 2nd Amount of material used (kg) as well as print status.

While data like "Print name" and "Start time" are not needed for the Power Bi report its still imported as it will work as a way to easily ID a print, "Start time" specifically for cases where multiple prints with the same name might have been done during a day.

```
='[BigRep log recovered.xlsx]Collected data'!$A$1:$A$10000
```

Above is the formula that is used to import the data from the "BigRep Log" file, the only difference in the formula is the specific column from which the data ranging from 1st to the 10000th cell is retrieved. The only extra step that has been done is calculating the "Total amount of material used", which is just the sum of the "Amount of material used" and "2nd Amount of material used".

	A	B	C	D	E	F	G	H	I	J
1	Print name	Start date	Start time	Total print time (Hours)	Type of material used	Amount of material used (Kg)	2nd Type of material used	2nd Amounbt of material used (Kg)	Total amount of material used	Print status
2	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/26/2024	12:58 PM	0,00	BVOH	0.00	PLX	0.00	0	Print aborted
3	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/26/2024	04:35 AM	0,05	BVOH	0.00	PLX	0.00	0	Print aborted
4	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/25/2024	10:17 AM	18	BVOH	0.01	PLX	0.95	0,96	Print aborted
5	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/23/2024	10:20 AM	47,13	BVOH	0.06	PLX	2.48	2,54	Print finished
6	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/21/2024	07:26 AM	47,13	BVOH	0.06	PLX	2.49	2,55	Print finished
7	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/21/2024	07:04 AM	0,00	BVOH	0.00	PLX	0.00	0	Print aborted
8	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/20/2024	11:16 AM	19,53	BVOH	0.01	PLX	1.06	1,07	Print aborted
9	BONE4_PABA599032--_ROLLER_GUIDE-FOR_W46_AND_W50_PULSATION_DAMPER.gcode	3/18/2024	11:37 AM	47,13	BVOH	0.06	PLX	2.48	2,54	Print finished
10	BONE4_PABA659291--_FRAME_2.gcode	11/24/2023	04:50 AM	94,97	PLX	4.62		0	4,62	Print aborted
11	BONE4_PABA659291--_FRAME_2.gcode	11/19/2023	03:08 PM	101,73	PLX	4.98		0	4,98	Print finished
12	BigRep_One_4_Z_T1_0.6_NZ_0.3_LH_0.8_LW.gcode	11/19/2023	02:50 PM	0,05	PLA	0.00		0	0	Print aborted
13	BigRep_One_4_Z_T1_0.6_NZ_0.3_LH_0.8_LW.gcode	11/19/2023	02:30 PM	0,00	PLA	0.00		0	0	Print aborted
14	BigRep_One_4_Z_T1_0.6_NZ_0.3_LH_0.8_LW.gcode	11/19/2023	02:25 PM	0,00	PLA	0.00		0	0	Print aborted
15	BONE3_PABA654161--_DISTANCE_GUIDE-FRAME.gcode	11/2/2023	08:06 AM	0,00	PLX	0.00		0	0	Print aborted
16	BONE3_PABA703570--_ASSEMBLY_JIG-PRIMARY_FIXTURE_FOR_EXHAUST_1_1.gcode	10/26/2023	11:58 AM	23,48	PLX	1.29		0	1,29	Print aborted
17	BONE3_suojus.gcode	10/25/2023	07:52 AM	24,00	HI-TEMP	1.46		0	1,46	Print finished
18	BigRep_One_4_XY_Step_01_0.6_NZ_0.3_LH_0.8_LW.gcode	10/19/2023	01:49 PM	0,00	PLA	0.00	PLA	0.00	0	Print aborted
19	0	0	0						#VALUE!	

Figure 15 The imported data in PB data Excel file.

7.2.2 Building up the first data table

Of the imported data not, everything is needed for the Power Bi report, data like “Print name” and “Start time” is only included to make identifying a specific print much easier as prints can share the same start date, print time, used amount of material, etc. but can't share the same start time and date.

Once the data has been imported the next step is to build up the first data table that is going to work as the “Master data table”, the data table that all the following calculations and Power Bi for some of its tables are going to use as a source.

Most of the data is directly taken from the list of imported data without any extra steps being necessary as the data is already in a format that both Excel and Power Bi can read and understand. Only two of the data “Year extracted” and “Print failed or not?” require extra steps, a brief explanation of the data and an overview of the formula are below.

```
=MID(K2:K10000; SEARCH("."; K2:K10000; SEARCH("."; K2:K10000) + 1) + 1; 4)
```

The first formula is the one used for the “year extracted” data, this as the name might imply is the year extracted from the “Start date” in column “K”.

The formula works by using the “MID” function to extract the following four characters. The starting point for the function is found by the formula by using two “SEARCH” functions, the first “SEARCH” function looking for the first “.” And the second “SEARCH" is used to find the following “.” after the first one.

```
=IF(J2=0; ""; IF(OR(ISNUMBER(SEARCH("Print finished"; J2)); ISNUMBER(SEARCH("Print finishedExpectations met"; J2))); "Print Successful"; "Print Failed"))
```

The next formula above is used to answer the question if the print failed or not. If failed, the result of the cell will read “Print Failed” If the print was successful it reads “Print Successful”.

The formula works in three steps. First, it checks if the cell in column “J” is empty or not, if empty it returns the value as blank if not empty it moves on to the next step. In the next step, it uses the “SEARCH” function to look for the phrase “Print finishedExpectations met” or “Print Successful” and if either of these phrases is found the result of the cell is “Print Successful” while if neither of these phrases is found the result of the cell is “Print failed”.

	K	L	M	O	P	Q	R	S	T	U
1	Start date	Start time	Total print time (Hours)	Total Amount used	1st Material usedmn1	1st Amount used (Kg)	2nd Material used	2nd Amount used (Kg)	year extracted	Print fail or not?
2	3.26.2024	12:58 PM	0,00	0	BVOH	0	PLX	0	2024	Print Failed
3	3.26.2024	04:35 AM	0,05	0	BVOH	0	PLX	0	2024	Print Failed
4	3.25.2024	10:17 AM	18,00	0,96	BVOH	0,01	PLX	0,95	2024	Print Failed
5	3.23.2024	10:20 AM	47,13	2,54	BVOH	0,06	PLX	2,48	2024	Print Successful
6	3.21.2024	07:26 AM	47,13	2,55	BVOH	0,06	PLX	2,49	2024	Print Successful
7	3.21.2024	07:04 AM	0,00	0	BVOH	0	PLX	0	2024	Print Failed
8	3.20.2024	11:16 AM	19,53	1,07	BVOH	0,01	PLX	1,06	2024	Print Failed
9	3.18.2024	11:37 AM	47,13	2,54	BVOH	0,06	PLX	2,48	2024	Print Successful
10	11.24.2023	04:50 AM	94,97	4,62	PLX	4,62		0	2023	Print Failed
11	11.19.2023	03:08 PM	101,7333333	4,98	PLX	4,98		0	2023	Print Successful
12	11.19.2023	02:50 PM	0,05	0	PLA	0		0	2023	Print Failed
13	11.19.2023	02:30 PM	0	0	PLA	0		0	2023	Print Failed
14	11.19.2023	02:25 PM	0	0	PLA	0		0	2023	Print Failed
15	11.2.2023	08:06 AM	0	0	PLX	0		0	2023	Print Failed
16	10.26.2023	11:58 AM	23,48333333	1,29	PLX	1,29		0	2023	Print Failed
17	10.25.2023	07:52 AM	24	1,46	HI-TEMP	1,46		0	2023	Print Successful
18	10.19.2023	01:49 PM	0	0	PLA	0	PLA	0	2023	Print Failed
19	0	0		0		0		0	#VALUE!	
20	0	0		0		0		0	#VALUE!	
21	0	0		0		0		0	#VALUE!	
22	0	0		0		0		0	#VALUE!	
23	0	0		0		0		0	#VALUE!	
24	0	0		0		0		0	#VALUE!	
25	0	0		0		0		0	#VALUE!	
26	0	0		0		0		0	#VALUE!	
27	0	0		0		0		0	#VALUE!	
28	0	0		0		0		0	#VALUE!	
29	0	0		0		0		0	#VALUE!	
30	0	0		0		0		0	#VALUE!	
31	0	0		0		0		0	#VALUE!	
32	0	0		0		0		0	#VALUE!	
33	0	0		0		0		0	#VALUE!	
34	0	0		0		0		0	#VALUE!	
35	0	0		0		0		0	#VALUE!	

Data process | 2023 | 2024 | 2025 | 2026 | 2027 | 2029 | 2030 | 2028 | 2031 | 2032 | 2033

Figure 16 Screenshot of the Processed imported data in PB data Excel file.

7.2.3 Total and yearly summary

The step that’s done in the Excel file before moving on to the Power Bi report is summarizing data for both the “Total” and yearly (summary of the data for each year) summary, this is done to ensure that all the data needed for the Power Bi report is available.

The following is going to be a summary of the data that is summarized in the tables that can be seen in Figures 15 & 16. The formulas won't be displayed as they are quite simple, it should be clear based on the explanations below of how they work.

1) **Total print time:** This is the total time spent printing and is calculated by simply using the "SUM" function to calculate the sum of all the values in column "M" and "Total print time (Hours)".

2) **Total Print Successful & Total Print Failure:** Counts the number of times that a print has been successful. This one works by using the "COUNTIF" formula which counts the number of times "Print Successful" appears in column "U", the same formula is used to count the number of times "Print Failed" appears with the only difference being that it looks for "Print Failed" instead.

3) **Total PLA kg and other material:** Counts the total sum of a specific material, with the only difference in the formula between the materials being what material it looks for. The formula works by using the "SUMIFS" function to summarize the values of the cells in column "Q" if the value in column "P" on the same row contains the specific material that the formula is told to look for, this is repeated for the second material where it checks columns "R" and "S" and the values from these two columns are added together.

4) **Total amount of material used (kg):** This is the sum of the "Total (material) kg" and uses the "SUM" function for the range from "Total PLA kg" to "Total HI-TEMP-CF kg".

5) **Total wasted material and successfully used material (kg):** This is the sum of material that has been either successfully used or wasted due to a print failing or a print being aborted mid-print. Works by using the "SUMIFS" function and counts the sum of column "M" if the value of the cell on the same row in column "U" reads "Print Successful" or "Print Failed" depending on if the sum of wasted or successful material is counted.

Total

.	total print time	Total Print Successful	Total Print Failure	Total PLA kg	Total PLX kg	total HI-Temp kg	Total BVOH kg	total TPU kg	total PETG kg	total PRO HT	total HI-TEMP-CF kg	Total amount of material used (kg)	Total wasted material (kg)	Total Successfully used material (kg)
Total	423,22	5	12	0,00	20,35	1,46	0,20	0,00	0,00	0,00	0,00	22,01	7,94	14,07

Figure 17 Screenshot of the Total data summary from PB data Excel file.

The yearly summary works the same as the "Total summary", with the main difference being that all formulas use the "COUNTIFS" function to ensure that it only counts the values if the value in column "T" is the specific year (in the case for Figure 16 it only counts the value for a cell if the value in column "T" reads "2023").

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Year	Print Successful	Print Failed	PLA Kg	PLX Kg	HI-Temp Kg	TPU kg	BVOH kg	PETG kg	PRO HT kg	HI-TEMP-CF kg	Total amount of material used (kg)	Total print time (hr)	Total wasted material (kg)	Total Successfully used material (kg)
2	2023	2	7	0	10,89	1,46	0	0	0	0	0	12,35	244,23	5,91	6,44

Figure 18 Screenshot of the 2023 data summary from PB data Excel file.

8 Wärtsilä Additive Manufacturing Log Bot

With the source for the data and a way to retrieve the data chosen, the next step is to write the script. The bot will be used to collect the data as well as process it so that Power Bi will be able to read and understand it.

This is where WAML (Wärtsilä Additive Manufacturing Log Bot) comes into play. The bot's task is the following: Log into BigRep connect and collect the specific data from it, paste the collected data into the BigRep log Excel file to log the data. Lastly, it performs Excel calculations to process the collected data into a format that Power Bi can understand. These steps will then be repeated after a set interval to ensure the data displayed on Power BI is up to date.

The above-mentioned is a summary of what the WAML bot does and in what order. A more in-depth overview of the process as well as how each step works can be found in the following sub-chapters below.

8.1 Data collection

The collection of data from BigRep Connect is not only the most important task for the bot but also the first step it takes once the process is started.

The first step at this stage is to log into BigRep connect, to do this the application "Use Application/Browser" is used to, this application makes it possible for Studio to open an application or browser which it then can use. For this it opens Google Chrome and uses the "Type into" application to write the link to BigRep connect after which the bot will hit enter. Once this is done the bot will arrive at the login page for Connect, here it will once more use the "Type into" application to write in the login credentials which is followed by the "Click" function to hit the login button to log into the site and arrive at the "Print History" page.

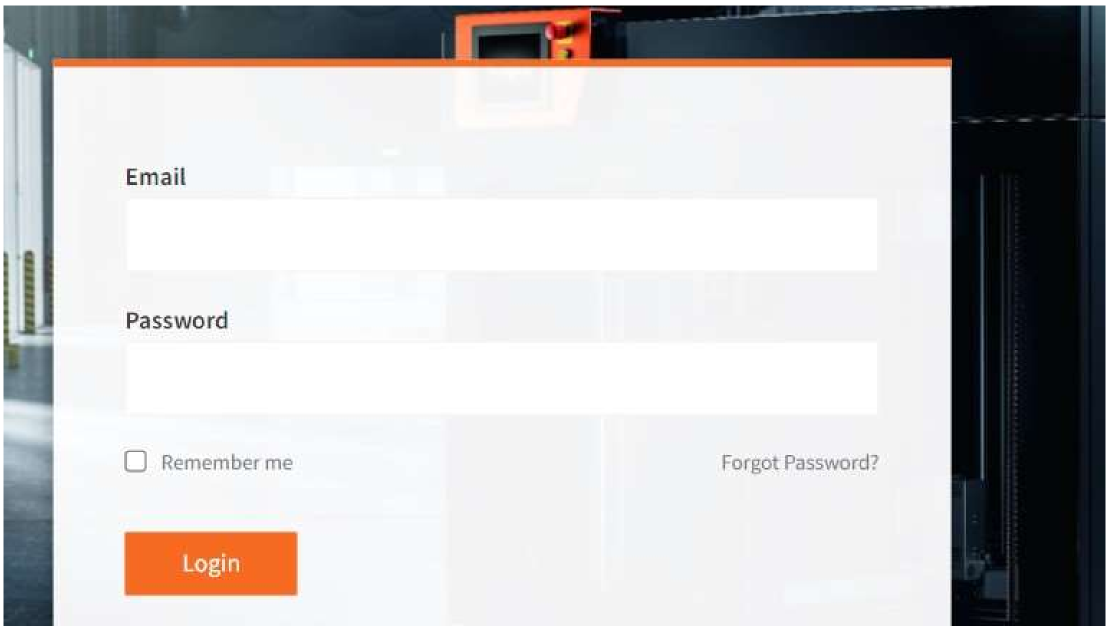


Figure 19 Login page to BigRep Connect

On the Print history page, we get all the data we need like print name, start time and date, type of material, used amount of material, and the status of the print. To collect this data the

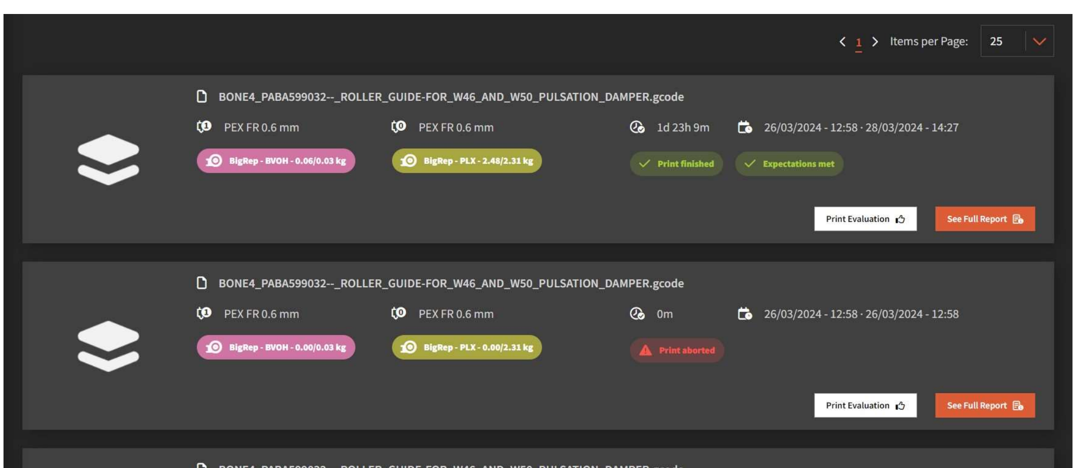


Figure 20 Screenshot of the Print history page with logged prints.

“Data scraping” application is used, but before it is used there are two things that need to happen before that. First, a ten-second delay happens as soon as the bot is logged in on the site (the delay is added by using the “Delay” function), it is set to ensure that everything on the page is loaded in before the bot starts to try and navigate the site. Secondly, the “Mouse Scroll” application is needed to be used to navigate down the page to where the print history can be found.

The way the Data Scraping tools work is by extracting structured data from the application, browser, or document that’s open. What makes data “structured data” is data that repeats in a predictable pattern which makes it possible for Studio to always know where the data can be found, a great example of structured data is the example used by Studio Documentation on their page regarding Data Scraping where they give the following example “For example, all Google search results have the same structure: a link at the top, a string of the URL and a description of the web page” (UiPath, 2024).

With the help of the data scraping tool, Studio can find data that matches the pattern of the original data that you first showed it, thus collecting it and making a column of data with it and a second column can be made if a new set of data in a new pattern is shown. The data collected through data scraping is then saved as a data table. Collecting data from multiple pages is possible as well if the data follows a similar pattern and a way for Studio to navigate to the next page is given.

Originally collecting data from multiple pages was planned, but there was some problem with Studio seeming to forget the pattern it was supposed to follow, specifically for the second material as well as seeming to miss a couple of prints after moving onto another page. This was solved by having the page set to display the newest 25 prints (this is set in the URL that is typed by Studio) and having Studio set to only collect data from the first page as the amount is enough to ensure all the prints in a month are collected.

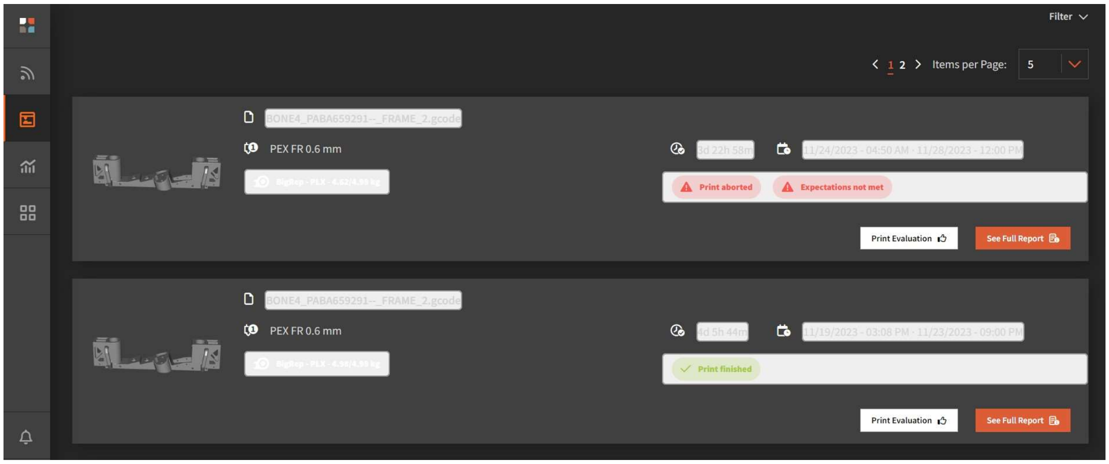


Figure 21 Screenshot showing the highlighted data that Ui-Path has found a pattern for.

By using the Data scraping tool data like print name, start time and date, end time and date, total print time, used material and amount as well as print status can be extracted from the page. The data is then saved into a Data Table called "ExtractDataTable".

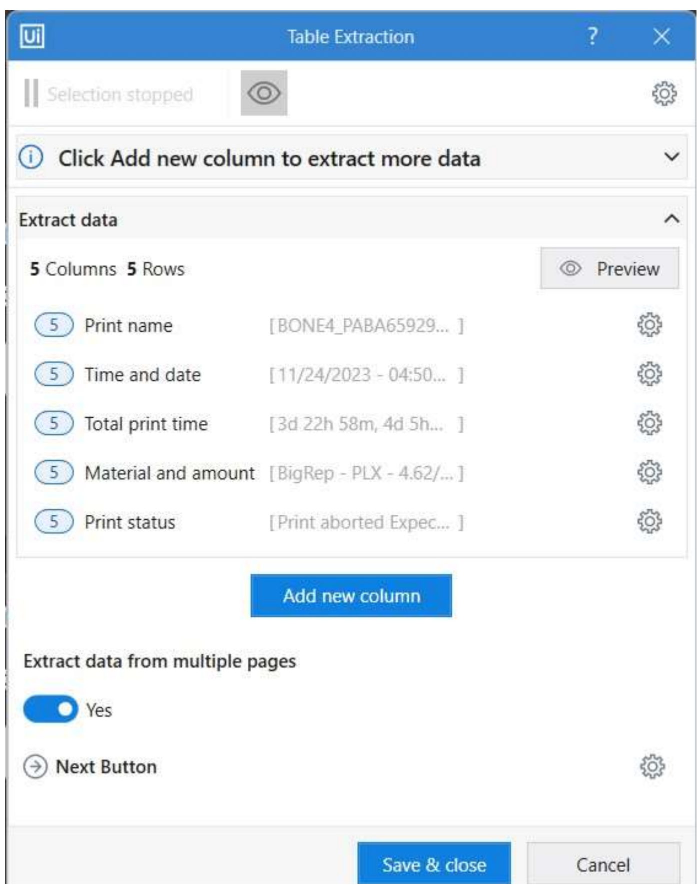


Figure 22 The extracted table of data

8.2 Data pasting

Once the data from the page is collected it needs to be pasted into an Excel file, this step is partly done to create a log of all the prints but also to process the data collected from BigRep connect as the format of some of the data collected by Studio is in a format that neither excel nor Power BI can read.

But before the data can be processed it needs to be added into Excel while at the same time making sure it isn't erasing existing data that's already in the Excel file by the new data being pasted over the old data.

To ensure the old data isn't erased Studio will have to first find the first empty cell in column A in the Excel file as this will mean the new data will be pasted below the old data. For this the following steps are taken by Studio to find the empty cell, using the "Read Range Workbook" application to open and read the specific Excel file, for this to work you'll first have to indicate the specific file to open by selecting it then give the name of the sheet that's to be read. Next what Studio will do with the read Excel file needs to be specified, in this case, the "Assign" application is used to write a variable. In this case, the variable is an introw using the value "DTExcel.Rows.Count+2" to find the first empty row. Lastly the

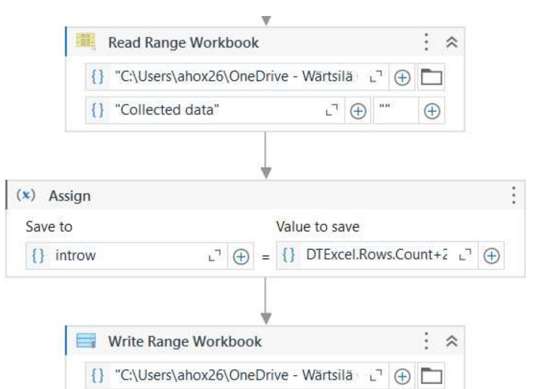


Figure 23 Screenshot showing the process with which Ui-path is able to find the first empty cell

"Write Range Workbook" is used to write the extracted data into the Excel file, here once the specific Excel file is specified, the data table that's to be pasted into it is given so the "ExtractDataTable" is used in this case. Lastly, the starting cell is specified here the starting cell is specified as ""A"&introw" which uses the A column in Excel and the introw variable used in the previous "Assign" application to find the starting cell. Once all this is taken care of the data is pasted into Excel.

8.3 Remove duplicate data

After the data collected from BigRep Connect has been pasted into the Collected data sheet in the BigRep log Excel file there is a need for the data to be processed, to ensure that Power Bi will be able to read the data. But before that, the duplicated data must be removed.

First, Studio needs to open the Excel file, this is done by using the "Use applications" application to open the Excel file into which the data was pasted into. Once the file is open there is a five-second delay to ensure that everything in the Excel file is loaded before Studio starts to perform any of the following steps. Once the delay is over Studio is set to use the "click" application to click on the "Collected data" sheet tab in Excel, this is to ensure that the correct sheet is open.

Once the sheet is open Studio will navigate to the Data tab in Excel and click it, followed by it clicking on column B to highlight the whole column, followed by it then clicking on the "Remove Duplicates" button in Excel.

This will cause a "Remove Duplicates Warning" window to appear, which is Excel saying that it has found data next to the selected data and asking if the other data is also to be included or not, the default setting of expanding the selection is used. To proceed Studio is to click the "Remove Duplicates..." button but due to this being in a new window the "Use Application" application is needed for Studio to be able to proceed, simply select the new window in the "Use Application" and then use the click application to press the button.

It is followed by a new window called "Remove Duplicates" where the columns with data that Excel mentioned in the previous window are displayed. All of these are to remain checked as Excel will search for duplicates per row and to proceed the "Use Application"

Figure 24 Remove Duplicate Warning.

and "Click" applications are used once more.

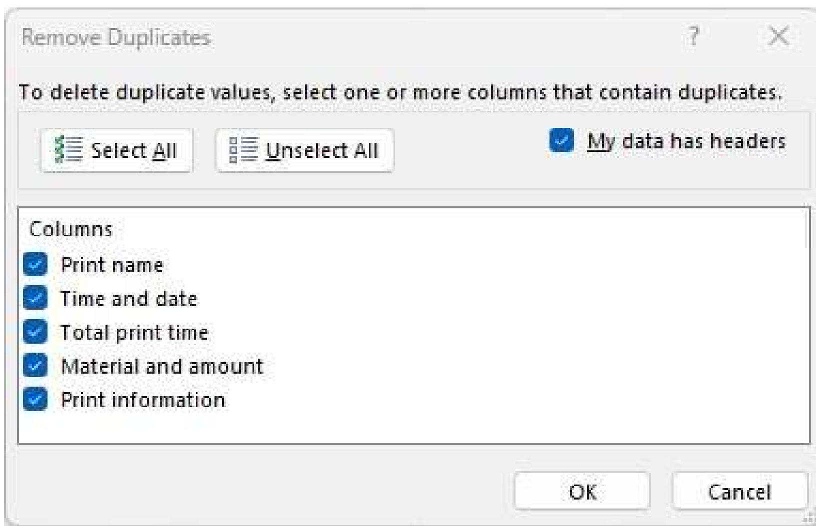


Figure 25 Remove duplicate window

As the Remove Duplicate window is closed another window appears telling how many duplicate values were found and removed. Once Studio closes the window all the data in Excel is updated with duplicate data removed.

8.4 Excel calculations

Usually, Excel can perform calculations by itself and update the sheets whenever a new value is added or updated. The problem though is that due to the number of calculations that need to be done in the Excel file, it will cause it to crash if everything is done at once. Due to this, the Calculations must be done manually instead of automatically, meaning the calculations will happen if the "Calculate Now" is clicked or the Excel file is saved.

This works fine for most of the calculations that need to be done, though there are a couple of calculations that won't be done if not manually double-clicked before pressing enter, the reason for this is unclear and there are no real other options for getting these calculations done other than using this function. The values whose formulas need to be manually calculated are "Start date", "Start time", "Time, Days, Hours and minutes", Days, Hours, Minutes, "Raw material data" and "Actually used/Simulated used". The process uses "Click" and "Keyboard Shortcuts" Applications to manually do the calculations, Studio uses the click function with the click type being set to double to click the first cell in which the formula starts, in this case, it is always on the second row underneath the header. Once the cell is double-clicked the keyboard shortcut application is used to send an enter key command thus making Excel calculate the value in that column. This is then repeated for all the other values.

Once all values that need to be manually calculated are done Studio using the click application moves first to the formula tab and then over to the "Calculate now" button, by clicking it all the remaining values on the sheet are calculated automatically.

Once the calculations are completed Studio clicks on the save icon before closing the file, thus ending the entire process until it is once more activated.

9 Power Bi report

"BigRep Print log" is the name of the Power Bi report that's created from the data collected from BigRep Connect, processed in the "BigRep log" and "BigRep PB data" Excel files, and is designed to give a good overview of the result from all the prints as well an individual report for each year ranging from 2023 to 2033.

As the Power Bi report contains a summary of both the total summary and a summary for each year the choice was made to keep the layout for all the pages identical to make it easier to compare the results on different pages. The following subchapters are going to cover each of the data points that are displayed in the report, what they cover as well as from which table in "BigRep PB data" it draws data from.

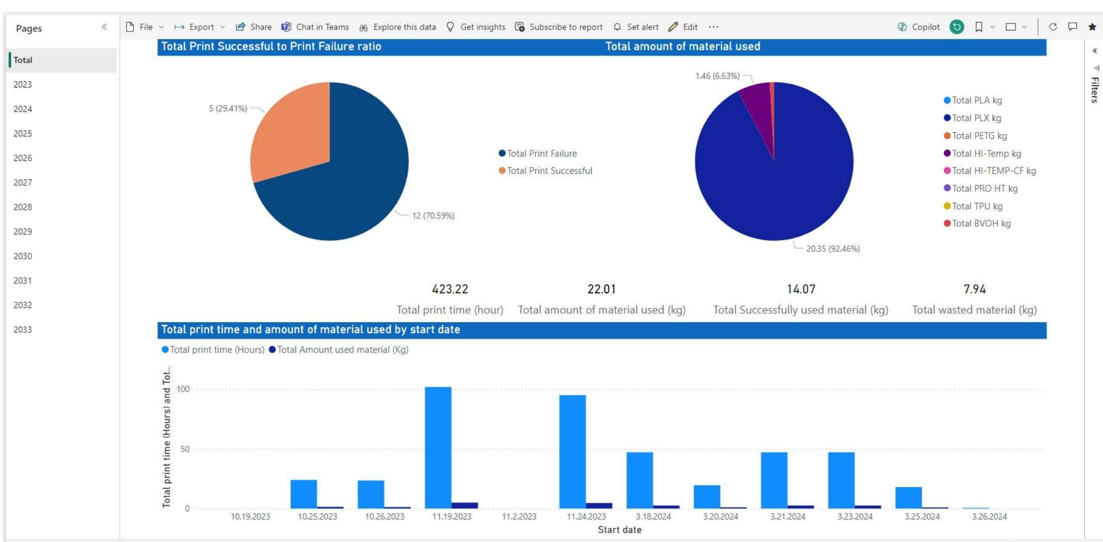


Figure 26 Screenshot of the Power Bi report showcasing the total summary.

9.1 Total Print Successful to Print Failure ratio.

The pie chart below showcases the ratio between successful and failed prints, including the amount of each as well as the percentual value. The source of data for the chart, amount of successful and failed prints can be found in “Table22” for the “Total” report while for each year it can be found in the table representing each year (data for the 2023 number of successful prints and failed prints can be found in the 2023 tab under the name “Print Successful” and “Print failed”, data for the other years are found under the same name in their own tabs).

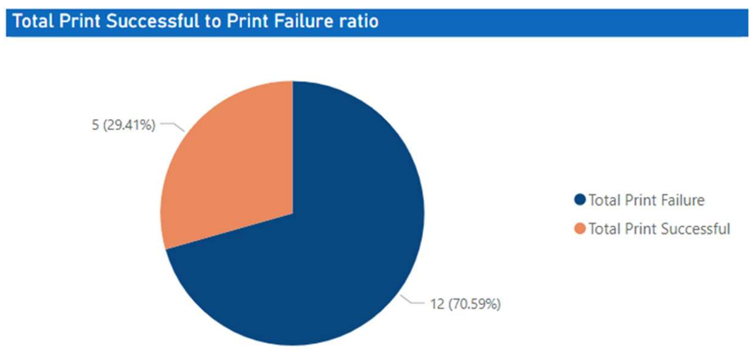


Figure 27 Screenshot of the Print Succesful to Print Failure ratio pie chart.

9.2 Total amount of material used

The pie chart below showcases the ratio of the amount of differential material used, including the amount of each and the percentual value of the material compared with others. The source of data for the chart and the amount of each material can be found in Table22 for the “Total” report while for each year it can be found in the tabs for each year.

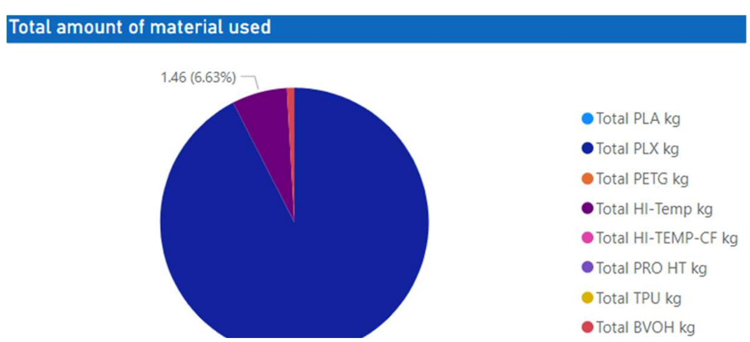


Figure 28 Screenshot of the Total amount of used material used pie chart.

9.3 Total print time and amount of material used by start date.

The Clustered column chart in the report showcases the used amount of material and total print time by date, the idea is that this will help give an idea of how the time and amount of material used correlate with each other. It's worth noting that the Cluster column chart, while able to show columns for both material and time it's not able to show two legends on the y-axis, and the legend in the report showcases the number of hours. Even with a legend for the used amount of material missing the values for the material amount are still accessible by clicking on a column for which you want to know the value for.

Regarding the source used for the chart, it's the same for the charts in "Total" and for each of the years, the only difference is that for the ones showcasing values for a specific year, a filter has been used so that it will only show values for that specific year.

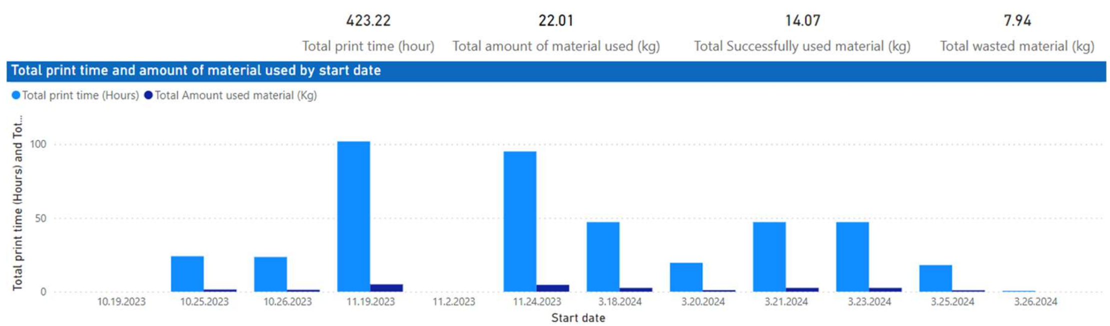


Figure 29 Screenshot of the total print time and amount of material used by start date chart.

Lastly, we got the four values that can be seen in the screenshot above, these are included to give a numeric value of the total time spent printing, the material used as well as material successfully used or wasted.

Sources for these data are the calculations done in the "Total data summary" table in the PB data Excel file.

10 Deployment of the system

Once the system was built, tested, and proven that it was successfully able to collect the data from BigRep Connect and process it into a format that Power BI was able to read and use for the report the next step was to integrate the system into Wärtsiläs network.

10.1 The original plan

The original plan for the system was to have it run on an old laptop, PC or even a Raspberry Pi 4 as the program couldn't be run in the background on a normal laptop that someone was using to work without the user losing control of it for a couple of minutes whenever the program was running. This is due to that the version I created ran on the work laptop, referred to the Excel files on it, and used its screen to navigate the website and Excel file visually, thus a separate laptop or pc was needed so that the program could run without any problems.

10.2 The solution

As a solution to the earlier mentioned problem, it was suggested that I could reach out to Hannes Hudd, manager of Wärtsiläs Business Process Automation Development team, and ask him if his team could create an RPA from the UI-Path Studio program.

Once I had reached out to the team a meeting was quickly arranged to discuss the system, the program I had created, and how it works as well providing answers to any other questions they had about it. Once it was clear how the program worked and what it needed to be able to do the project was handed over to Avelino Salvante Jr. (Solution Expert, RPA) of the team, and the Excel files and Ui-Path Studio files I had were handed over so that he could create the RPA.

The RPA that he created followed mine quite closely when it came to the steps it followed but was in many ways simpler and more effective. The biggest change was removing the whole processing step of the raw extracted data from BigRep Connect which was done in the first Excel file. Instead of having the data first extracted and pasted into the Excel file before processing it, all the processing of the data was done in Ui-Path Studio and then pasted into Excel fully processed.

The processing that's done now in Studio has all the same steps as when it was previously done in Excel, using the same types of formulas and having all the same steps (this includes the extra steps) to ensure that the location of the data is the same as in the old version and thus not needing to make any changes to the Power Bi Excel file.

Once the RPA was set up and was tested and approved the RPA is set to run once a week, on Friday at 4 pm.

11 Adaptability of the process for other printers

The possibility exists for the system to be adapted for use in collecting data from other printers or other sources as well, either to make a brand-new report or add the collected data to the existing report.

The largest change that would need to be made for the process to work is regarding the source of data, this is the source being the one that determines how the data looks and if any form of formatting of the data is required for it to be able to be used. Another aspect that's also worth considering regarding the source is how much or for how long it's able to store data. If there isn't a limit or it's capable of storing multiple years' worth of print data, it could be used as a direct source for Power Bi.

12 Possible future improvements

There are always ways an existing system could be improved and for this system, there are two points of improvements that could be made to ensure the whole process could work even better in the future.

The first point of improvement could be finding a new source for the data to get away from BigRep Connect and being reliant on the site working, especially to ensure all the data presented is up to date. A problem with Connect during the project was having the site being updated with the newest prints once they were completed, the problem seems to be on the BigRep side and leading to the prints displayed on the "Print History" page to not always being up to date. Due to this having another source for the data could be a great improvement of the system, but can be challenging to do so without having to change the software on the printer and thus losing the warranty.

The second and much simpler improvement would be to combine the two Excel files into one file, as the use of two files is a leftover from when all the calculations were done in Excel, and many of those steps not being needed anymore as UI-Path Studio takes care of these in the final version that was made when the RPA was created.

13 Conclusion

The goal of this thesis was to create a system that would log prints from a specific 3D printer and by using the data gathered from the printer create a report. The writer of this thesis considers this goal to have been met. The original goal of the project was to create a management system for all the 3D printers at Wärtsiläs Additive Manufacturing department, though this was quickly narrowed down to only focus on one of the printers, the BigRep "bigrep ONE" printer as it was the one with the most interested in gathering statistic from. The change of the goal to focus on only one printer was helpful as it allowed for a focus on only one printer, one source, and a set of data that needed to be processed.

When it comes to how the project was tackled it was done methodically, starting with the practical side of the project. The first task was to identify potential data sources. Once a suitable source of data was discovered, the next step became retrieving the data, processing and logging the data, followed by the creation of a Power BI presentation based on it. The attention was shifted towards writing the thesis once the majority of the practical work was completed, minimizing the need for possible extensive rewrites due to unforeseen issues.

The project was a challenge as the writer of this thesis had to learn how to use new software and troubleshoot various problems encountered during the testing of the Ui-Path program and Excel. Even with these challenges the solution that was developed utilizing UI-path Studio to collect the data from BigRep Connect, pasting it into Excel to log and process the data before using it to make a Power BI report proved to be successful at the task it was expected to do.

The theory section in this thesis should give a clear and in-depth overview of 3D printing technology, how it works, and the advantages of the technology in manufacturing and private use. The hope is also that an idea of the difference between Information technology (IT) and Operational Technology (OT) was clarified.

In conclusion, the project was successful in meeting its goals, showing the possibility of using UI-Path Studio, Excel, and Power BI to manage and analyze data collected from a 3D printer.

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15 Table of figures