

DESIGNING A 3D-PRINT TOOL FOR INDUSTRIAL ROBOT USING AN EXTERNAL AXIS EXTRUDER

EUROPEAN PROJECT SEMESTER



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ABSTRACT

Since the first 3D printing technology had been created in 1984 by Charles Hull (Stereolithography), this new manufacturing process never stopped to evolve. Nowadays, 3D printers have become more and more accessible and they can be found in many different fields going from rocket engines to functional human organs.

Our project was to attach a 3D printing system to a robotic arm in order to 3D print big object without having a space limitation as if you were using a traditional 3D printer. The 3D printing system will be an extruder mainly composed by a barrel and a plasticizing screw.

To make this project a success, we went through all of these steps: doing a lot of research about 3D printing and about the materials used for printing, buying all the elements for the extruder, building it in Technobothnia laboratory, fixing it to the ABB – IRB – 1200 robot, programming a working solution with simulation, and last but not least, 3D printing a chair for our supervisor.

ABBREVIATIONS

EPS	European Project Semester
3D	Three Dimensional
PM	Project Management
SLS	Selective Laser Sintering
SLM	Selective Laser Melting
EBM	Electronic Beam Melting
FDM	Fused Deposition Modelling
ABS	Acrylonitrile Butadiene Styrene
PLA	Polylactic Acid
PET	Polyethylene Terephthalate
MU	Motor Unit

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I – EPS PRESENTATION

The European Project Semester is a “program offered by nineteen European universities in twelve countries throughout Europe (Finland, The Netherlands, Norway, Poland, Spain, Germany, Belgium, Portugal, France, Romania, Austria and the United Kingdom). The EPS is offered to third year university/college students. EPS is created with engineering students in mind, but other students are also welcome.” (**European Project Semester website**)

“Since its start in 1994, EPS has become a huge success. The EPS-program is crafted to address the design requirements of the degree and prepare engineering students with all the necessary skills to face the challenges of today's world economy. Classes are offered to students in a cohort format; that is students participating in EPS meet together as a group each day to build their engineering skills in class and then meet in teams of 2-10 students to work on their dedicated projects. International student teams work on interdisciplinary projects with commercial businesses and industries, selected to match the students' specializations and capabilities as well as to develop their inter-cultural communication and teamwork skills.” (**Presentation from Novia University of Applied Sciences website**)

The program will run for sixteen weeks, finishing on the 28th of May. As well as the physical project, courses in Swedish, English, Eco-design and Project Management.

II – NOVIA UAS PRESENTATION

Novia UAS (University of Applied Sciences) is “a modern institution offering a high professional education. It was created in 2008 by the merging of the Sydväst Polytechnic and the Swedish Polytechnic.

Novia UAS offers both Bachelor's and Master's degrees as well as further education in Swedish and English these five fields” (**Presentation from Novia University of Applied Sciences website**):

- Technology and Seafaring
- Health and Welfare Business
- Health and Welfare
- Natural Resources
- Arts and Humanities

“Novia University of Applied Sciences is the largest Swedish-speaking UAS in Finland with over 4000 students. With traditions dating back to 1813, Novia University of Applied Sciences offers multidisciplinary higher education with a practical orientation. Novia UAS is training students to become experts and developers based on the requirements of working life. High quality degree programs provide students with a proper platform for their future careers.

You can obtain a degree from Novia UAS in many ways. You can study for an entire Bachelor/Master degree programme in English, you can get a double degree or you can develop yourself or your organisation by using our commissioned education in Finland or abroad.” (**Presentation from Novia University of Applied Sciences website**)

III – PRESENTATION OF THE TEAM

Our small but by no means any less capable team consists of three students arising from different corners of the continent. We are spearheaded by our project leader, Mika Billing.

Ben Cardwell (21) – Glasgow, Scotland

I am currently studying my third year of Mechanical and Electronic Systems Engineering at Glasgow Caledonian University. I have one more year for my Bachelors and a further year for a Masters. I have been taught about many different engineering types in my three years including of course mechanical, electrical, material, power, programmable and chemical. I was attracted to the possibility of exchange for a long time before finding the EPS. Novia's excellent lab facilities and the chance to immerse myself in an environment strange to my norm was both the excitement and nerves that pushed me to apply. I hope to learn a lot about my chosen field, mechanical engineering and work together in a team to produce a great project.

Mathieu Gonzalez (21) – Tarbes, France

I am currently in my fourth year of General Engineering at the ENIT, French National Mechanical/Industrial Engineering School.

The National Engineering School of Tarbes (ENIT) is a 5-year school that has been training general engineers in the fields of Mechanical Engineering and Industrial Engineering for over 50 years.

These five years are divided into ten semesters including a training cycle of three periods of immersion in an industrial environment (two internships and an end-of-studies project), which constitute 30% of the total volume of the curriculum.

From the seventh semester, the school offers five options to its students

- Mechanical engineering
- Industrial engineering
- Engineering of materials and structures and processes
- Integrated systems design
- Buildings and public works

I decided to go for the Engineering of materials and structures and processes which allows me to study: materials and design, commissioning of materials metallurgy, durability, metals and composites.

In terms of international studies, I always wanted to go for an EPS exchange semester instead of a normal semester of studies. Indeed, I really think that you can learn a lot, personally and professionally, by working in a multicultural group to realize a project.

Frédéric Demarbaix (21) – Antwerp, Belgium

I am in my third and last year for my bachelor electromechanics at AP university of applied sciences. AP only offers bachelor degrees in a big variety of fields. Electromechanics is one of them, the first year is for everyone the same but from the second year there are multiple specializations.

- Maintenance
- Automations
- Process Automation
- Climatization
- Technical advisor

In this specialization the last 2 years where specific to the specialization. I have chosen for maintenance. Here I learned what types of maintenance there are, maintenance techniques and have to physically do maintenance on machines.

I wanted to go on the EPS adventure to learn about different cultures and I wanted to see how technical situations get solved in different countries to learn from them and use that in my coming professional life.

IV – BELBIN TEST

IV.1 – ROLE PRESENTATION

Resource Investigators:

“Resource Investigators are innovative and curious. They explore available options, develop contacts, and negotiate for resources on behalf of the team. They are enthusiastic team members, who identify and work with external stakeholders to help the team accomplish its objective. They are outgoing and are often extroverted, meaning that others are often receptive to them and their ideas. On the downside, they may lose enthusiasm quickly, and are often overly optimistic.” (Belbin.com)

Team Workers:

“Team Workers are the people who provide support and make sure that people within the team are working together effectively. These people fill the role of negotiators within the team and they are flexible, diplomatic and perceptive. These tend to be popular people who are very capable in their own right, but who prioritize team cohesion and helping people get along. Their weaknesses may be a tendency to be indecisive, and to maintain uncommitted positions during discussions and decision-making.” (Belbin.com)

Coordinators:

“Coordinators are the ones who take on the traditional team-leader role and have also been referred to as the chairmen. They guide the team to what they perceive are the objectives. They are often excellent listeners and they are naturally able to recognize the value that each team member brings to the table. They are calm and good-natured, and delegate tasks very effectively. Their potential weaknesses are that they may delegate away too much personal responsibility, and may tend to be manipulative.” (Belbin.com)

Plants:

“The Plant is the creative innovator who comes up with new ideas and approaches. They thrive on praise but criticism is especially hard for them to deal with. Plants are often introverted and prefer to work apart from the team. Because their ideas are so novel, they can be impractical at times. They may also be poor communicators and can tend to ignore given parameters and constraints.” (Belbin.com)

Monitors:

“Monitors are best at analysing and evaluating ideas that other people (often Plants) come up with. These people are shrewd and objective, and they carefully weigh the pros and cons of all the options before coming to a decision. Monitor-Evaluators are critical thinkers and very strategic in their approach. They are often perceived as detached or unemotional. Sometimes they are poor motivators who react to events rather than instigating them.” (Belbin.com)

Shapers:

"Shapers are people who challenge the team to improve. They are dynamic and usually extroverted people who enjoy stimulating others, questioning norms, and finding the best approaches for solving problems. The Shaper is the one who shakes things up to make sure that all possibilities are considered and that the team does not become complacent. Shapers often see obstacles as exciting challenges and they tend to have the courage to push on when others feel like quitting.

Their potential weaknesses may be that they're argumentative, and that they may offend people's feelings." (Belbin.com)

Implementers:

"Implementers are the people who get things done. They turn the team's ideas and concepts into practical actions and plans. They are typically conservative, disciplined people who work systematically and efficiently and are very well organized. These are the people who you can count on to get the job done.

On the downside, Implementers may be inflexible and can be somewhat resistant to change." (Belbin.com)

Finishers:

"Finishers are the people who see that projects are completed thoroughly. They ensure that there have been no errors or omissions and they pay attention to the smallest of details. They are very concerned with deadlines and will push the team to make sure the job is completed on time. They are described as perfectionists who are orderly, conscientious and anxious.

However, a Completer-Finisher may worry unnecessarily, and may find it hard to delegate."

(Belbin.com)

IV.2 – TEAM TEST RESULTS

IV.2.1 - INDIVIDUAL RESULTS

Ben-

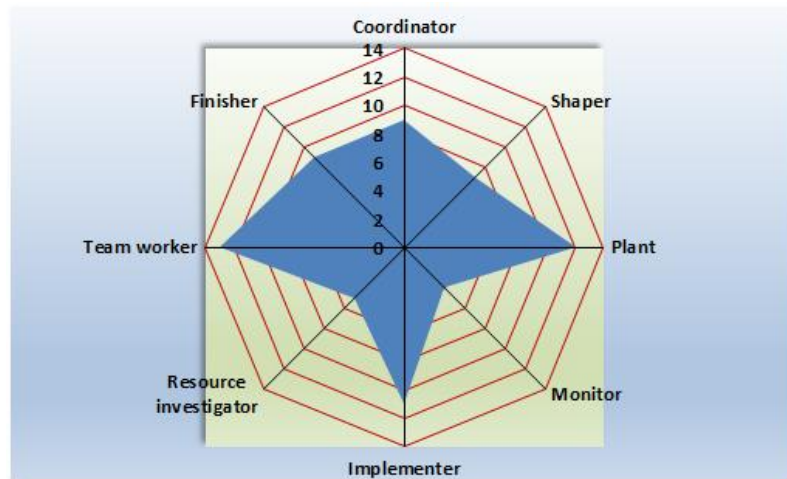


Figure 1: Belbin test Ben

Strengths-

- Cooperative group member, is diplomatic and sensitive to others needs.
- Someone who thinks outside the box to resolve difficult situations.
- Someone to rely on, takes control and gets to work.

Allowable Weaknesses-

- Struggle to confront group confrontation, and can be indecisive.
- Their mind might not always be on task, constantly looking for loopholes/shortcuts.
- Can be perceived as stubborn if things aren't going their way, slow to get on board with others.

Roles Lacking-

- Plant- Could be shy in pressure situations, take a back seat when there is a seemingly difficult task to overcome.
- Resource Investigator- An introvert, might lack enthusiasm for the project.
- Monitor- Avoids making difficult decisions.

Mathieu-

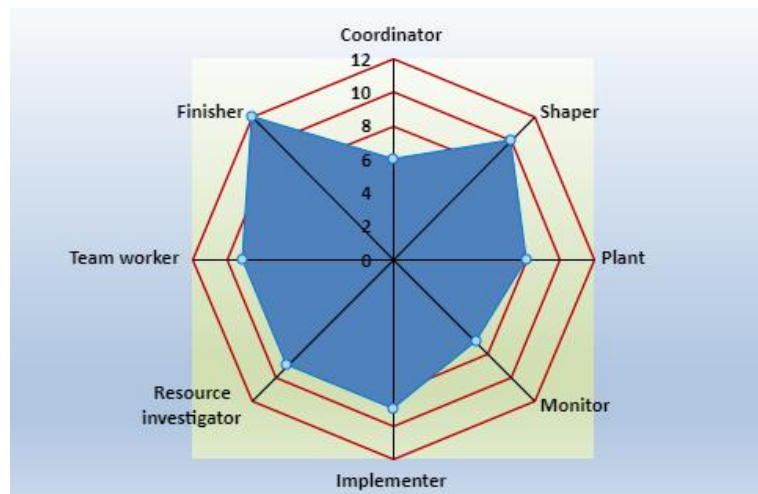


Figure 2: Belbin test Mathieu

Strengths-

- The perfectionist, looks more so at the negatives to maximise project success.
- Cool customer under pressure, has a great work drive and attitude.
- Super enthusiastic, looks out with the project to find new ideas to bring back.

Allowable Weaknesses-

- Potential to become overstressed about the situation leading to lapses in judgement.
- Could be too ruthless in getting tasks done, leading to group conflicts.
- After the initial hype dies down, so too might their enthusiasm.

Roles Lacking-

- Coordinator- Could struggle to lead the group and delegate roles equally.
- Monitor – Unable to take a step back and judge all the options rationally.

Frédéric-

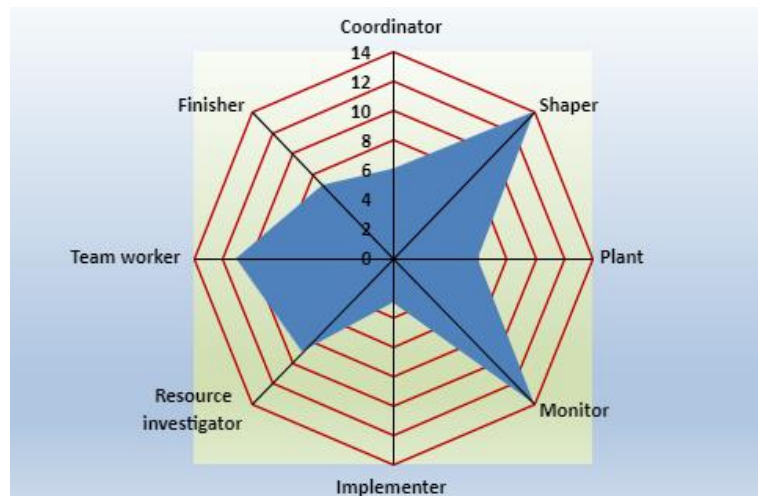


Figure 3: Belbin test Frédéric

Strengths-

- Careful and decisive, takes their time to assess all options before making a decision.
- Strives off of pressure, doesn't lose focus or momentum
- Works hard to provide for the team, gets the team together nicely.

Allowable Weaknesses-

- Struggle to be the driving force of the team, unable to lift others.
- Very headstrong which could lead to provocation with another likeminded member.
- Will put their ideas to the side to keep up good team morale.

Roles Lacking-

- Implementer- Could let other do majority of the work, unreliable.
- Plant- Struggles to find solutions, relies on others to do so.
- Finisher- Might not complete tasks to their fullest, lack of effort.

IV.2.2 OVERALL RESULTS

Findings-

From each of our results we were able to find the teams strengths and weaknesses in each area. This allows us to assign project roles based on ability and shortcomings. Doing this at the start allows us to avoid any wasting of valuable project time in finding out who is suited to each role. We took the results more as a base to work from, rather than fact. Some of the opinions that come from the specific roles could be perceived as quite harsh so taking the questionnaire more loosely and in a constructive reading ensures no demoralization.

One thing that stood out in our collective results was that we did not have a particularly strong coordinator. On the outside this would look like there was no clear leader in the group to organise and dictate project progress. In our case, we are only a group of three so with good communication and cooperation the need for a coordinator will be dramatically reduced. Sharing the responsibility equally ensures everybody knows what they are doing and where the project is at. We all have particularly strong team member scores which is only evident that sharing the responsibility is a good call to make.

V – PRESENTATION OF THE PROJECT

DESIGN A 3D-PRINT TOOL FOR AN INDUSTRIAL ROBOT USING AN EXTERNAL AXIS EXTRUDER

Additive manufacturing (AM) are common field of industry and daily life. Almost everyone heard about 3D printing and rapid prototyping technologies. Dynamic evolution of methods gives us new possibilities and open new chances.

Common 3D printing machines are based on a typical 3 linear axis construction, similar to 3-axis milling routers. In recent years, printers based on industrial robots have been developed. This is form of AM in which "printer" is placed on a robot, constituting the ability for Robotic Additive Manufacturing (RAM). This technology enables printing of much larger objects than what is possible using normal 3D-printing methods.

Furthermore, the object can be printed onto any surface, whereas traditional 3D printing must start from a flat and horizontal surface. Robot in the Technobothnia laboratory is currently printing under another project. It uses an external controller that controls the extruder motor. The system is complex and can be made simpler with an additional robot axis and Robot Studio 3DP- add-on.

It is also intended to find a method for printing larger pieces. To find new materials and extruder technologies. ***(From the project description written by Mika).***

VI – PROJECT MANAGEMENT

VI.1 – OBJECTIVES AND WORK BREAKDOWN STRUCTURE

At the very beginning of a project, we created a clear idea of what our project is about and what we intend to achieve.

For this first Project Management task, we tried to identify four elements:

- **Task:** To design a 3D print tool for industrial robot using external axis extruder
 - Gather data and study about industrial robots and 3D printing
 - Develop a 3D print extruder with external axis on ABB IRB-1200 robot
 - Produce and implement a working program for the robot
- **Interested Parties:**
 - Roger Nylund
 - Mika Billing
 - Technobothnia
 - Robotics Industries
 - 3D Printing Industries
 - Project Team
- **Resources:**
 - Mika Billing
 - Technobothnia Lab
 - Budget (1500 euros)
 - Internet
 - Previous Projects
 - ABB Robot Studio
 - Novia
- **Environments:**
 - Coronavirus Pandemic (online meetings, only two days a week in Technobothnia, etc)
 - Weather, potential for heavy snowfall or black ice to prevent safe travel of team members.
 - Sick member

Once the project clearly defined, we tried to list every task we will need to complete in order to provide the final result. In order to do that, we used a Project Management tool named: **Work Breakdown Structure (WBS)**.

This tool is used to organize the main project into smaller tasks easier to be handled. Indeed, the Project Management Body of Knowledge (PMBOK 5) defines the Work Breakdown Structure as a *"hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables."* (**Work Breakdown Structure, Wikipedia**).

First, we decided to divide the main project into three smaller categories:

- Project management
- Project
- Deliverables

For each category, we listed every task that we will have to do and if necessary, we also divided these tasks into smaller tasks to be as precise as possible:

- Project management:
 - Definition of the project
 - Work breakdown structure (WBS)
 - Scheduling
 - RACI matrix
 - Cost management
 - Risk management
- Project:
 - Gather data about robots and external axis
 - Gather data about materials and extruder
 - Develop 3D-print extruder with external axis for an industrial robot
 - Design layout and simulate with Robot Studio
 - Add external axis on the robot
 - Build and program a working solution
- Deliverables:
 - Midterm report and oral presentation
 - Final report and oral presentation
 - 3D printing result

With the project approaching its end, a feedback can be made on this first Work Breakdown Structure. In its globality, all the project tasks were covered but some of them needed a change: not receiving the extruder in time, the team decided to use all the resources to design and produce a prototype as close as possible from the real printing head.

All the upstream work to finally 3D print the chair has been completed however the result will not be achieved completely since the extruder is not here.

VI.2 – COST MANAGEMENT

VI.2.1 – BUDGET MANAGEMENT

Cost management is a project management tool used to keep track on the budget and the way we use it throughout the entire project.

For this project, we had 1500€ at our disposal to buy anything we needed to succeed with our mission.

The table below lists every expense done so far and the ones that will need to be done for the project (hence the question mark):

Project budget: 1500€	
Item	Price (€)
Screw + barrel	333,67
Temperature controller	50,05
1.75mm and 3.0mm nozzles	50,05
Breaker	25,03
Thermocouple	50,05
Hopper	41,71
Heater	50,05
Shipping cost	125,13
ABS material	30
PLA material	30
PET material	30
Cooling system (fans, etc)	?
Material feeding tube	?
3D-printing the plastic version of the extruder	?
Cables	?

Total (€)	815,74
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Figure 4: Budget management

In addition to this budget, our supervisor Mika Billing bought an ABB Motor Unit before our arrival and this motor cost 6000€.

He also contacted the ABB Robot company for them to install this external axis motor unit on the ABB – IRB – 1200 robot present in Technobothnia laboratory and this intervention cost approximately 2500€.

Moreover, as an information, the robotic arm used for this project cost approximately 25 000€.

VI.2.2 – EARNED VALUE ANALYSIS

To determine the Actual Cost of the project, we based our study on the average salary of an engineer in Finland in 2021: 3960€ a month or approximately 28,2€ per hour (based on a 35h working week).

Thanks to this approximation, we were able to determine the created value of our project by counting every hour of work.

So, we created a template to count every hour of work divided them in two categories: project working hours and lessons hours:

Week 1	M	T	W	T	F	S	S	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)									
Project working and meetings									

Figure 5: Template earned value analysis

Each one of us had to update this table daily so we can keep track on the working hours without missing anything.

Mathieu's total:

28,2 euros per hour									
Week 1	08/02/2021	09/02/2021	10/02/2021	11/02/2021	12/02/2021	13/02/2021	14/02/2021	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)		3	4					23	648,6
Project working and meetings	2	2	2	2	2	3	3		
Week 2	15/02/2021	16/02/2021	17/02/2021	18/02/2021	19/02/2021	20/02/2021	21/02/2021	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)	2				2			19	535,8
Project working and meetings	3	3	3	3	3				
Week 3	22/02/2021	23/02/2021	24/02/2021	25/02/2021	26/02/2021	27/02/2021	28/02/2021	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)			1,5					27,5	775,5
Project working and meetings	4	4	4	4	4	3	3		
Week 4	01/03/2021	02/03/2021	03/03/2021	04/03/2021	05/03/2021	06/03/2021	07/03/2021	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)								20	564
Project working and meetings	4	4	4	4	4				
Week 5	08/03/2021	09/03/2021	10/03/2021	11/03/2021	12/03/2021	13/03/2021	14/03/2021	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)								0	0
Project working and meetings									
Week 6	15/03/2021	16/03/2021	17/03/2021	18/03/2021	19/03/2021	20/03/2021	21/03/2021	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)								35	987
Project working and meetings	5	5	5	5	5	5	5		
Week 7	22/03/2021	23/03/2021	24/03/2021	25/03/2021	26/03/2021	27/03/2021	28/03/2021	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)	1,5							43,5	1226,7
Project working and meetings	3	8	8	7	4	6	6		
Week 8	29/03/2021	30/03/2021	31/03/2021	01/04/2021	02/04/2021	03/04/2021	04/04/2021	Total (h)	Total (€)
Lessons (Project Management, 3D printing ...)		2						29	817,8
Project working and meetings	6	6	4	5	3	3			

Week 9		05/04/2021	06/04/2021	07/04/2021	08/04/2021	09/04/2021	10/04/2021	11/04/2021			
Lessons (Project Management, 3D printing ...)									Total (h)	17	
Project working and meetings		3	4	2	3	5			Total (€)	479,4	
Week 10		12/04/2021	13/04/2021	14/04/2021	15/04/2021	16/04/2021	17/04/2021	18/04/2021			
Lessons (Project Management, 3D printing ...)									Total (h)	21	
Project working and meetings		2	2	4	6	4	2	1	Total (€)	592,2	
Week 11		19/04/2021	20/04/2021	21/04/2021	22/04/2021	23/04/2021	24/04/2021	25/04/2021			
Lessons (Project Management, 3D printing ...)									Total (h)	12	
Project working and meetings		2	2	1	3	2	1	1	Total (€)	338,4	
Week 12		26/04/2021	27/04/2021	28/04/2021	29/04/2021	30/04/2021	01/05/2021	02/05/2021			
Lessons (Project Management, 3D printing ...)									Total (h)	19	
Project working and meetings		3	4	3	4	5			Total (€)	535,8	
Week 13		03/05/2021	04/05/2021	05/05/2021	06/05/2021	07/05/2021	08/05/2021	09/05/2021			
Lessons (Project Management, 3D printing ...)									Total (h)	9	
Project working and meetings						3	3	3	Total (€)	253,8	
Week 14		10/05/2021	11/05/2021	12/05/2021	13/05/2021	14/05/2021	15/05/2021	16/05/2021			
Lessons (Project Management, 3D printing ...)									Total (h)	25	
Project working and meetings		5	4	3	5	4	2	2	Total (€)	705	
Week 15		17/05/2021	18/05/2021	19/05/2021	20/05/2021	21/05/2021	22/05/2021	23/05/2021			
Lessons (Project Management, 3D printing ...)									Total (h)	24	
Project working and meetings		3	4	2	6	2	3	4	Total (€)	676,8	
Week 16		24/05/2021	25/05/2021	26/05/2021	27/05/2021	28/05/2021	29/05/2021	30/05/2021			
Lessons (Project Management, 3D printing ...)									Total (h)	5	
Project working and meetings		2	2	1					Total (€)	141	

Figure 6: Earned Value Mathieu

Note: The red zone corresponds to our trip to Lapland

Ben's total:

Week 1	08/02/2021	09/02/2021	10/02/2021	11/02/2021	12/02/2021	13/02/2021	14/02/2021
Lessons (Project Management, 3D printing ...)		3	4				
Project working and meetings	1	1	1	1	1	0	0
Week 2	15/02/2021	16/02/2021	17/02/2021	18/02/2021	19/02/2021	20/02/2021	21/02/2021
Lessons (Project Management, 3D printing ...)	2				2		
Project working and meetings	2	2	2	2	2	1	1
Week 3	22/02/2021	23/02/2021	24/02/2021	25/02/2021	26/02/2021	27/02/2021	28/02/2021
Lessons (Project Management, 3D printing ...)			1,5				
Project working and meetings	2,5	4	3	4	2,5	1,5	2
Week 4	01/03/2021	02/03/2021	03/03/2021	04/03/2021	05/03/2021	06/03/2021	07/03/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	4,5	3	4	2		
Week 5	08/03/2021	09/03/2021	10/03/2021	11/03/2021	12/03/2021	13/03/2021	14/03/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings							
Week 6	15/03/2021	16/03/2021	17/03/2021	18/03/2021	19/03/2021	20/03/2021	21/03/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	3	5	3	5	3,5	1,5	1
Week 7	22/03/2021	23/03/2021	24/03/2021	25/03/2021	26/03/2021	27/03/2021	28/03/2021
Lessons (Project Management, 3D printing ...)	1,5						
Project working and meetings	3	8	3	4	0	0	0
Week 8	29/03/2021	30/03/2021	31/03/2021	01/04/2021	02/04/2021	03/04/2021	04/04/2021
Lessons (Project Management, 3D printing ...)		2					
Project working and meetings	3,5	3	3	5	3	2	0
Week 9	05/04/2021	06/04/2021	07/04/2021	08/04/2021	09/04/2021	10/04/2021	11/04/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	3	3,5	3	5	4	0	0
Week 10	12/04/2021	13/04/2021	14/04/2021	15/04/2021	16/04/2021	17/04/2021	18/04/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	2	3	6	3	2	0
Week 11	19/04/2021	20/04/2021	21/04/2021	22/04/2021	23/04/2021	24/04/2021	25/04/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	1,5	1,5	0	4	4	2	0
Week 12	26/04/2021	27/04/2021	28/04/2021	29/04/2021	30/04/2021	01/05/2021	02/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	4	2	3	3	1,5	0	0
Week 13	03/05/2021	04/05/2021	05/05/2021	06/05/2021	07/05/2021	08/05/2021	09/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	0	4	0	3	1	0	0
Week 14	10/05/2021	11/05/2021	12/05/2021	13/05/2021	14/05/2021	15/05/2021	16/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	3	4	2,5	5	3,5	2	1
Week 15	17/05/2021	18/05/2021	19/05/2021	20/05/2021	21/05/2021	22/05/2021	23/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	4	2	6	3	1	1
Week 16	24/05/2021	25/05/2021	26/05/2021	27/05/2021	28/05/2021	29/05/2021	30/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	2	1				

28,2 euros per hour

Total (h) 12 Total (€) 338,4

Total (h) 16 Total (€) 451,2

Total (h) 21 Total (€) 592,2

Total (h) 15,5 Total (€) 437,1

Total (h) 0 Total (€) 0

Total (h) 22 Total (€) 620,4

Total (h) 19,5 Total (€) 549,9

Total (h) 21,5 Total (€) 606,3

Total (h) 18,5 Total (€) 521,7

Total (h) 18 Total (€) 507,6

Total (h) 13 Total (€) 366,6

Total (h) 13,5 Total (€) 380,7

Total (h) 8 Total (€) 225,6

Total (h) 21 Total (€) 592,2

Total (h) 19 Total (€) 535,8

Total (h) 5 Total (€) 141

TOTAL (h) 243,5 TOTAL (€) 6866,7

Figure 7: Earned Value Ben

Frédéric's total:

Week 1	08/02/2021	09/02/2021	10/02/2021	11/02/2021	12/02/2021	13/02/2021	14/02/2021
Lessons (Project Management, 3D printing ...)		3	4				
Project working and meetings	0	0	0	2	0	0	3
Week 2	15/02/2021	16/02/2021	17/02/2021	18/02/2021	19/02/2021	20/02/2021	21/02/2021
Lessons (Project Management, 3D printing ...)	2				2		
Project working and meetings	0	2	0	3	3	2	0
Week 3	22/02/2021	23/02/2021	24/02/2021	25/02/2021	26/02/2021	27/02/2021	28/02/2021
Lessons (Project Management, 3D printing ...)			1,5				
Project working and meetings	1	4	2	4	4	0	3
Week 4	01/03/2021	02/03/2021	03/03/2021	04/03/2021	05/03/2021	06/03/2021	07/03/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	3	2	4	4	0		
Week 5	08/03/2021	09/03/2021	10/03/2021	11/03/2021	12/03/2021	13/03/2021	14/03/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings							
Week 6	15/03/2021	16/03/2021	17/03/2021	18/03/2021	19/03/2021	20/03/2021	21/03/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	0	2	1	5	2	3	5
Week 7	22/03/2021	23/03/2021	24/03/2021	25/03/2021	26/03/2021	27/03/2021	28/03/2021
Lessons (Project Management, 3D printing ...)	1,5						
Project working and meetings	3	6	4	4	5	2	5
Week 8	29/03/2021	30/03/2021	31/03/2021	01/04/2021	02/04/2021	03/04/2021	04/04/2021
Lessons (Project Management, 3D printing ...)		2					
Project working and meetings	6	6	4	5	3		
Week 9	05/04/2021	06/04/2021	07/04/2021	08/04/2021	09/04/2021	10/04/2021	11/04/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	1	2	4	3	1	1
Week 10	12/04/2021	13/04/2021	14/04/2021	15/04/2021	16/04/2021	17/04/2021	18/04/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	3	2	6	3		
Week 11	19/04/2021	20/04/2021	21/04/2021	22/04/2021	23/04/2021	24/04/2021	25/04/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	1	1	2	4	2	1	3
Week 12	26/04/2021	27/04/2021	28/04/2021	29/04/2021	30/04/2021	01/05/2021	02/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	1	1	2	3	3	2
Week 13	03/05/2021	04/05/2021	05/05/2021	06/05/2021	07/05/2021	08/05/2021	09/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	1	4	2	3	1		
Week 14	10/05/2021	11/05/2021	12/05/2021	13/05/2021	14/05/2021	15/05/2021	16/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	2	2	5	4	2	1
Week 15	17/05/2021	18/05/2021	19/05/2021	20/05/2021	21/05/2021	22/05/2021	23/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	3	2	2	4	1	3	4
Week 16	24/05/2021	25/05/2021	26/05/2021	27/05/2021	28/05/2021	29/05/2021	30/05/2021
Lessons (Project Management, 3D printing ...)							
Project working and meetings	2	2	1				

28,2 euros per hour

Total (h) 12 Total (€) 338,4

Total (h) 14 Total (€) 394,8

Total (h) 19,5 Total (€) 549,9

Total (h) 13 Total (€) 366,6

Total (h) 0 Total (€) 0

Total (h) 18 Total (€) 507,6

Total (h) 30,5 Total (€) 860,1

Total (h) 26 Total (€) 733,2

Total (h) 14 Total (€) 394,8

Total (h) 16 Total (€) 451,2

Total (h) 14 Total (€) 394,8

Total (h) 14 Total (€) 394,8

Total (h) 11 Total (€) 310,2

Total (h) 18 Total (€) 507,6

Total (h) 19 Total (€) 535,8

Total (h) 5 Total (€) 141

TOTAL (h) 244 TOTAL (€) 6880,8

Figure 8: Earned Value Frédéric

Then we just assembled the results of each project member so we could finally determine the Earned Value of the project. This gave the following results:

Ben	TOTAL (h)	243,5	TOTAL (€)	6866,7
Frederic	TOTAL (h)	244	TOTAL (€)	6880,8
Mathieu	TOTAL (h)	329	TOTAL (€)	9277,8
	TOTAL (h)	816,5	TOTAL (€)	23025,3

Figure 9: Earned Value Analysis result

VI.3 – RISK MANAGEMENT

During a project, some situations can go wrong because of risks and this can lead to a project failure. The aim of the Risk Management is to identify these situations at the very beginning of the project for preventing them to endanger the entire mission.

So, we decided to do an early brainstorming to spot these possible risks and this is the result we obtained:

- Conflicts within the project team
- Misunderstanding of guidelines
- Sickness or trips (especially because we are a small group of three members)
- ABB – IRB – 1200 robot failure
- Problem with the software Robot Studio
- 3D print extruder failure
- Lack of motivation
- Bad communication
- Bad time management
- Loss of files or work document
- Bad distribution of work (one member can be overload of work)
- Laboratory / workshop tools occupied

After this brainstorming, we decided to rank these risks using a risk matrix. This is a visual representation of the possible risks affecting a project and this is how it works:

- We classify risks according to the probability of occurrence: LOW, MEDIUM or HIGH.
- We also estimate the negative impact of each risk: LOW, MEDIUM or HIGH.

Risk	Probability	Impact
Conflicts within the project team	Low	Low
Misunderstanding of guidelines	Medium	Low
Sickness or trips	Medium	Medium
ABB – IRB – 1200 robot failure	Low	High
Problem with the software Robot Studio	Medium	Medium
3D print extruder failure	Low	High
Lack of motivation	Low	Medium
Bad communication	Low	Low
Bad time management	Medium	Medium
Loss of files or work document	Low	High
Bad distribution of work	Low	Medium
Laboratory / workshop tools occupied	Medium	Medium

		IMPACT →		
		LOW	MEDIUM	HIGH
PROBABILITY ↓	LOW	Conflicts within the group Bad communication	Lack of motivation Bad distribution of work	ABB-IRB-1200 robot failure 3D print extruder failure Loss of files or work document
	MEDIUM	Misunderstanding of guidelines	Sickness or trips Problem with the software RobotStudio Bad time management Laboratory / workshop tools occupied	
	HIGH			

Figure 10: Risk management

One risk has not been taken into consideration: not receiving the extruder in time. This would have been classified as “medium probability” with a “high impact”.

Especially during this pandemic situation, it was probably something we should have apprehended. But it is also something that we couldn't plan: for instance, the production time for our extruder was established by the company to be within one month and to this day, it is still not finished or at least, still not shipped (the order was made the 23rd of May).

VII – TECHNOLOGICAL PRESENTATION

VII.1 – ROBOTIC

Robotic is a scientific domain integrating both computer science and engineering. This multidisciplinary field regroups all the activities in relation with robots going from their design and construction to their final use in many various industries.

Mainly used to the assistance of human, robots can be found in loads of different engineering fields such as:

- Mechanical engineering
- Electrical engineering
- Mechatronics
- Electronics
- Bioengineering
- Computer engineering
- Software engineering

As said previously, Robotic were developed to help humans in their tasks. Robots can be used in many different situations but nowadays, they are mostly found in hazardous environments (radioactive area, bomb deactivation) or where conditions are not compatible with human survival (in space, underwater, high or low temperature).

The robot Unimate, the first robot able to be programable and digitally controlled, was created and released for an industrial application: lifting and stacking hot metal pieces.

Nowadays, in our world, robots tend to be used more for an economical reason. Where humans can make mistakes, robots, because of their accuracy and reliability, can be used to prevent any error while saving money. (*Robotic, Wikipedia.org*)

VII.2 – ROBOTS

Robots are a man-aiding, man-made creation, built from science, engineering, and technology. Often, their purpose is to imitate or execute an action more efficiently than a human. Since the birth of Robots, there has been both a fascination and wariness of the future implications. In today's world, robots have become far more intelligent than any being, with the hope that one day they can think for themselves. This obsession has led to various blockbuster movies depicting how everyday life will eventually look. Originally robots were designed for much smaller tasks for example building cars on an assembly line but now, uses for robotics have become instrumental in modern society from performing surgeries to exploring other planets. (*Robots, builtin.com/robotics*)

Robots may be ever-expanding, however, the main principles of development still run true. Most will be mechanically made, to enable the effectiveness of performance in the specific environment of use. They still need the electrical components too, for example, an electrical current source to power the device. Also, most robots will contain a computer program built-in, which will act as the brain in carrying out their intended tasks.

Types of Robot:

Pre-Programmed- Contain a code or program that will instruct them to do an often-simple task better than a human.

Humanoid- Act in a realistic mimic of a human. Copies the human's behaviour for a task such as, running, walking, carrying objects, etc.

Autonomous- Operate in open environments usually without human supervision. Using sensors to navigate around a space, they can operate successfully by themselves. Often used for cleaning, lawn trimming, delivering goods, and so on.

Teleoperated- Described as semi-autonomous robots as they use a wireless network to connect to a controller which a human can use to operate from a safe distance. This type of robot is usually used for situations where the environment is not easily accessible for the human for example in dangerous weather, high mountains, etc.

Augmenting- This type of robot is usually made for humans. It can enhance humans' capabilities or replace some that had been previously lost for example prosthetic limbs.

(Robots, builtin.com/robotics)

VII.3 – 3D PRINTING

VII.3.1 – HISTORY OF 3D PRINTING

1950's

During the 50s, the idea of printing three dimensional objects came to fruition. It was first described by Raymond F Jones in his “Tools of the Trade” story where he described it as a “molecular spray”. The story was published in the “Astounding Science Fiction” magazine issue of November 1950. **(3D Printing, Wikipedia.org)**

1970's

In 1971, Johannes F Gottwald was the first to lay claim on the idea of 3D printing. He did so on a Liquid Metal Recorder which was able to deposit a metal fabrication on a reusable surface. This was regarded as the first patent describing 3D printing.

In 1974, a British chemist and author wrote about the concept of 3D printing in his “New Scientist” magazine column, the Ariadne. **(3D Printing, Wikipedia.org)**

1980's

In early 1980, two additive methods for producing three dimensional plastics products were created by Hideo Kodama, a researcher at the Nagoya Municipal Industrial Research Institute. These methods were to fabricate 3D plastics using photo-hardening thermostat polymers.

R.H. Research was created in early 1984 by Robert Howard to create a colour 2D printer using melted thermoplastic. Also, in 1984, Chuck Hall of 3D Systems Corporation and American entrepreneur Bill Masters, separately filed for patents related to 3D printing processes.

In 1986, Chuck Hall, mentioned previously was granted his patent and in that year 3D Systems Corporation were able to produce the first commercial 3D printer, the SLA-1. **(3D Printing, Wikipedia.org)**



Figure 11: 3D printer SLA - 1

1990's

In 1993, an inkjet 3D printer company called at the time, Sanders Prototype, produced a new 3D printing process based on high-precision polymer flow with a dissolvable structure. This was known as a dot-on-dot technique.

And in 1995, German research organization, produced the selective laser melting process which was a rapid prototyping technique which used a high power-density laser to melt and fuse metallic powders together. **(3D Printing, Wikipedia.org)**

2010's

In the 2010's it was made clear that metal removal would not be the only metalworking process carried out by 3D work envelope. This decade saw engine brackets and large nuts be created in job production. Additive manufacturing was fast becoming universally renown as the future.

Thanks to Filabot, in 2012, a system allowing any 3D printer to print with far greater range of plastics was created.

In 2014 a car containing many 3D printed elements was introduced by Swedish supercar company, Koenigsegg. Called the Urbee, it was the first of its kind.

Early 2015 saw Airbus, the multinational aerospace corporation, announce its A350 model which contained more than one thousand components, formed from 3D printing.

GE Aviation, an aircraft engine supplier, announced in 2017 that they had created a helicopter engine with 16 parts instead of 900 with the aid of additive manufacturing. **(3D Printing, Wikipedia.org)**

2020's

Today's world sees 3D printers being used universally. They have become vastly more accessible to the average user due to the level of quality and price of the machines. 3D printing has become a staple in corporations and businesses, for many seeing it as the future. **(3D Printing, Wikipedia.org)**

VII.3.2 – 3D PRINTING PRESENTATION

3D printing, also called additive manufacturing is a forty-year process in which three dimensional objects are formed from a file created with computer assistance. 3D printing has produced a wide array of objects, from small items such as tools and toys to massive productions such as bridges and plane parts, and how they do this is by adding material layer by layer until the sculpture is complete.

The process starts off with a plan, a blueprint of the model intended to be created. It is then, using a 3D modelling software, designed, and sent to the printer. The printer uses this information, then pushes material through a tube, melts it, and then deposits the melted material. As the material leaves the tube it begins to cool and harden. The printer continues going layer by layer until the sculpture is fully complete.

3D printing has been a major hit for businesses and companies as it allows them to create complex parts cheaper and faster than the usual. They can bypass the forging, moulding and sculpting phases and better yet they can do it all on site, even the same day. **(3D Printing, Wikipedia)**

Due to their ease to be manufactured, plastic polymers were the first materials used for the 3D printing process.

However, loads of new technologies have merged involving new materials such as metals or ceramics. **(3D Printing, Wikipedia)**

3D printing can be really useful because you can create an object from scratch but you can also repair a broken object by 3D print directly on it.

3D print also allows you to create really complicated shaped object that you would not normally be able to create with normal manufacturing process. **(3D Printing, Wikipedia)**

3D printing is also really seductive because of all the technologies that already exist. Below, there is a non-exhaustive list of 3D-printing process:

VII.3.2.1 – STEREOLITHOGRAPHY

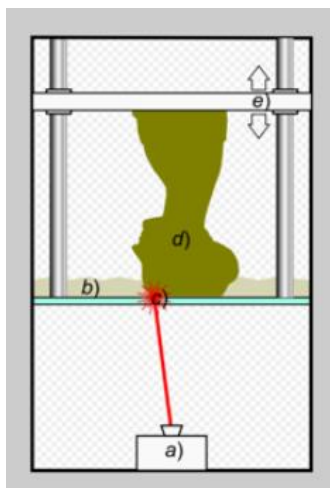


Figure 12: Stereolithography

Stereolithography is a technology using liquid plastic placed in an enclosure with a transparent bottom.

With an ultraviolet laser and a specific pattern, the liquid material will solidify layer by layer to create the final product.

With the help of a lifting platform, the product is progressively dragged up for the layer to be created. **(3D Printing, TechPats Blog)**

VII.3.2.2 – SELECTIVE LASER SINTERING (SLS)

SLS is an Additive Manufacturing process using a powdered and a high-density laser. Based on a certain pattern, the material will be sintered by the laser creating layers to finally obtain the product. **(3D Printing, TechPats Blog)**

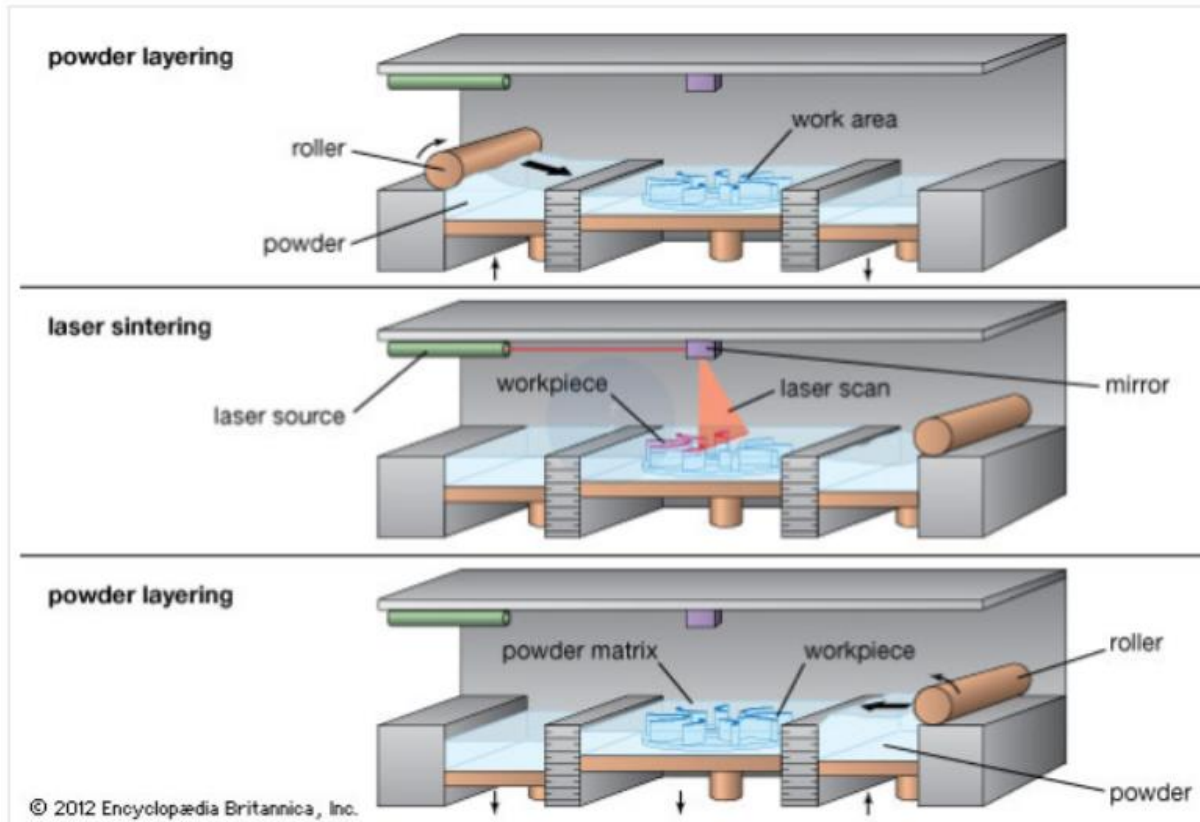


Figure 13: Selective Laser Sintering

VII.2.1.3 – SELECTIVE LASER MELTING (SLM)

As for the SLS process, Selective Laser Melting technology uses powder material and a laser but instead of just sintering the powder, it will be completely melted to create the final product. **(3D Printing, TechPats Blog)**

VII.3.2.5 – FUSED DEPOSITION MODELLING (FDM)

This 3D printing technology is only used for thermoplastic materials. Most of the time in a filament shape, the material will be melted in order to go through a nozzle to extrude the polymer. The object is then created layer by layer. More complex products can be made by using few different materials and this manufacturing process is called multi-material 3D printing. (**3D Printing, TechPats Blog**)

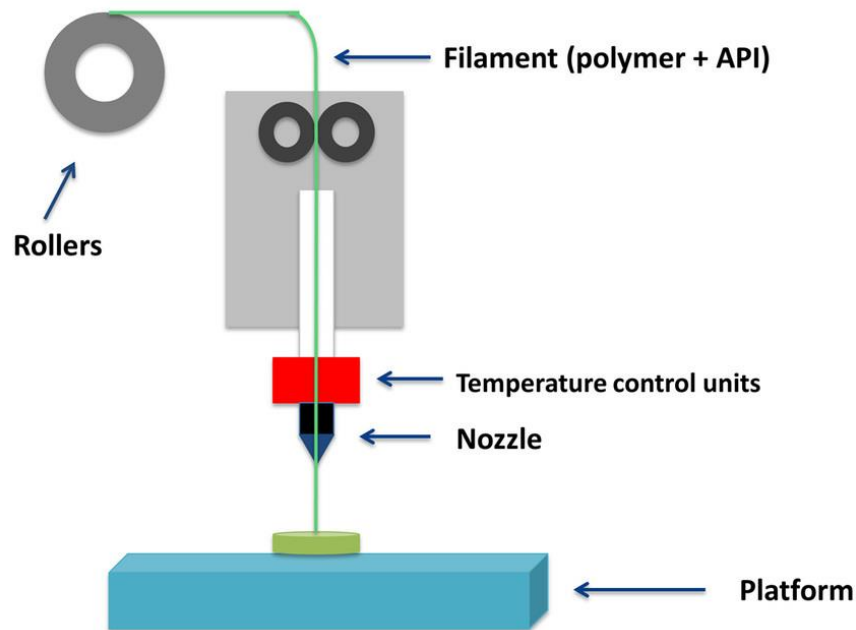


Figure 14: Fused Deposition Modelling

This technique is the one we used for our project. The thermoplastic polymers chosen (see the next paragraph) will be melted in an extruder and will be ejected through a nozzle to form the layers. The only difference is that we didn't use filaments but instead, we used polymers granulates.

VIII – MATERIALS

When designing the printer, it is very important to look at the materials that will be used for the 3D printing. The different plastics all have different melting points. So, if the chosen plastics would have a low melting point, the extruder could be made from a plastic with a much higher melting point. The downside to this, is that plastics in general have a higher thermal insulation compared to metals. For this reason, the extruder will be made out of metal.

For this project, we will be focusing on 3 different plastics: ABS, PLA and PET. These are all widely used in 3D printing. A common specificity shared by these three polymers is their ability to be biodegradable. This is very important to make sure that the printing head won't add to climate change. The printer will also be able to print other materials but we really wanted to be eco-friendly.

VIII.1 – ABS - Acrylonitrile Butadiene Styrene

Acrylonitrile Butadiene Styrene (ABS) is an amorphous thermoplastic polymer. Being a thermoplastic material means that ABS can have a rubbery behaviour by raising the temperature (superior at the glass transition temperature) or can solidify by cooling it down.

These two transitions can occur indefinitely in contrary with thermosetting polymer whose transition is irreversible.

When heating up ABS, it will go through a glass transition which consist in modifying the material from a hard and “glassy” state into a viscous or rubbery state. This transformation will take place around 105°C; but when injecting or 3D-printing, in this case, it will be heated up to around 230°C – 260°C.

(Acrylonitrile Butadiene Styrene, Wikipedia)

When using styrene and acrylonitrile in presence of polybutadiene, a polymerisation occurs to create the ABS by mixing long chains of polybutadiene with small ones of poly(styrene-co-acrylonitrile) Every group from this chemical composition plays an important role:

- ABS can be stronger than basic polystyrene by creating between its chains thanks to the polarity of the nitrile groups.
- Acrylonitrile is also used to improve the chemical and mechanical properties of the polymer (the fatigue resistance, the rigidity or the hardness)
- To balance with the hardness of the acrylonitrile, the polybutadiene provides ductility and a good shock resistance. ***(Acrylonitrile Butadiene Styrene, Wikipedia)***

Monomers in ABS polymer:

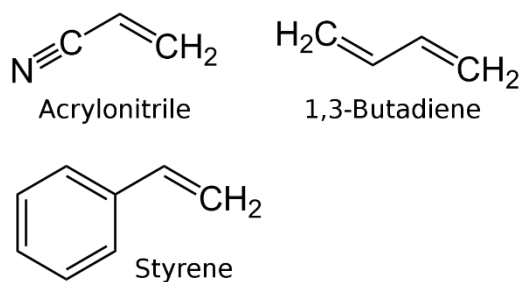


Figure 15: Monomers of ABS polymer

Mechanical properties can also be improved by modifying the chemical composition. For instance, the impact resistance can be amplified by adding polybutadiene. Thus, different grades of ABS can be obtained by modifying its mechanical properties thanks to the modification of its formula. (**Acrylonitrile Butadiene Styrene, Wikipedia**)

For example, the typical properties of ABS are presented below:

Property	Value
Young's Modulus (GPa)	2.28
Tensile Strength (MPa)	43
Flexural modulus (GPa)	2.48
Flexural Strength (MPa)	77
Notched Izod (kJ/m)	0.203
Heat Deflection Temperature, 1.81 MPa, (C)	81

Figure 16: ABS properties

VIII.2 – PLA – Polylactic Acid

Polylactic Acid (PLA) is a thermoplastic polyester mainly used for 3D printing. Its popularity has grown because of its inexpensiveness and for its ease of implementation: it can be printed at a “low temperature” (around 205°C) and it does not require to head the support bed. Another important characteristic is the eco-friendly aspect. Indeed, because created from corn and sugarcane, PLA is completely renewable and biodegradable. ***(Ultimate guide for materials – Tips for 3D printing with PLA, SIMPLIFY 3D)***

We have listed all the pros and cons about the PLA below:

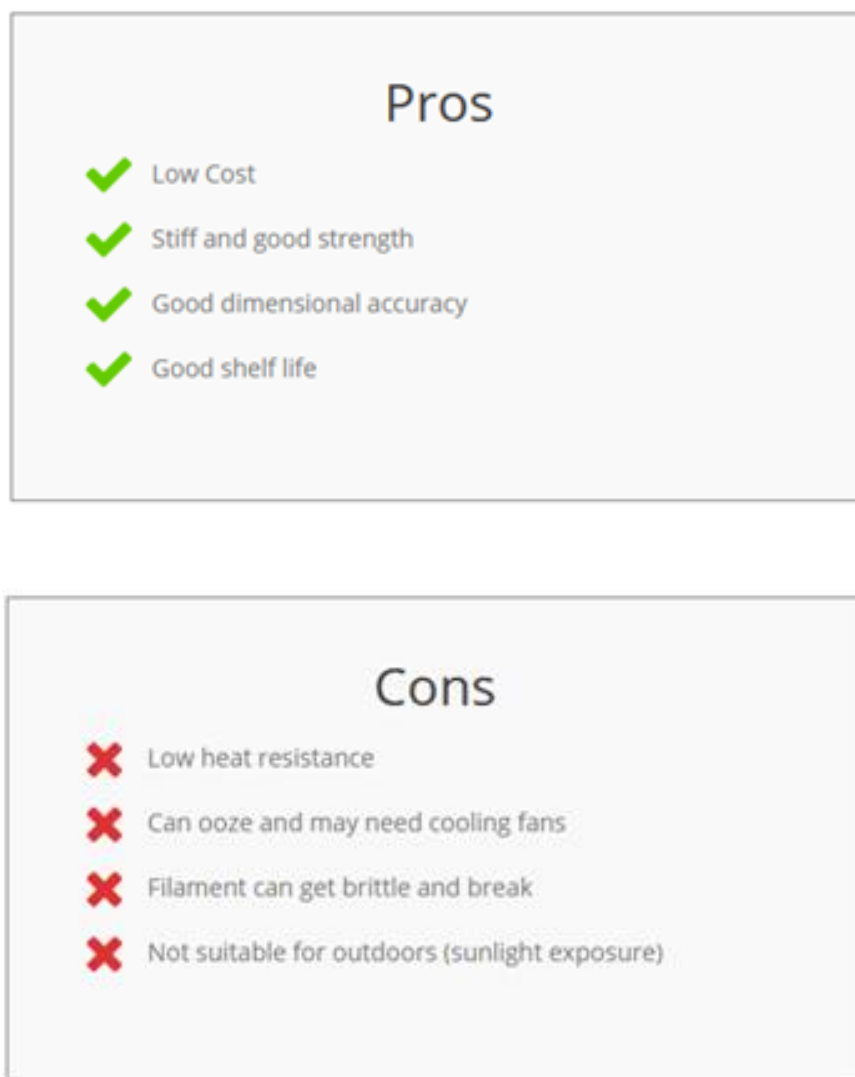


Figure 17: PLA pros and cons

Properties:

- Chemical properties:

Because of its chiral structure (a molecule chiral is a molecule without symmetrical plan), PLA can exist with different forms. PLA can also be soluble in several solutions such as solvents or hot benzene for instance. *(Polylactic Acid, Wikipedia)*

- Physical and mechanical properties:

Depending on the crystallinity rate, PLA can exist both as an amorphous or semi-crystalline polymer. Its glass transition appears around 60 °C but when it comes to 3D printing, the temperature of use is 205°C. *(Polylactic Acid, Wikipedia)*

- End of life

With the PLA, five end-of-life scenarios are possible:

- **A chemical recycling:** PLA can be chemically recycled into monomers by using hydrolysis technique or by using a thermal depolymerization. Once the monomers obtained and purified, they can be used for the manufacturing of new PLA. And because the PLA is thermoplastic polymer, you can do this process of recycling without any loss of original properties. *(Polylactic Acid, Wikipedia)*
- **Composting:** after a chemical hydrolysis process and a microbial digestion, PLA can be biodegradable under specific conditions (from 40°C to 50°C). During this process of decomposition, PLA will turn into water and carbon dioxide in a 50 to 90 days period. This decomposition can also occur without these industrial conditions but it will take hundreds to thousands of years for the PLA to be decomposed. *(Polylactic Acid, Wikipedia)*
- **Incineration:** when it comes to plastic incineration, you might encounter some difficulties related to the release of toxic gases or toxic chemicals. So, you can safely incinerate PLA without releasing dioxins or heavy metals. *(Polylactic Acid, Wikipedia)*
- **Landfill:** as explained before in the composting paragraph, without an industrial environment, PLA can be decomposed but it will extremely slow. That is why this end-of-life option is the least preferable one. *(Polylactic Acid, Wikipedia)*

VIII.3 – PET - Polyethylene Terephthalate

Polyethylene Terephthalate (PET) is definitely popular as it is commonly used in our everyday life: you can find it as fibers in the textile industry, as packages for the food industry, and it can also be associated with glass fibers for composite materials.

PET can also be used in 3D printing but in the form of PETG, Polyethylene Terephthalate Glycol-Modified. This is an extra tough 3D print material which has an extreme high strength filament able to achieve very sturdy and strong prints.

This co-polyester is a great alternative to ABS or PLA. (*Polyethylene Terephthalate, Wikipedia*)

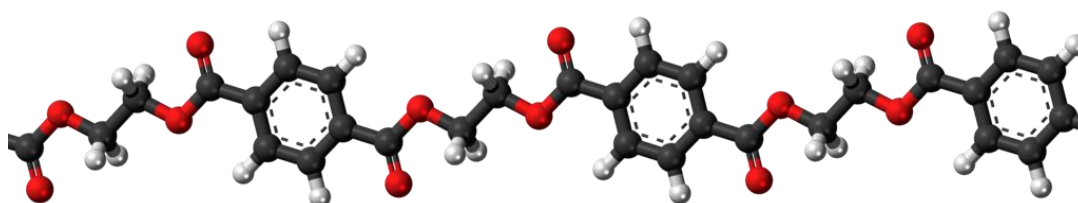


Figure 18: PET molecule

As the name “Polyethylene terephthalate” indicates, this polymer is created by forming a chain of “ethylene terephthalate” monomers.

Depending on the percentage of crystals, PET can be found both as an amorphous or semi-crystalline polymer.

Its colour depends directly on its structure: PET is transparent when amorphous and it is opaque when semi-crystalline.

In its natural state, PET is semi-crystalline but it can be amorphous by rapidly cooling melted polymer below the T_g (glass transition temperature around 67 – 81°C) because PET’s molecules do not have enough time to arrange themselves into an organized semi-crystalline structure. (*Polyethylene Terephthalate, Wikipedia*)

PET is very popular in many different domains; for example:

- Plastic bottles for soft drinks (since 1973 by Nathaniel Wyeth)
- Flexible food packaging
- Waterproof barrier cables submerged in the sea
- **3D printing filament**
- **3D printing plastic PETG**

(*Polyethylene Terephthalate, Wikipedia*)

PET is also recyclable in two different ways:

- A mechanical recycling to restore the original properties of the material.
- A chemical recycling to obtain the initial raw materials purified.

(Polyethylene Terephthalate, Wikipedia)

Mainly known for its water bottle application, here is for example the process of PET bottle recycling:

- *"Bale opening, briquette opening."*
- *"Sorting and selection for different colours, foreign polymers especially PVC, foreign matter, removal of film, paper, glass, sand, soil, stones, and metals."*
- *"Pre-washing without cutting."*
- *"Coarse cutting dry or combined to pre-washing."*
- *"Removal of stones, glass, and metal."*
- *"Air sifting to remove film, paper, and labels."*
- *"Grinding, dry and / or wet."*
- *"Removal of low-density polymers (cups) by density differences."*
- *"Hot-wash."*
- *"Caustic wash, and surface etching, maintaining intrinsic viscosity and decontamination."*
- *"Rinsing"*
- *"Clean water rinsing."*
- *"Drying."*
- *"Air-sifting of flakes."*
- *"Automatic flake sorting."*
- *"Water circuit and water treatment technology."*
- *"Flake quality control."*

(Polyethylene Terephthalate, Wikipedia)

IX – EXTRUDER

Our project is: Design a 3D-Print tool for industrial robot using an external axis extruder.
To this end, we already had access to the robot ABB – IRB – 1200 (in the Technobothnia laboratory) as well as the motor ABB – MU 80, ordered by Mika Billing before our arrival.

IX.1 – ABB – MU 80 PRESENTATION

ABB offers standardized motor unit packages complete with cables, serial measurement board bow and safety options. (**ABB Website**)

The Motor Unit 80 used for the project is the smallest product from ABB and all of its specific data are below:

Technical data

Parameter	MU 80
Minimum suitable bus voltage in IRC5 (V DC) ⁱ	280
Nnom: nominal speed (rpm)	6,000
Nrms: speed @ rms torque (rpm)	3,000
T0: Low speed torque 0 to 10 rpm (Nm) ⁱⁱ	0.96
Trms: torque @ rms speed (Nm) ⁱⁱ	0.96
Tnom: torque @nominal speed (Nm) ⁱⁱ	0.96
Tacc: max dynamic torque (Nm) (Torque absolute max)	2.5
Kt: torque constant (Nm/A) ^{vii}	0.39
iMax (A)	8.7
Temp max: max allowed average winding temperature (deg C)	140
Temp amb: allowed ambient temperature (deg C)	-5 to 55
Jtot: total inertia motor unit (kgm ²)	0.36x10 ⁻⁴
m: mass (kg)	1.37
Sealing class: IP rating acc. to IEC529	IP 40

Figure 19: MU 80 Technical data

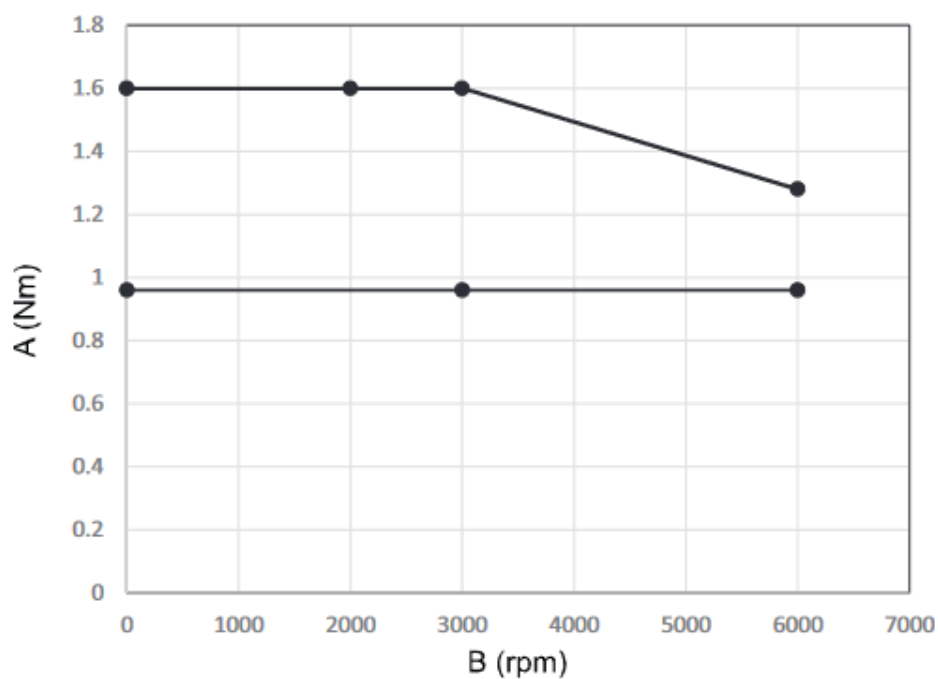
- I The minimum suitable DC bus voltage affects the available torque at high speed.
- ii During normal conditions. If ambient temperature > 40°C, or poor cooling conditions, reductions may apply. Conversion factor if the ambient temperature is higher than 40°C:
 - Ambient temperature = 45°C => 0.97
 - Ambient temperature = 52°C => 0.94
- vii Nominal value. Variations (from +5% to -20%) due to tolerances, winding temperature, and other factors may apply.

Brake data

Brake data	MU 80
T _{brake min} : minimum brake torque (Nm)	0.8
T _{brake max} : maximum brake torque (Nm)	2
Brake voltage: brake voltage requirement (V DC)	24±10%
Brake power consumption (W)	<12
Max inertia: max allowed load inertia at N _{nom} (kgm ²) ⁱ	0.64

Figure 20: MU 80 Brake data

Performance diagram of the MU 80:



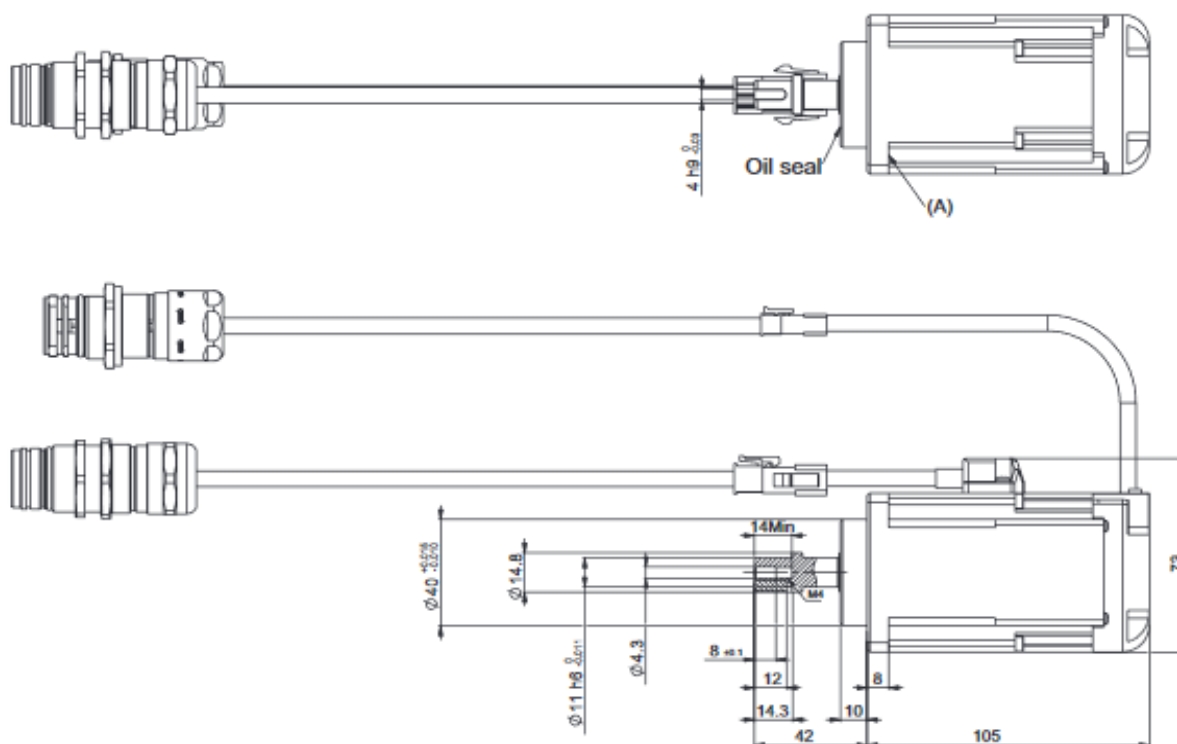
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Pos	Description
A	Motor torque
B	Motor speed
C	Acceleration Torque LV
D	Constant Torque

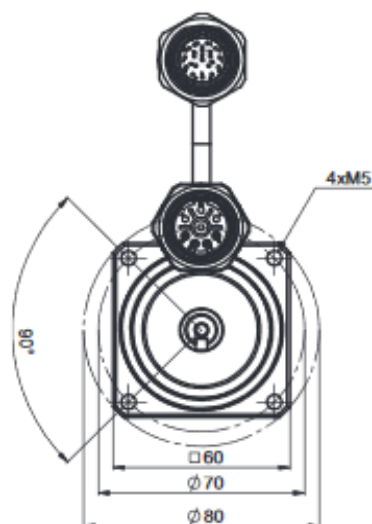
Figure 21: MU 80 Performance diagram

Data sheet of the Motor Unit 80:

MU 80



xx1700001334



xx1700001335

Rs	Description	Tightening torque [Nm] $\pm 10\%$
A	Mounting screw M 4 (quality 8.8), max. washer $\phi 9$ mm.	4

Figure 22: ABB - IRB - 1200 Data sheet

IX.2 – ABB – IRB – 1200 PRESENTATION

For our 3D printing project, we will be using a 3D-print extruder attached to a robotic arm with an external axis.

A robotic arm is a mechanical arm, much like the human arm, that can be programmed to rotate, extract, move directionally etc. The arm is used for many strenuous tasks that us, humans, might find exhausting, dangerous or time consuming. The best example for this must be the assembly line where fatigue and inaccuracy are to be eliminated to be as productive as possible.

The charm to robots is that they are not human. They can perform to a far higher degree in tough environments for example, poor lighting, toxic chemicals, and tight spaces. Lifting heavy, working long hours are all not a problem for the robot.

Some of the criteria for picking the right robotic arm for you includes:

Degrees of Freedom (DOF) – “A *DOF* is the freedom of movement of a rigid body in a three-dimensional space”. Explained better as the spaces the robotic arm can move through freely in a direction. For example, a 6DOF robotic arm would be able to move freely in six directions; x, y, z, roll on x, pitch forward or backward on the y, and rotate on the z.

Strength – The strength of the robot is important as you need to know how much load it will be able to carry. This also ties in with the stress that the robot will be able to endure. The flip side is if you choose a robot that is too strong, you pose the risk of losing accuracy.

Accuracy – Depending on the intended use, the accuracy plays a major role. If small, delicate parts are being used, the robot must be able to have the nimbleness and care to carry out the operation without damaging.

Presentation of the ABB – IRB – 1200 robot used during this project:



Figure 23: ABB - IRB - 1200

ABB – IRB – 1200 is a family of two robots that are quite similar but with some different specifications. Both can be installed at any angles and include few technical features (IP 40 protection, Food Grade Lubrication, SafeMove2, Foundry Plus 2 and Clean Room option).

The difference is in the range and the limit payload that can be carried: one of them has a 700 mm range and can support a 7 kg payload, while the other has a 900 mm range for a 5 kg payload.

Food Grade Lubrication and Clean Room option:

"This Food Grade Lubrication (NSF H1) option includes Clean Room ISO class 3 and IP67 protection rating which ensure uncompromising safety and hygiene for food and beverage applications. The Clean Room ISO class 3 design eliminates the potential for contamination of the food handling area. This option provides smooth surfaces and makes it easy to keep clean and maintain in environments such as CNC machine tending and material handling in the food industry. This results in features that allow for 15% smaller cells with 10% shorter cycle times." **(ABB Website)**

SafeMove2

"The IRB 1200 SafeMove2 becomes the smallest ABB robot to feature the advanced safety-certified monitoring and control software solution which allows robots and operators to work more closely together by restricting robot motion to precisely what is needed for a specific application." **(ABB Website)**

Compact

"The IRB 1200 has no offset in axis two, which results in a longer stroke than other small robots and it, meaning it can be placed very close to the work piece and still be functional. This allows for a much more compact installation when the robot is mounted on the ceiling inside a small cell, such as in electronics machining or polishing applications. The robots' large useable working area contained in a small package leads to shorter cycles and more compact machines." **(ABB Website)**

Foundry Plus 2

"The IRB 1200 is also available with Foundry Plus 2, ABB's optional protection system which allows it to withstand harsh environments for example heavy duty metal casting and automotive applications." **(ABB Website)**

Features and benefits

- "15% smaller cells that have 10% shorter cycle times"
- "Available with Food Grade Lubrication"
- "Optionally with SafeMove2 functionality"
- "Available with Foundry Plus 2 protection for harsh environments"
- "IP40 protection as standard; Clean Room, IP67 and Foundry Plus 2 protection are also available options"
- "4 air ducts, 10 customer signals and Ethernet routed internally from wrist flange to foot"
- "Mountable at any angle"
- "Large useable working area in a compact footprint"

(ABB Website)

Data sheet of the ABB – IRB – 1200 family:

Specification

Robot version	Reach (m)	Payload (kg)	Armload (kg)
IRB 1200-7/0.7	0.7	7	0.3
IRB 1200-5/0.9	0.9	5	0.3
Number of axes	6		
Protection	Standard robot (IP40) or IP67, Foundry Plus 2 based on IP67, Food Grade Lubricant and Clean Room (ISO class 3) based on IP67		
Mounting	Any angle		
Controller	IRC5 Compact/IRC5 Single Cabinet		
Integrated signal and power supply	10 signals on wrist		
Integrated air supply	4 air on wrist (5 Bar)		
Integrated ethernet	One 100/10 Base-TX ethernet port		

Performance (according to ISO 9283)

	IRB 1200-7/0.7	IRB 1200-5/0.9
1 kg picking cycle		
25 x 300 x 25 mm	0.42 s	0.42 s
Max. TCP Acceleration	35 m/s ²	36 m/s ²
Acceleration time 0-1 m/s	0.06 s	0.06 s
Position repeatability	0.02 mm	0.025 mm

Technical information

Electrical Connections

Supply voltage	200-600 V, 50-60 Hz
Rated power	4.5 kVA
transformer rating	
Power consumption	0.39 kW

Physical

Robot base	210 x 210 mm
Robot height	
IRB 1200-7/0.7	869 mm
IRB 1200-5/0.9	967 mm
Robot weight	
IRB 1200-7/0.7	52 kg
IRB 1200-5/0.9	54 kg

Environment

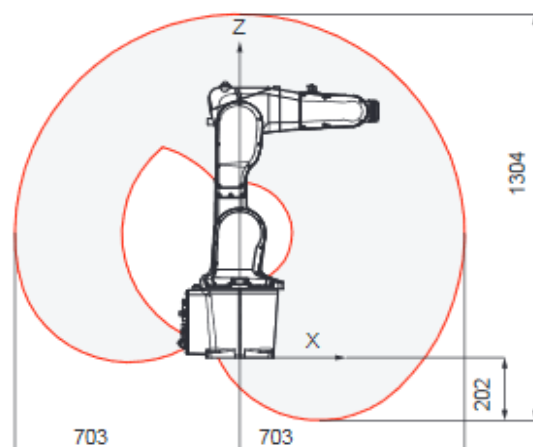
Ambient temperature for robot manipulator	
During operation	+ 5°C (41°F) to + 45°C (113°F)
With food grade lubrication during operation	+ 5°C (41°F) to + 35°C (113°F)
Complete robot during transportation and storage	- 25°C (-13°F) to + 55°C (131°F)
During short periods (max. 24 hours)	up to + 70°C (158°F)
Relative humidity	Max. 95%
Noise level	< 70 dB

Movement

Axis movement	Working range	Axis max. speed
Axis 1 rotation	+170° to -170°	288°/s
Axis 2 arm	+135° to -100° ¹	240°/s
Axis 3 arm	+70° to -200°	300°/s
Axis 4 wrist	+270° to -270°	400°/s
Axis 5 bend	+130° to -130°	405°/s
Axis 6 turn	Default: +400° to -400° Max. rev: ±242	600°/s

¹Axis 2 for IRB 1200-5/0.9 is +130° to -100°

Working range, IRB 1200 7/0.7



Working range, IRB 1200 5/0.9

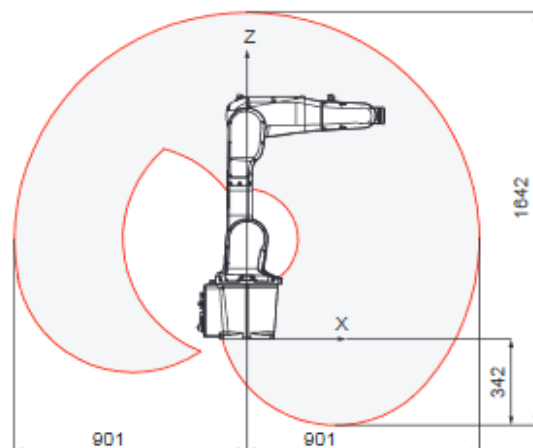
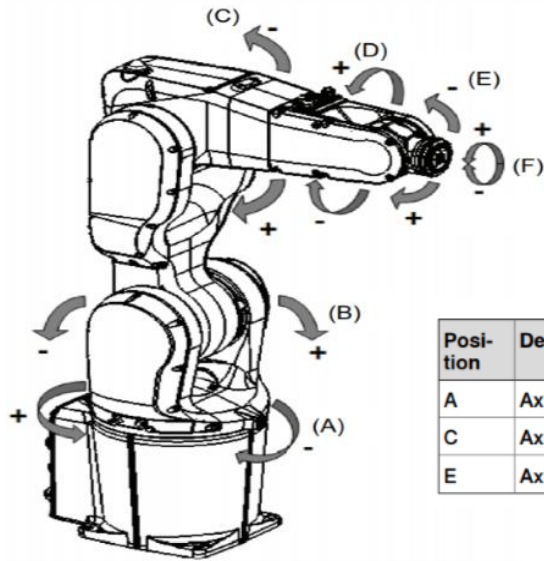
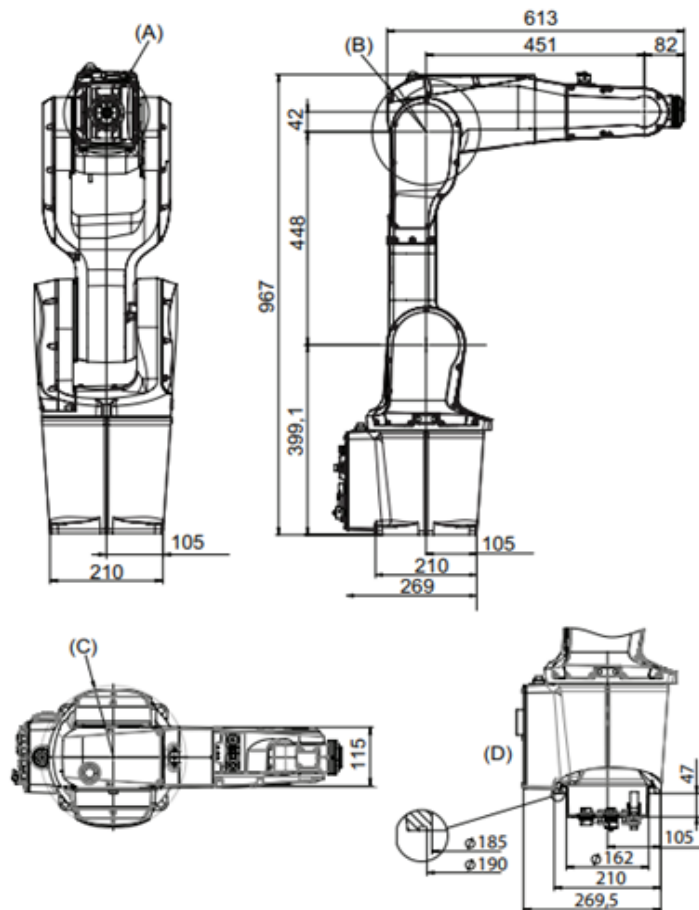


Figure 24: ABB - IRB - 1200 Data sheet 2.0



Position	Description	Position	Description
A	Axis 1	B	Axis 2
C	Axis 3	D	Axis 4
E	Axis 5	F	Axis 6



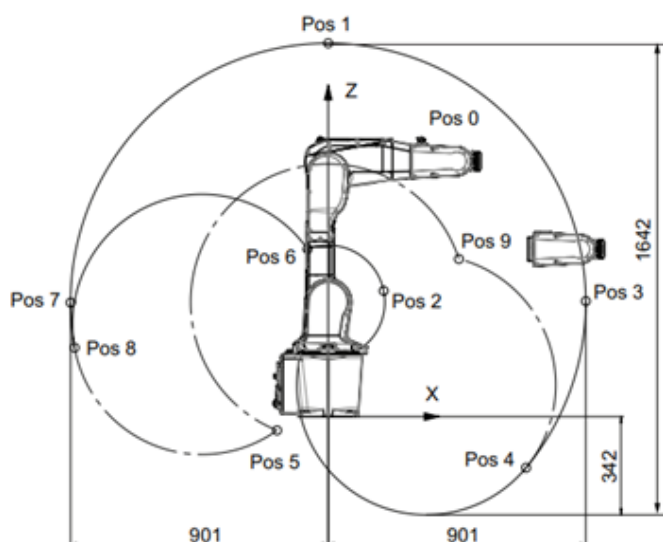
Pos	Description
A	Minimum turning radius axis 4 R=79 mm
B	Minimum turning radius axis 3 R=111 mm
C	Minimum turning radius axis 1 R=138 mm
D	Valid for option Robot cabling routing, 966-1 From below

Figure 25: ABB - IRB - 1200 Data sheet 3.0

The robot has six axes meaning that it will have six different types of range of motion. Range of motion for the robot is how much each joint can move directionally. The values are shown in the figures below.

Location of motion	Type of motion	IRB 1200-7/0.7	IRB 1200-5/0.9
Axis 1	Rotation motion	+170° to -170°	+170° to -170°
Axis 2	Arm motion	+135° to -100°	+130° to -100°
Axis 3	Arm motion	+70° to -200°	+70° to -200°
Axis 4	Wrist motion	+270° to -270°	+270° to -270°
Axis 5	Bend motion	+130° to -130°	+130° to -130°
Axis 6	Turn motion	Default: +400° to -400° Maximum revolution: $\pm 242^{\circ}$ ⁱ	Default: +400° to -400° Maximum revolution: $\pm 242^{\circ}$ ⁱ

ⁱ The default working range for axis 6 can be extended by changing parameter values in the software. Option 610-1 Independent axis can be used for resetting the revolution counter after the axis has been rotated (no need for "rewinding" the axis).

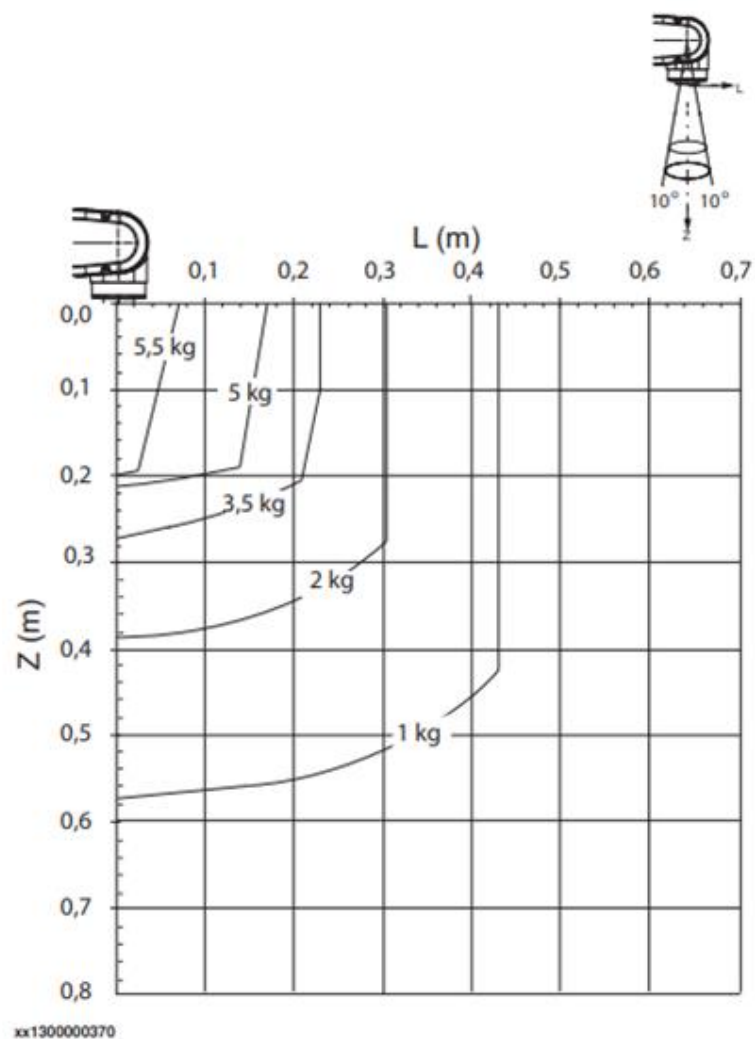


xx1300000387

Position in the figure	Positions at wrist center (mm)		Angle (degrees)	
	X	Z	Axis 2	Axis 3
Pos0	451	889	0°	0°
Pos1	0	1300	0°	-85°
Pos2	194	438	0°	+70°
Pos3	901	402	+90°	-85°
Pos4	692	-178	+130°	-85°
Pos5	-179	-48	-100°	-200°
Pos6	-72	583	-100°	+70°
Pos7	-901	397	-90°	-85°
Pos8	-887	240	-100°	-85°
Pos9	458	549	+130°	-200°

Figure 26: ABB - IRB - 1200 Data sheet 4.0

IRB 1200 - 5/0.9 "Vertical wrist" ($\pm 10^\circ$)



For wrist down (0° deviation from the vertical line).

	Description
Max load	5.5 kg
Z _{max}	0.199 m
L _{max}	0.069 m

Figure 27: ABB - IRB - 1200 Data sheet 5.0

In Technobothnia laboratory, we will work with the ABB – IRB – 1200-5/0.9 which correspond to the 900 mm reach variant that can carry up to 5 kg + 30% of payload.

Therefore, we had to think of a solution that could 3D-print while being light enough to be carried by the robot.

The first step of this mission was to fully understand how an extruder works:

IX.3 – EXTRUDING PROCESS

Extrusion is a manufacturing process consisting in introducing solid thermoplastic polymer inside of an extruder (either filament or granulates). Then, using a plasticizing screw, the material will be conveyed, melted, mixed, plasticized and compressed all the way through the barrel to finally go over a nozzle therefor giving the shape of the product. (*L'extrusion des thermoplastiques, Plasturgiejp.free*)

IX.3.1 – DESCRIPTION OF A SINGLE SCREW EXTRUDER

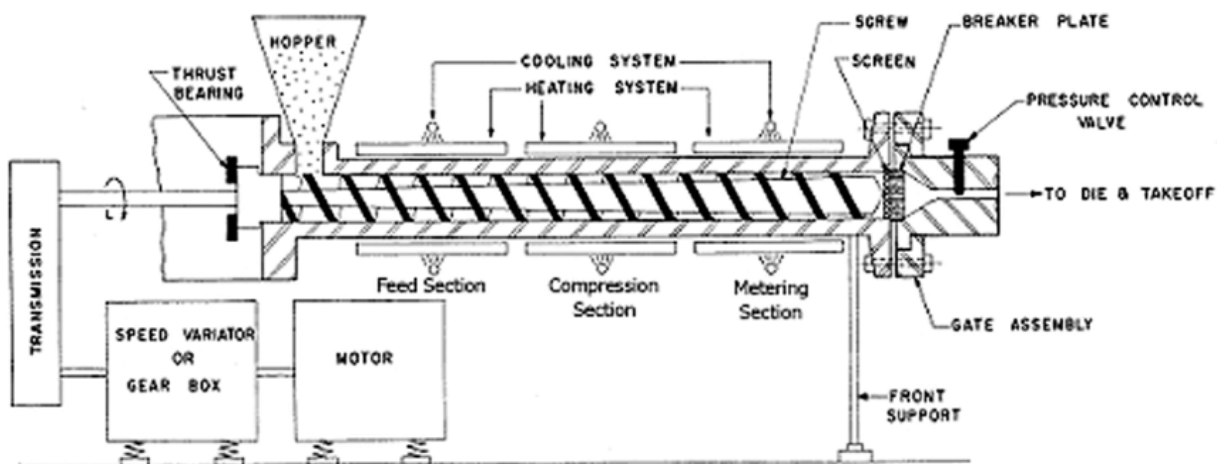


Figure 28: Single screw extruder

An extruder is mainly composed of a high-strength steel barrel in which the plasticizing screw will be driven in rotation by the motor.

The plastic material will go from a solid state to a rubbery or molten state thanks to a thermo-regulated system heating the barrel.

IX.3.2 – DESCRIPTION OF THE THERMO-REGULATED BARREL

The cylinder or barrel is generally made of nitrided steel or coated with a bi-metallic layer to resist abrasion and corrosion.

The temperature control is realized by resistances placed into 3 to 6 zones depending on the length of the barrel. These heating elements are regulated by a PID controller and they are often associated with cooling systems such as fans or cooling liquid in case of overheating. **(L'extrusion des thermoplastiques, Plasturgiejp.free)**

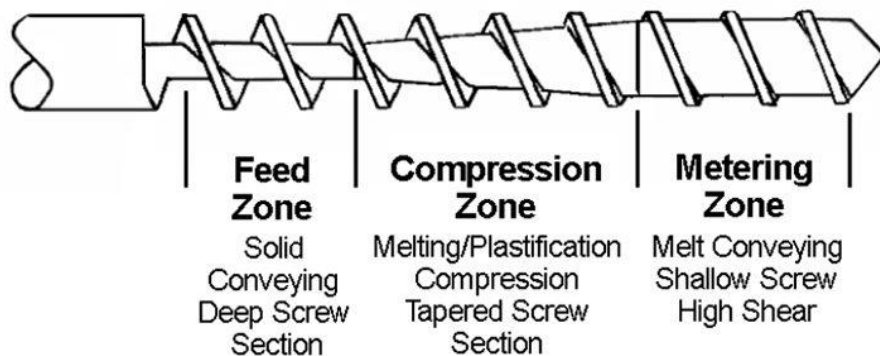


Figure 29: Extrusion screw

- *Feed zone: feeding and conveying the plastic granulates to the compression zone.*

In this area, the solid polymer is introduced inside of the extruder through a hopper and is being conveyed to the next compression zone.

To this end, we must assure that:

- The temperature of the screw is lower than the temperature of the barrel
- The screw is polished
- The material stays solid

(L'extrusion des thermoplastiques, Plasturgiejp.free)

- *Compression zone: plasticize the material and put it under progressive pressure.*

In this area, the diameter of the screw is progressively increasing. This will create internal shearing forces in the material. These, combined with the energy coming from the heating elements, will modify the polymer state. Indeed, the material will go from a solid state to a rubbery state.

(L'extrusion des thermoplastiques, Plasturgiejp.free)

When leaving the compression zone and before entering the pumping zone, the material must be completely melted.

For this:

- the pushing force of the material in the feeding area must be sufficient
- The temperature and heating power of the barrel are sufficient
- The space between the screw and the barrel must not be too important

(L'extrusion des thermoplastiques, Plasturgiejp.free)

- *The pumping area: mix, homogenize the material and increase the pressure on the polymer.*

The plastic material is now completely melted and the pressure inside of the extruder ensures the continuous flow of material going through the nozzle thus creating the final product. ***(L'extrusion des thermoplastiques, Plasturgiejp.free)***

After all this research and understanding, we were confronted with a question: how to obtain this extruder?

At this point, we had two options:

- Designing our own extruder
- Buying an extruder on the market

The second option being the easiest, we started to search on the Internet for such products and we ended up contacting few companies.

1) The first answer we had was only for a screw and a barrel:

- A 15 mm diameter screw in Gr12MoV for a price of 70\$ (58.39 €).
- A 45 mm diameter and 380 mm length barrel in stainless steel (38CrMoAlA) for a price of 130\$ (108.44 €)

So, knowing that the total budget of this project is 1500 €, this offer was really interesting but the big problem was that the weight of the screw plus the barrel was approximately 6 kg. But we still had to include our 1.4 kg motor and also all the other elements such as the heating system, the hopper, etc.

So, in total, we would have had a roughly 10 kg extruder. That's why we decided to abandon this offer.

2) The second answer and only other one was for a full extruder:

- 16 mm diameter screw
- 32 mm diameter barrel in 38CrMoAlA with nitriding treatment so very hard
- Temperature controller
- 1.75mm and 3.0mm nozzles
- Breaker
- Thermocouple
- Hopper
- Heater

For this offer, the company said that the total weight was between 5 kg and 7 kg. So, it is roughly the same weight as the first offer except for the fact that this one includes every item and not only the screw and the barrel.

The global price for this offer is 870.00 USD so approximately 729.58 €. So, moneywise, this offer looks interesting because we have a 1500 € budget for this project and it was supposed to be used only for possibly buying the extruder and the materials.

This was the document sent by the company:



JAIHO GROUP
NINGBO JAI HO MACHINERY CO.,LTD

ADD.:No.26,Dinghai Industry, Zhoushan,Zhejiang
contact:Thomas Jil Email:thomas@jaihogroup.com.cn,

TEL:86-574-89086758 FAX:86-574-87359334 www.jaiho-screw.com, www.jaihogroup.com.cn

Customer: Mathieu GONZALEZ

Date:5TH MAR 2021

Adds.:Wolffintie 33, 65200 Vaasa, Finland.

PI No.:JG1926701-181X

PROFORMA INVOICE						
Item	Name	Drawing	Qty	Treatment	Delivery time	Unit price/set
1	D16 screw barrel for extruder	From supplier	1 Set	38CrMoAlA material / chrome plating	Within 30 days	\$400.00
2	Temperature controller	Standard	1 set(3pcs/set)	Standard		\$60.00
3	1.75mm and 3.0mm nozzle		2 pc			\$60.00
4	Breaker		1 pc			\$30.00
5	Thermocouple		1 set(3pcs/set)			\$60.00
6	Hopper		1 pc			\$50.00
7	Heater		1 set(3pcs/set)			\$60.00
Freight cost by air						\$150.00
Total price						\$870.00

Technical Parameter :

- 1.Hardness after hardening and tempering: HB280-320;
- 2.Surface roughness: Ra0.4μm

Terms and Conditions :

Trade Terms : Express
Production Time: Within 30 days after received deposit.
Packing: Slushing oil coated& film wrapped in plywood case.
Mode of Transport: Express
Payment Terms: Through Alibaba
Other: All delivered products are brand new at shipment
Quotation validity: 2 month

宁波佳义和机械有限公司
NINGBO JAI HO MACHINERY CO., LTD

BENEFICIARY BANK: BANK OF NINGBO

BANK ADDRESS: NO.700 Ningnan(S) Road, Yinzhou District, Ningbo 315100, R.P.CHINA
SWIFT CODE: BKNBCN2N
BENEFICIARY: NINGBO JAI HO MACHINERY CO.,LTD
ADDRESS: RM3-11, No.672 Yongfeng West Road, Ningbo 315000,R.P.CHINA
ACCOUNT NO.: 4001 2025 0000 37496 (USD)

Figure 30: Company's quotation

After discussing about this offer, we decided to buy it but we still had in mind that we would probably need to modify some of these items and we will develop this below during the presentation of each item from the extruder:

- ***Screw and barrel***

For this single screw extruder, we will use a screw and a barrel with these specifications:

- A screw with a 16 mm diameter, a length of approximately 330mm and a linearity of 0.015mm
- A barrel with a with an outer diameter of 32mm and a length of 330mm as well.
- Both are made in an alloy-steel of high quality:
 - 38CrMoAlA
 - 42CrMo
 - SKD61
- Processing technics:
 - Heat treatment
 - Quenching
 - Nitriding treatment:

This process works by heating the metal piece under an atmosphere rich in nitrogen. Thanks to the temperature, nitrogen atoms will diffuse into the surface by modifying the internal microstructure to harden the surface.
 - Bimetallic alloy welding for screw
 - Bimetallic alloy centrifugal casting for barrel
 - Hard-chrome electroplating
- Technical parameters:
 - Nitriding layer depth of 0.5 – 0.8 mm
 - Nitrided hardness of 900 – 1000 HV
 - Bimetallic layer depth of 3 mm
 - Bimetallic hardness of 57 – 69 HRC
 - Hard-chrome plating hardness after nitriding **≥ 950 HV**
 - **Chrome plating layer depth of 0.03 – 0.09 mm**
 - **Surface roughness: Ra 0.4**

So, both the screw and the barrel are made out of steel so they will be heavy. We couldn't modify the screw because it is a really complex item and the most important one when it comes to have a working extruder.

Thus, we had a brainstorm about how we could gain weight out of this extruder and we ended up having two main ideas:

- Machining of the barrel:

For now, because we don't have the product yet, we can't study it in order to find if there is anything that is not essential for the proper functioning that we can take away.

- Designing our own barrel:

Because the barrel is made out of steel, it will probably be too heavy for our project. Another solution should be to create our own barrel out of aluminium instead of steel.

In our project, we are 3D-printing three kind of thermoplastic polymer so we will need to heat up the barrel up to approximately 250 °C. So normally, there is no problem using an aluminium barrel because the melting temperature of the aluminium is 658 °C.

For this solution, we will need to use all the drawing and 3D models of the barrel that we bought and we can for example machine it out from an aluminium slug or maybe 3D-prints it using a 3D metal printer (in Technobothnia laboratory)

- **Heating elements**

Band heaters are elements with different diameter and heights designed to heat and maintain the temperature of cylindrical parts.

Heat transfer is usually achieved by conduction or by radiation for these heating systems. They are suitable for solid heating as well as for liquids or gases heating.



Figure 31: Heating element

- **Heating controller**

In order to control precisely the temperature of the barrel and therefore the melting temperature of the plastic polymer, we are planning to use a PID controller as well as some thermocouples.

- **Nozzles**

For our project, we had to increase the thickness of 3D printing layers. Today, in Technobothnia laboratory, the ABB – IRB – 1200 is 3D printing layers with a 0,4 mm thickness. With this project, we intended to go for a layer thickness between 3 mm and 5 mm.

As indicated above, the offer from the company includes two nozzles: a 1.75 mm nozzle and a 3 mm nozzle.

Maybe we will need to buy or design a bigger nozzle or maybe we will also drill out the 1.75 mm nozzle to obtain a 5 mm nozzle.



Figure 32: Nozzles

X – PROJECT DEVELOPMENT

X.1 – 3D DIGITAL MODEL OF THE EXTRUDER

For the software we first decided to design a 3D model of our extruder with a 3D modelling software and then we implemented this virtual extruder in Robot Studio to have a simulation as close as possible to the reality.

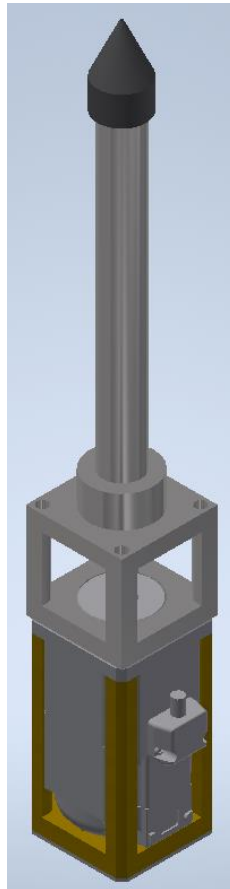


Figure 33: 3D Model of the extruder

X.2 – USE OF ULTIMAKER CURA

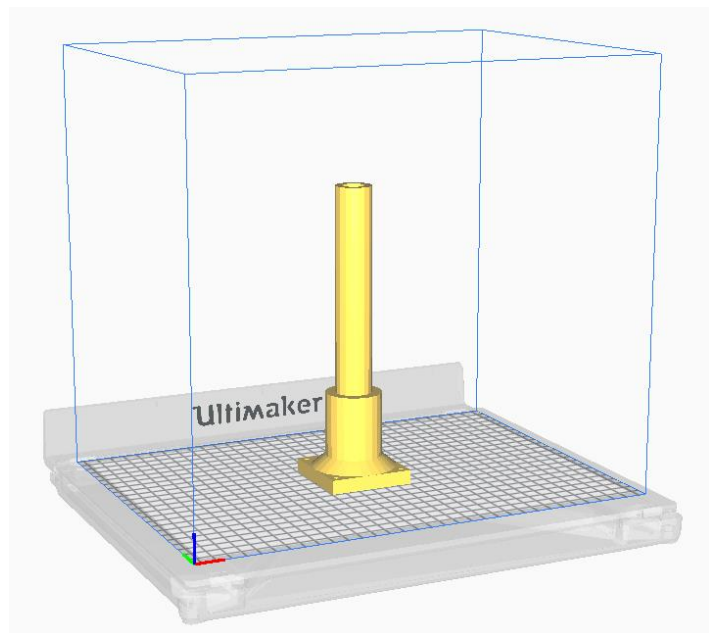
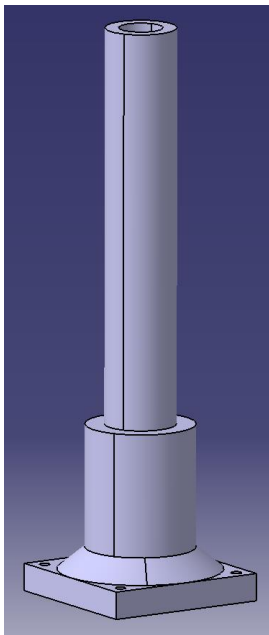
Ultimaker Cura is a slicing software used all around the world for 3D Printing project. After designing a digital model, the file must be imported in Ultimaker Cura to slice the object to be printed according to specific settings.

This software is considered universal as it is suitable with most of 3D printers. It can also work with the most usual 3D files formats such as OBJ or STL.

Not being able to receive our extruder in time, the team decided to produce a prototype as realistic as possible.

To this end, most of the components of the extruder were designed by using a 3D modelling software (Inventor or Catia V5R19). They were then imported in Ultimaker Cura to be sliced and finally 3D printed with Ultimaker printers.

For instance, using all the dimensions and drawings sent by the supplier, we were able to design the simplified plastic version of the barrel to finally import it in Ultimaker Cura:



Then, we need to prepare the slicing by first telling the software which material will be used for the printing. For this component, we used Generic White PLA.

The next step is to define all the settings for the printer according to the material defined previously:

Print settings

Profile: Fine - 0.1mm

Quality

Layer Height: 0.2 mm

Shell

Infill

Material

Printing Temperature: 205 °C

Build Plate Temperature: 60 °C

Speed

Print Speed: 70 mm/s

Travel

Cooling

Enable Print Cooling: ☒

Fan Speed: 100 %

Support

Generate Support: ☐

Build Plate Adhesion

Dual Extrusion

[Recommended](#)

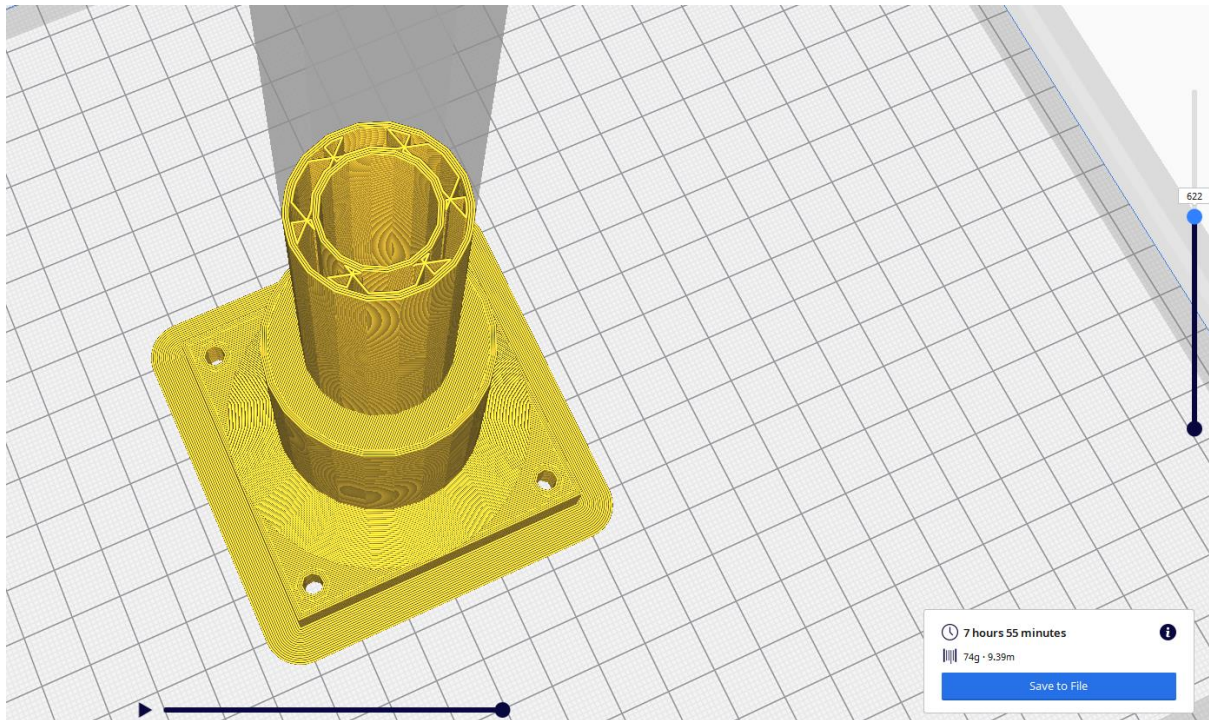
As it is presented on the picture above, first we specify the layer height (here it was 0.2 mm). The more the height will be small, the more accurate it will be but also the more time it will take to 3D print.

Because we used PLA, the printing temperature must be adequate so 205°C in this case. By heating the build plate with a 60°C temperature, the layers will naturally stick to the support bed without using the glue (as it would be needed if we were using ABS).

During the 3D printing lesson we attended, we were said that the speed for PLA must be 70 mm/s in order to have a good balance between quality and time of printing.

For the support, it depends on the orientation you choose for printing the component. By printing vertically our barrel, no support material was required. Furthermore, this question of orientation is really important as the mechanical properties of the object depend on it.

Once all of these settings defined, the object can be sliced and the result appears like this:



First, you can see on the bottom right of the screen that the 3D Print will require 74g of PLA for a total of 7 hours and 55 minutes.

The right cursor allows you to navigate through all the slices to observe how it will be printed. And the bottom cursor is a simulation of the printing (for example, here you can observe the layer number 622).

Ultimaker Cura was used for 3D printing the entire plastic prototype of our extruder but it was also used for slicing our chair in order to obtain the G Code necessary to program and simulate on the software Robot Studio.

X.3 – PLASTIC MODEL OF THE EXTRUDER V1

For our project to be a success, loads of tests will be required to obtain a working solution for our program and simulation. To this end, we thought that not using the real extruder should be a good option to prevent any risk of breaking it but also because it is easier.

Therefore, we decided to go for a plastic model to run these tests. The first step was to design a simplified digital version and for this, we used all the drawings sent by the company. This model will then be used to 3D print the plastic extruder.

Finally, we have inserted some weights inside of it to simulate the actual extruder mass which is roughly 5 to 6 kilograms. This was necessary to observe the robot behaviour with this maximal payload.

This 3D model of the extruder was realized based on all the drawings sent by the company and afterwards, the software Ultimaker Cura was used to 3D print the plastic extruder as you can see on the next picture:

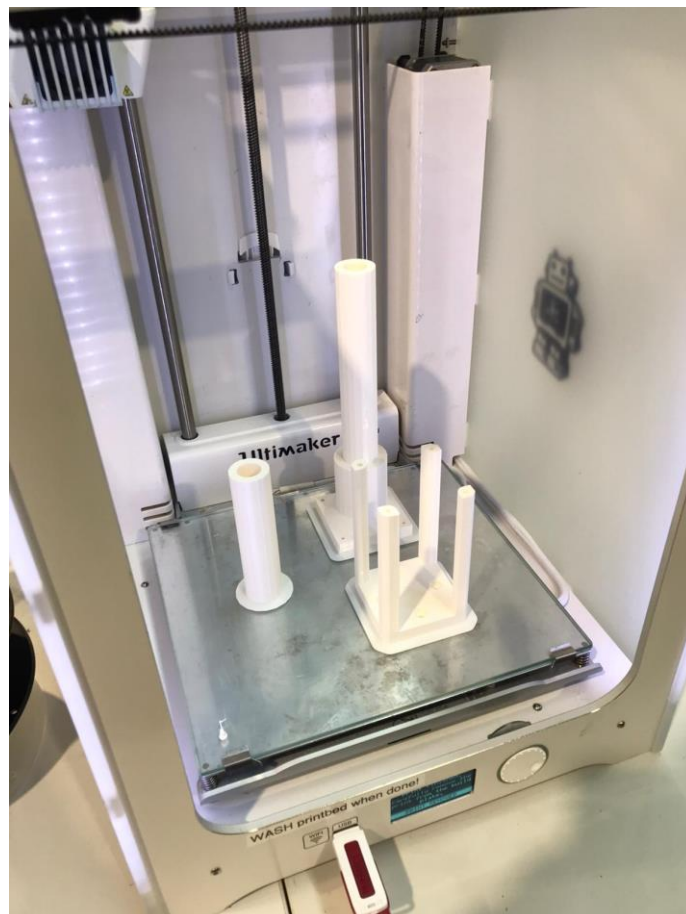


Figure 34: 3D printing the plastic extruder

Once every plastic part of the extruder was completed, we could assemble them together with the Motor Unit 80 and finally we implemented this solution on the ABB – IRB – 1200 Robot:

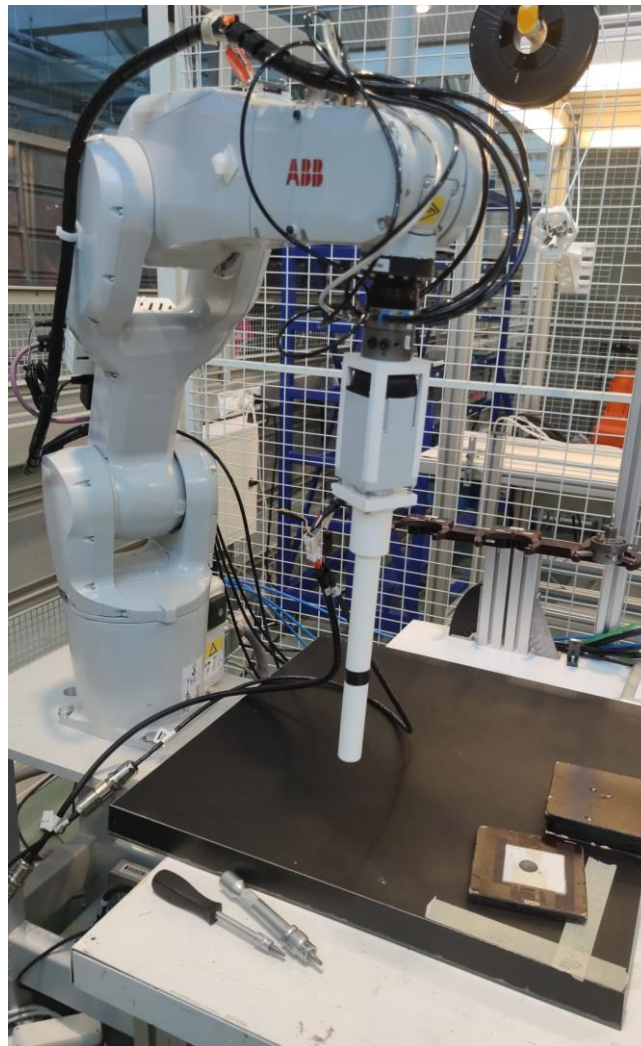


Figure 35: Plastic extruder installed on the ABB robot

This plastic model was mainly used for these two purposes:

- Visualize the behaviour of the robot and the extruder during the tests period.
- Being filed with weights to portray the 5 to 6 kg payload.

X.4 – PLASTIC MODEL OF THE EXTRUDER V2

We created a further updated barrel to visualise better the simulation of the true extruder. This barrel was made slightly smaller to incorporate the size of the Ultimaker printer of which it was made. Decreasing the length allowed for one full print enabling a more realistic prototype.

When designing the model, we made the dimensions too accurate for the Ultimaker resulting in the barrel being unable to fit onto the motor as the holes were too tight. To overcome this, we filed and sanded the main hole that fits on until it fits snugly. For the screw holes, drilling was effective, but it was then concluded that the screws were not long enough. Drilling the holes allowed the screw head to fit in and fall to our desired place. After deliberation with Mika, we were asked to secure the connection between barrel and motor further. We used small rods that ran right through providing a very secure fusion.

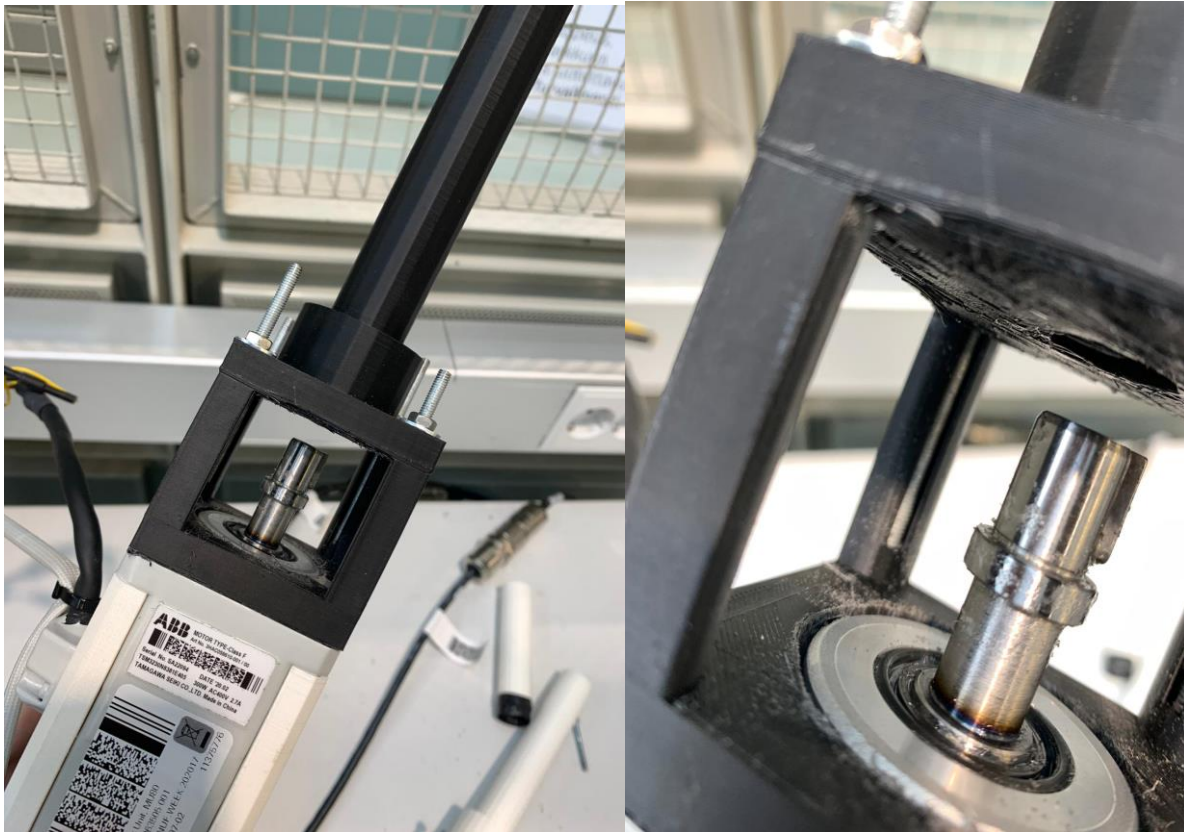


Figure 36: New barrel

Using the sand belt, we were able to eradicate some of the cylinder so that when the 3D printed screw was in, the turning would be visible. Again, the purpose would show closely how the real screw would look in the extruder. After the screw was printed, again we had to file and sand away at the barrel entrances to fit the screw. Eventually the screw was able to fit in however it was unable to turn. Using a dremel we were able to sand away the ridges of the screw and then using proper sanding paper to clean up the debris, the screw was able to turn. When attaching the screw to the motor it would not fit past a certain point. Again, we used the dremel to widen the screw hole. The barrel did come apart however glue worked in the reformation.

The screw did eventually attach to the motor securely. The screw holes were not aligned but it was decided the fit was secure enough without as it is only a prototype.



Figure 37: Sanding the screw

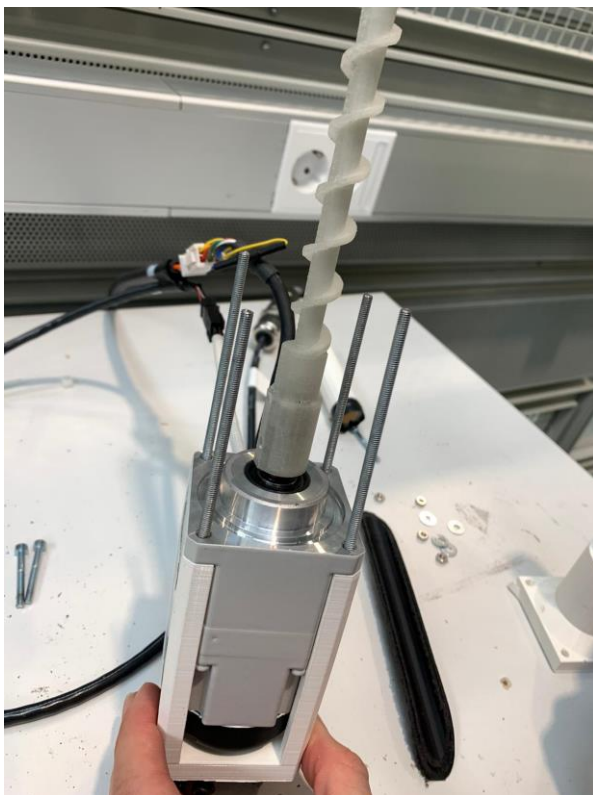


Figure 38: Screw inside the prototype extruder

X.5 – NEW HOLDER 3D PRINTED WITH FIBERS

When creating the first prototype, the strength was not a factor taken into account. The total package of the extruder would be around 6kg. This is not too much for the first holder. But during printing short and fast movement will be made. This can cause fatigue inside of the part. Therefore, this can lead to failure of the holder. The weakest point in any 3D printed part is between the layers. For the first holder, printing speed was deciding for the layers. This way, support material was not necessary for printing at the expense of strength and stiffness.

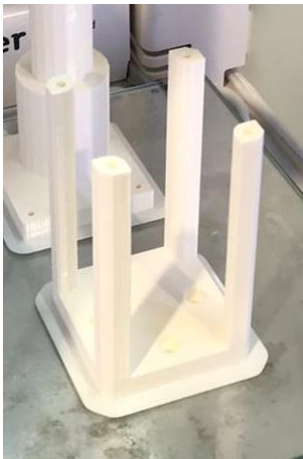


Figure 39: First printed holder

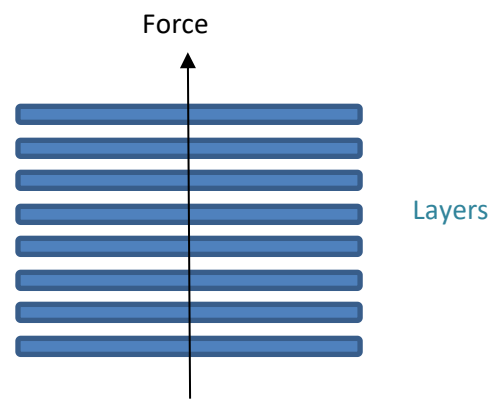


Figure 40: Layerlayout first holder

After realising the actual extruder would not arrive, a more realistic prototype was made. For solving the strength and stiffness problems, two things were done. The first and easiest change was to print the holder by laying it on its side instead of printing it vertically. This makes that the layers are in the same way as the forces that will take place (Figure 42: Layerlayout second holder). Second choice was to print inside of the layers continuous carbon fibres. Since these cannot be stretched, the part gets stronger in the same way as the layers and forces. These fibres are in the base of the holder as well. This makes the part stiffer. Since the complete printhead is long, stiffness is very important for an accurate printing.

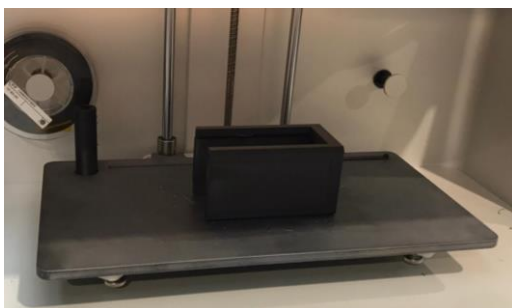


Figure 41: Second printed holder

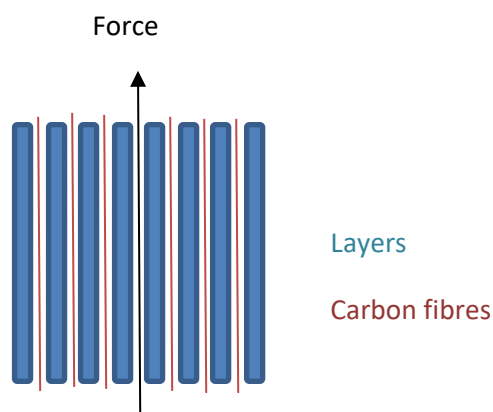


Figure 42: Layerlayout second holder

To help the holder, a metal reinforcement plate was used above the holder to spread the forces from the extruder. In the first prototype, this was secured to the holder by thread inside of the plastic part which was not as safe as the new solution.

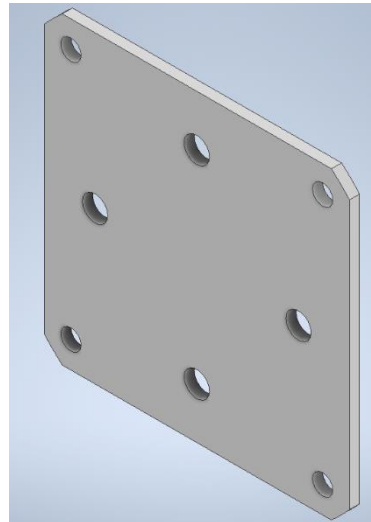


Figure 43: Reinforcement plate

Putting it all together acquires the next result (Figure 44: Complete prototype). Here are all the changes clearly visible and creates a nice overview of the complete printhead.

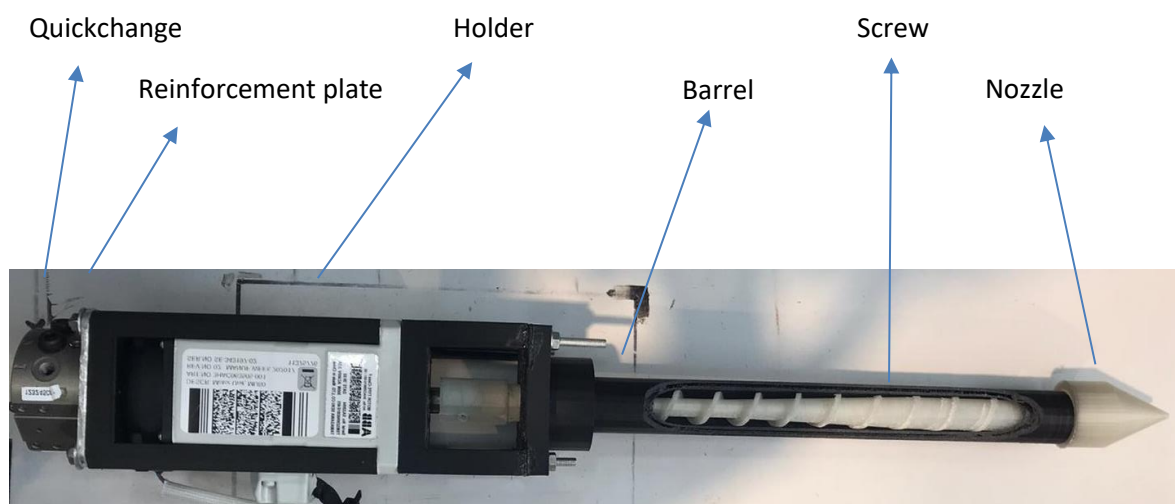


Figure 44: Complete prototype

X.6 – PROGRAMATION AND SIMULATION

X.6.1 – PRESENTATION OF ROBOT STUDIO

Our method of programming the robotic arm is through ABB Robot Studio. ABB Robot Studio is a simulation and offline programming software used to duplicate the physical environment so you can view exactly how your operation will look. The offline service provides a testing site for creation and simulation of an operation.

For some safety and economic reasons, ABB Robot Studio software can be used before or during the production. Indeed, in order to prevent any risk of breaking a robot or a product or even shutting down the manufacturing process, the software must be used to test the program and if needed to optimize it before starting the production.

In ABB Robot Studio, we will use ABB's own coding platform called RAPID to program the robot. The programming language was introduced to the world in 1994 along with S4 control system by ABB. This took the place of the previous program used by ABB: ARLA. **(ABB Website)**

X.6.2 – USE OF ROBOT STUDIO

After a quick period during which we had to understand and get started with the Robot Studio software, we realized a simple program and simulation.

Here is the virtual environment of Robot Studio:

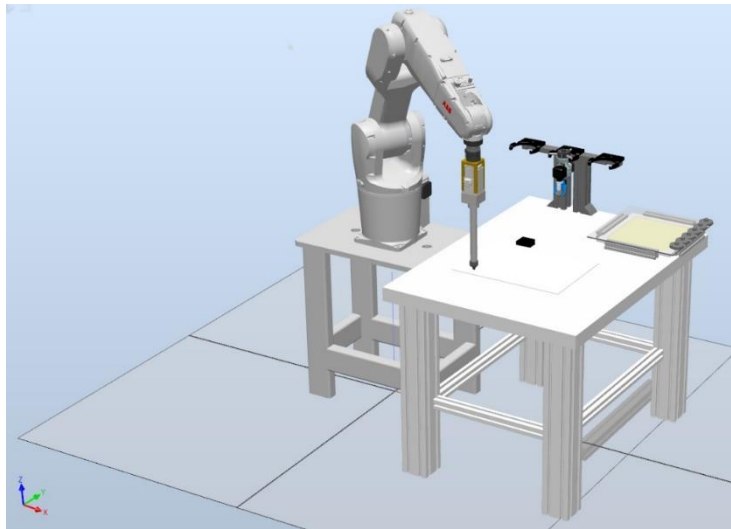


Figure 45: Virtual environment of Robot Studio

We can find the ABB – IRB – 1200 robot, the 3D model of the extruder, the table, the heating bed and the tool holder. What you can see on this window is an exact replica of what is in the laboratory. So, whenever you want to test your program without risking to break anything or stopping the production, you can use this software.

So, we first started to use this software by programming an easy path for the robot. There is, below, the first few lines of the program whose purpose is to define the starting position of the robot and the coordinates of the points the robot will need to reach. So, we first started to use this software by programming an easy path for the robot. There is, below, the first few lines of the program whose purpose is to define the starting position of the robot and the coordinates of the points the robot will need to reach.

```
T_ROB1/MainModule x
1  MODULE MainModule
2  TASK PERS wobjdata wMU80:=[FALSE,TRUE,"",[86.8637,636.116,602.54],[0.706557,-0.0278594,0.706559,0.0278511]],[[0,0,0],[1,0,0,0]]];
3  CONST robtarget p10:=[93.98,532.6,597.69],[0.0385722,-0.703917,0.709221,0.00436005],[0,-1,-1,0],[-106.278,9E+09,9E+09,9E+09,9E+09];
4  CONST robtarget p20:=[93.98,525.37,454.2],[0.0385828,-0.70393,0.709208,0.00437209],[0,-1,-1,0],[-106.245,9E+09,9E+09,9E+09,9E+09];
5  CONST robtarget p30:=[384.21,501.4,454.19],[0.0386165,-0.703933,0.709203,0.00436752],[0,-1,-1,0],[-106.234,9E+09,9E+09,9E+09,9E+09];
6  CONST robtarget p40:=[384.21,501.4,702.48],[0.0386444,-0.703932,0.709202,0.00437946],[0,-1,-1,0],[-106.24,9E+09,9E+09,9E+09,9E+09];
7  TASK PERS wobjdata wTable:=[FALSE,TRUE,"",[542.408,319.678,81.819],[0.707107,0,0,0.707107]],[[0,0,5],[1,0,0,0]]];
8  CONST robtarget pPrinttest10:=[316.440020237,455.54499483,250.700951307],[0,1,-0.000000054,0],[0,0,-3,0],[0,9E+09,9E+09,9E+09,9E+09];
9  CONST robtarget pPrinttest20:=[386.861387056,410.471211846,9.780819123],[-0.000000035,1,-0.000000568,-0.000000014],[0,0,-3,0],[0,9E+09,9E+09,9E+09,9E+09];
10 CONST robtarget pPrinttest30:=[386.861227842,255.870744352,9.780813363],[-0.000000007,1,-0.000000528,-0.000000021],[0,0,-3,0],[0,9E+09,9E+09,9E+09,9E+09];
11 CONST robtarget pPrinttest40:=[191.819196884,255.870883531,9.780792043],[0.000000004,1,-0.000000514,-0.000000012],[0,0,-3,0],[0,9E+09,9E+09,9E+09,9E+09];
12 CONST robtarget pPrinttest50:=[191.819372916,464.733186679,9.780768876],[-0.000000013,1,-0.000000496,-0.000000004],[0,0,-3,0],[0,9E+09,9E+09,9E+09,9E+09];
```

Figure 46: First part of the program

As we said, this program is really an easy one, the path contains only five points (coordinates defined in lines 8 to 12).

Then, below these first lines, you can find the main program:

```

13  PROC main()
14      ActUnit M7DM1;
15      ! IndCMove M7DM1,1,360;
16      !WaitTime 10;
17  FOR i FROM 1 TO 5 DO
18      r3DPTest;
19  ENDFOR
20
21      IndCMove M7DM1,1,0;
22      IndReset M7DM1,1\RefNum:=0\Short;
23  ENDPROC
24
25  PROC r3DPTest()
26      MoveL pPrinttest10,v300,z0,t3DPrintHead\WObj:=wTable;
27
28      MoveL pPrinttest20,v300,fine,t3DPrintHead\WObj:=wTable;
29      Set doTrace;
30      IndCMove M7DM1,1,360;
31      MoveL pPrinttest30,v50,fine,t3DPrintHead\WObj:=wTable;
32      IndCMove M7DM1,1,100;
33      MoveL pPrinttest40,v30,fine,t3DPrintHead\WObj:=wTable;
34      IndCMove M7DM1,1,-200;
35      MoveL pPrinttest50,v100,fine,t3DPrintHead\WObj:=wTable;
36      Reset doTrace;
37
38
39      MoveL pPrinttest10,v300,z0,t3DPrintHead\WObj:=wTable;
40      wTable.oframe.trans.z:= wTable.oframe.trans.z+1;
41
42  ENDPROC
43  ENDMODULE

```

Figure 47: Robot Studio's program

This program can be divided in different parts:

```

13  PROC main()
14      ActUnit M7DM1;
15      ! IndCMove M7DM1,1,360;
16      !WaitTime 10;
17  FOR i FROM 1 TO 5 DO
18      r3DPTest;
19  ENDFOR

```

This first part is used to activate the Motor Unit 80 with the command "**ActUnit M7DM1**". Then, the green lines are here to define the rotation speed of the motor (360 degrees per second); and after waiting for 10 seconds, the main program calls another program "**r3DPTest**" which will be run until the command "**for i from 1 to 5 do**" is over (ENDFOR).

Figure 48: Main program

Then, after the main program is completed, we need first to stop the rotation of the motor by setting the speed at zero degree per rotation. And finally, we can deactivate the Motor Unit.

```
IndCMove M7DM1,1,0;
IndReset M7DM1,1\RefNum:=0\Short;
ENDPROC
```

Figure 49: Deactivation program

And below the main program, you can find the smaller program called inside of the main one:

```
PROC r3DPTest()
  MoveL pPrinttest10,v300,z0,t3DPrintHead\WObj:=wTable;

  MoveL pPrinttest20,v300,fine,t3DPrintHead\WObj:=wTable;
  Set doTrace;
  IndCMove M7DM1,1,360;
  MoveL pPrinttest30,v50,fine,t3DPrintHead\WObj:=wTable;
    IndCMove M7DM1,1,100;
  MoveL pPrinttest40,v30,fine,t3DPrintHead\WObj:=wTable;
    IndCMove M7DM1,1,-200;
  MoveL pPrinttest50,v100,fine,t3DPrintHead\WObj:=wTable;
  Reset doTrace;

  MoveL pPrinttest10,v300,z0,t3DPrintHead\WObj:=wTable;
  wTable.oframe.trans.z:= wTable.oframe.trans.z+1;

ENDPROC
```

Figure 50: Second program

This program is used for the trajectory the robot will have. We defined the rotation speed in between every point: for example, between the second and the third point, the rotation speed will change from 360 degrees per second to 100 degrees per second.

We can also define the trajectory speed by changing the “v”: “v300” or “v50”.

X.6.3 – WORKING SOLUTION AND SIMULATION WITH ROBOT STUDIO

The software Robot Studio was a key to obtain a final working solution and a simulation of the 3D printing.

Being the digital twin of the Technobothnia laboratory environment, it is possible to visualize the printing without using the robot. This is useful for two reasons:

- While programming and simulating on the software, the robot is still available to be used at the same time
- In case of a wrong program, it is easier and safer to run the simulation and being able to spot any mistake without risking to break the printing head or the robot itself.

The final goal of this project was to 3D print a chair for our supervisor. Not being able to receive our extruder in time, we at least really wanted to have a working solution and a simulation on Robot Studio.

This guide will explain in details all the steps the team went through to achieve this objective:

1. *Choosing the chair*

Our printing head being around 40 cm long, we were constraint to find a model of a chair that we could 3D print without modifying the environment of the laboratory (add a new table for example).

To this end, we found the following chair: this a chair whose width is adjustable by adding parts.

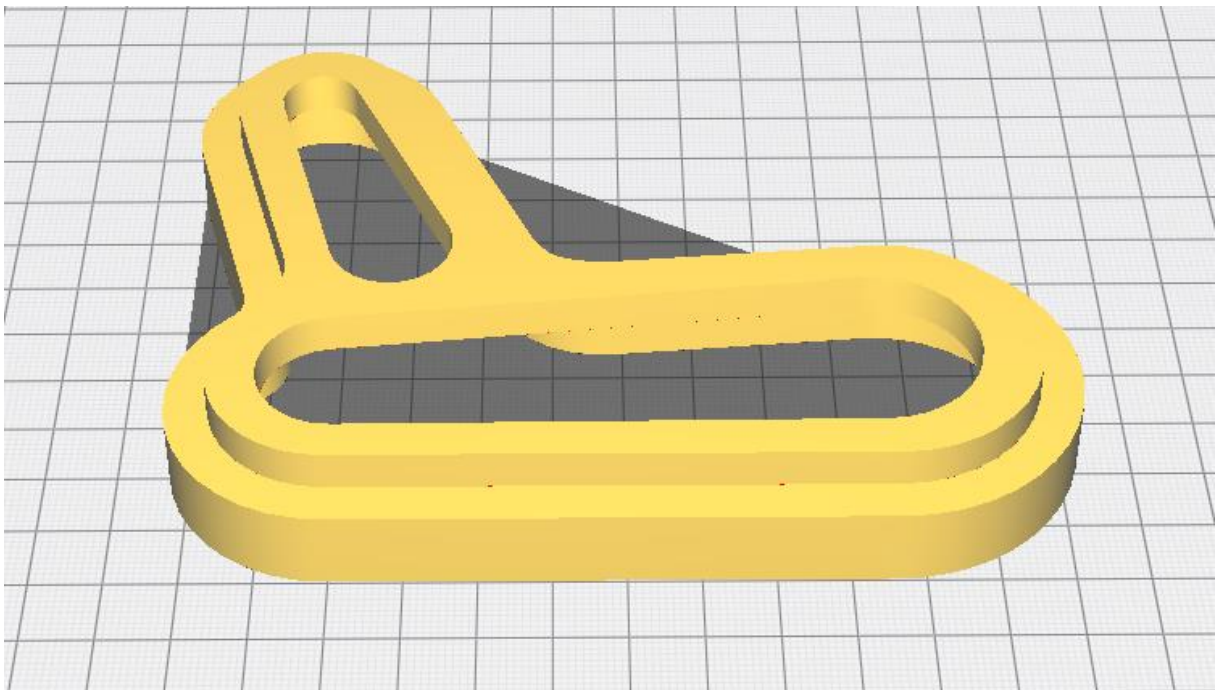


Figure 51: The chair chosen

2. Slicing the chair to obtain the g-code

Once the 3D model of the chair obtained, we need the G-code to be able to use Robot Studio (*"G-code instructions are provided to a machine controller that tells the motors where to move, how fast to move, and what path to follow."*, **G-code – Wikipedia**)

This G-code was created by slicing the chair in the software Ultimaker Cura (cf. Ultimaker Cura paragraph).

Then, after the 3D printing window selected in Robot Studio, the G-code file can be opened:

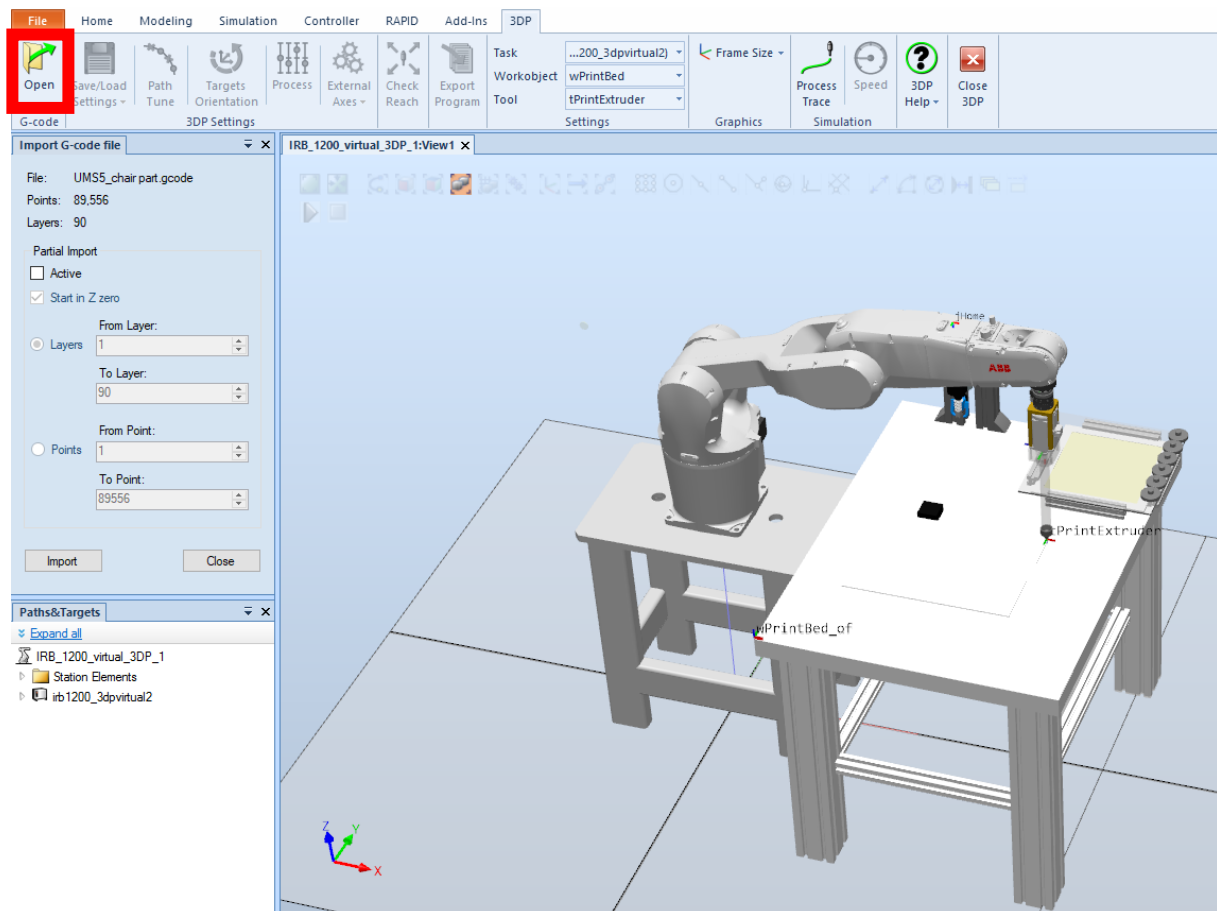


Figure 52: Opening the G-code

While opening the files, you have some information given about the G-code: the name of the file, number of points and the number of layers.

The "Import" window also let the choice between importing the whole G-code or only few layers. For our case, we need to 3D print the entire chair so we selected the whole code.

3. Target orientation

Once the model opened in the virtual environment, we have to ensure that its orientation is the same as the one from the printing head. This orientation is defined by 3 axes: x, y and z represented here in red, green and blue.

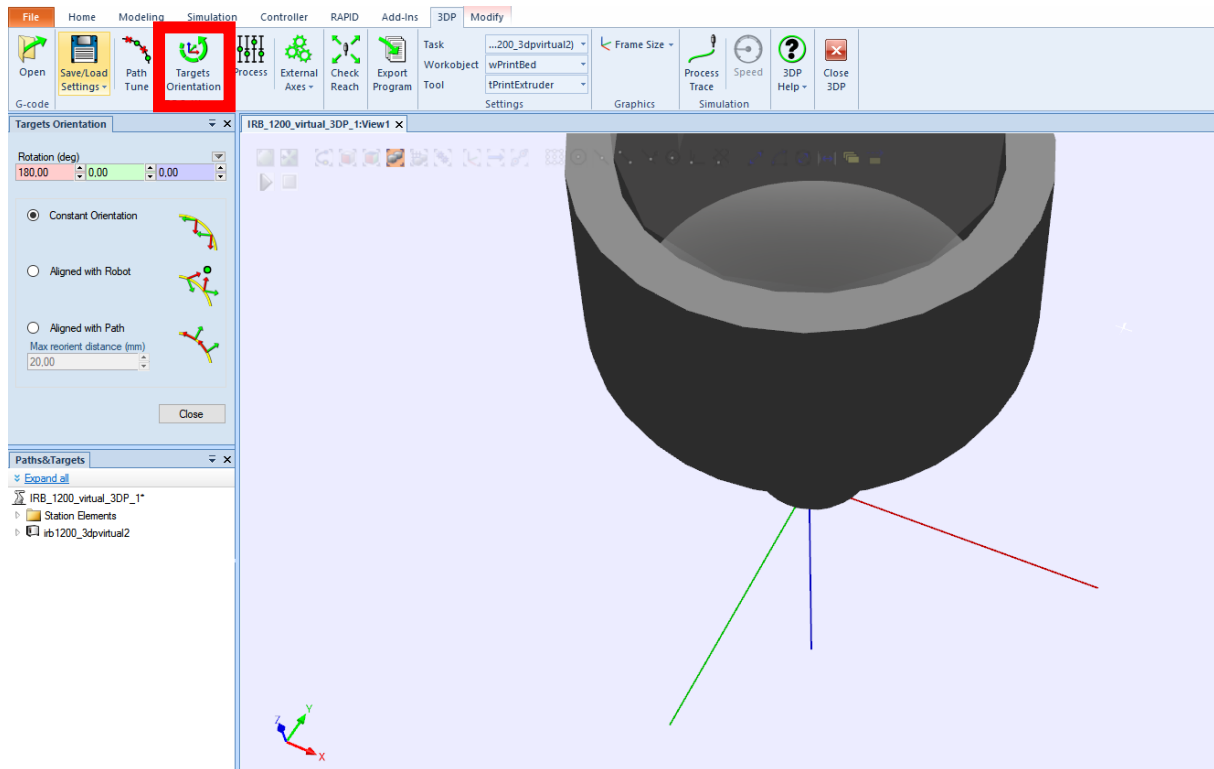
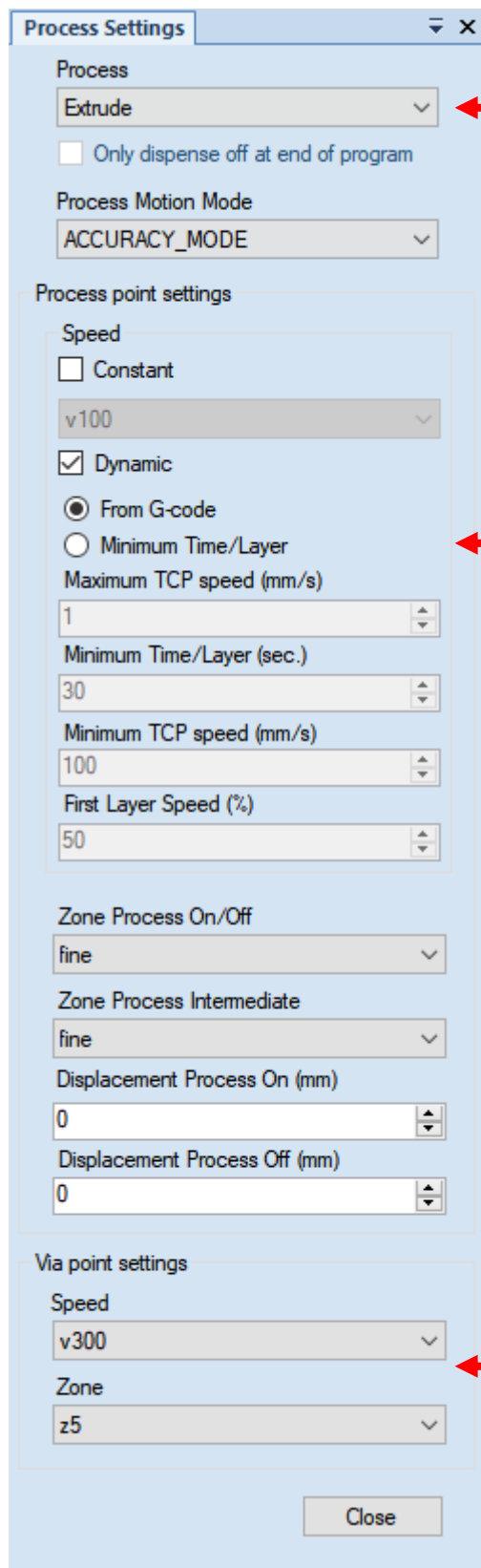


Figure 53: Target orientation

4. Process settings



The 'Process Settings' dialog box contains the following sections and settings:

- Process:** A dropdown menu set to 'Extrude'. A red arrow points to this dropdown.
- ☐ Only dispense off at end of program
- Process Motion Mode:** A dropdown menu set to 'ACCURACY_MODE'.
- Process point settings:**
 - Speed:**
 - ☐ Constant
 - ☒ Dynamic
 - ☒ From G-code
 - ☐ Minimum Time/Layer
 - Maximum TCP speed (mm/s): 1
 - Minimum Time/Layer (sec.): 30
 - Minimum TCP speed (mm/s): 100
 - First Layer Speed (%): 50
- Zone Process On/Off:** fine
- Zone Process Intermediate:** fine
- Displacement Process On (mm):** 0
- Displacement Process Off (mm):** 0
- Via point settings:**
 - Speed:** v300. A red arrow points to this dropdown.
 - Zone:** z5. A red arrow points to this dropdown.

A 'Close' button is located at the bottom right of the dialog box.

During this step, first we need to define which kind of process will be used when programming and simulation. In this case it will be an extrusion process and we want the motion to be precise hence the use of the "ACCURACY_MODE".

In this window, you want to cross this box to tell the program this information is already included in the G-code.

And finally, these two information specify where you want to start printing on the axis z and the speed of the robot when reaching this point.

Figure 54: Process settings

5. Extruder axis

This step is probably the most important as it is used to define how the printing head will be during the process: definition of the orientation during and out of the process, definition of the rotation speed (in revolutions per meter).

These settings must be adjusted according to the material used during the printing and also according to the expected quality.

Normally, the team should have done loads of tests playing with these settings but because of the extruder not being delivered in time, it was unfortunately not possible.

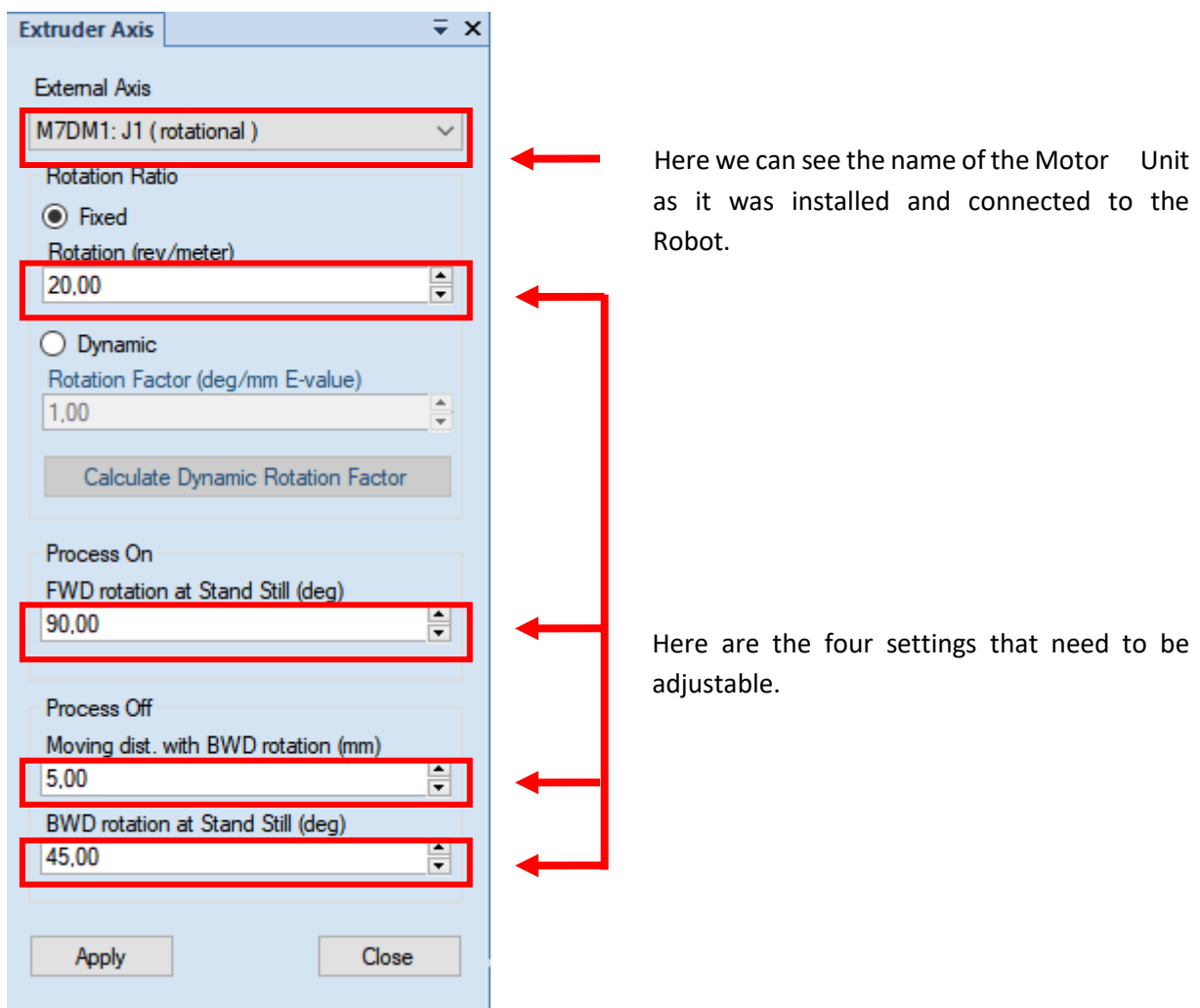


Figure 55: Extruder settings

6. Check reach

This is the last step before visualizing the simulation. This tool helps to see if every point will be reachable by the robot. If that is the case, a “succeeded” message box will appear to confirm the reachability (as it can be seen on the picture below).

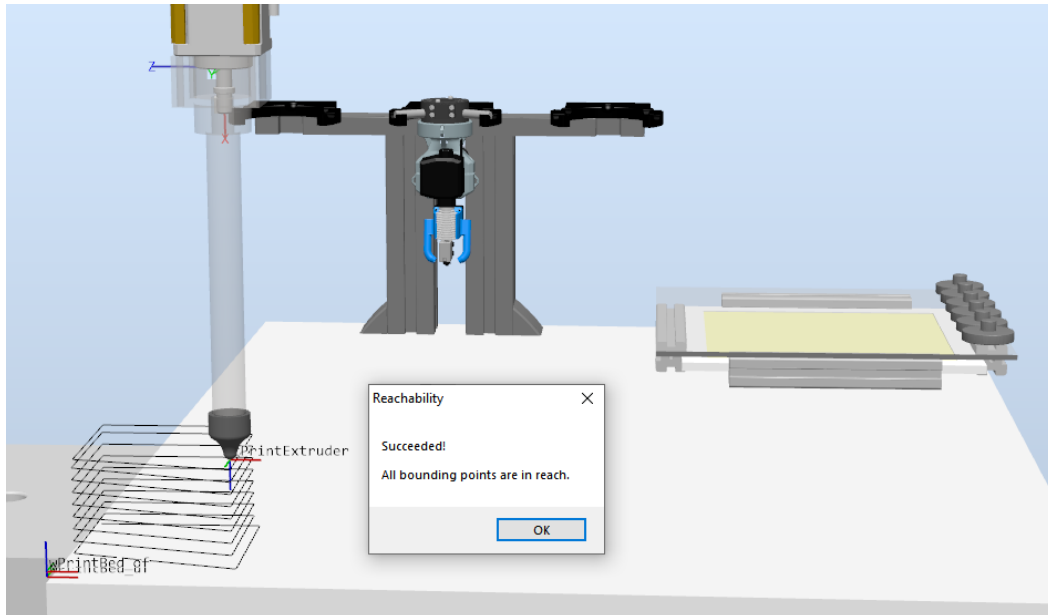


Figure 56: Check reach

7. Exporting the program and simulating

Once the program is finally ready, it can be exported and then loaded in the software to start the simulation:

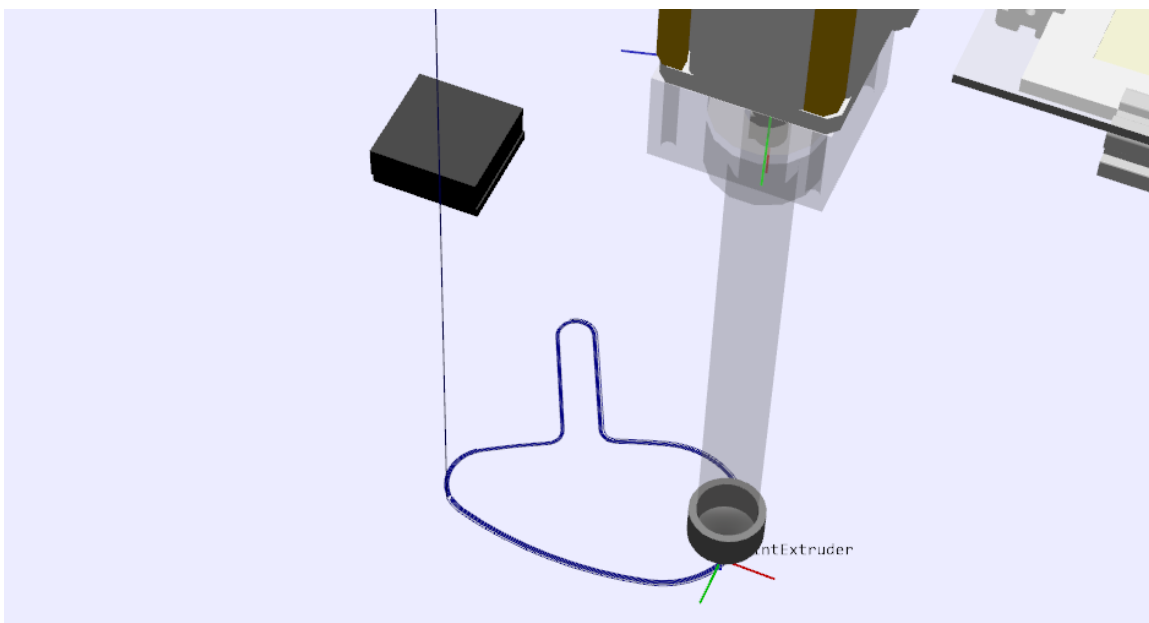


Figure 57: 3D printing the first layers

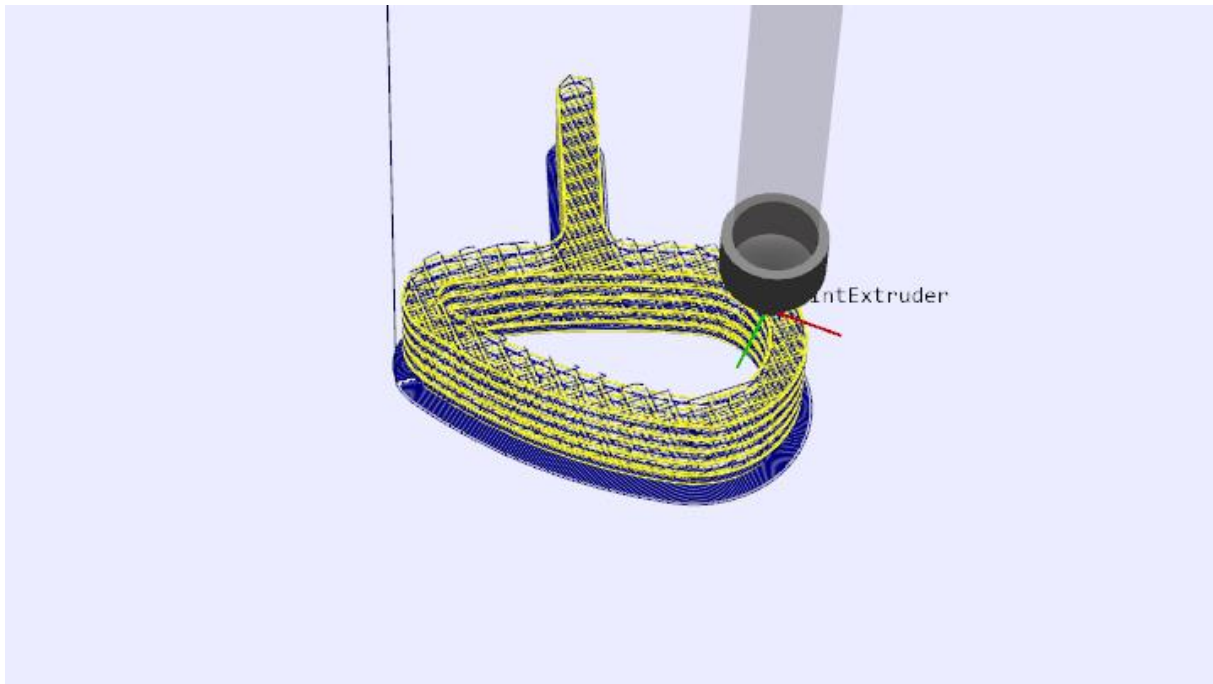


Figure 58: 3D printing simulation of the chair

The first picture represents the first layers being printed. Then we let the program run for couple hours to finally observe the result on the second picture.

At this point, the final working solution on the software Robot Studio was finally completed.

When exporting the program, the printing settings can be saved along. The original plan, was to play with these settings according to:

- The material used to print the chair
- The layer height (diameter of the nozzle)
- The quality expected

By saving loads of these solutions, we wanted to create a Database to facilitate the use of our product. For instance, if our project was to be sold, we would have provided the Database for the company to be able to quickly find the appropriate settings for their solution.

Unfortunately, not having the extruder in time, the team couldn't create this Database because we were not able to realise all these tests.

This is how the Database would have looked like:

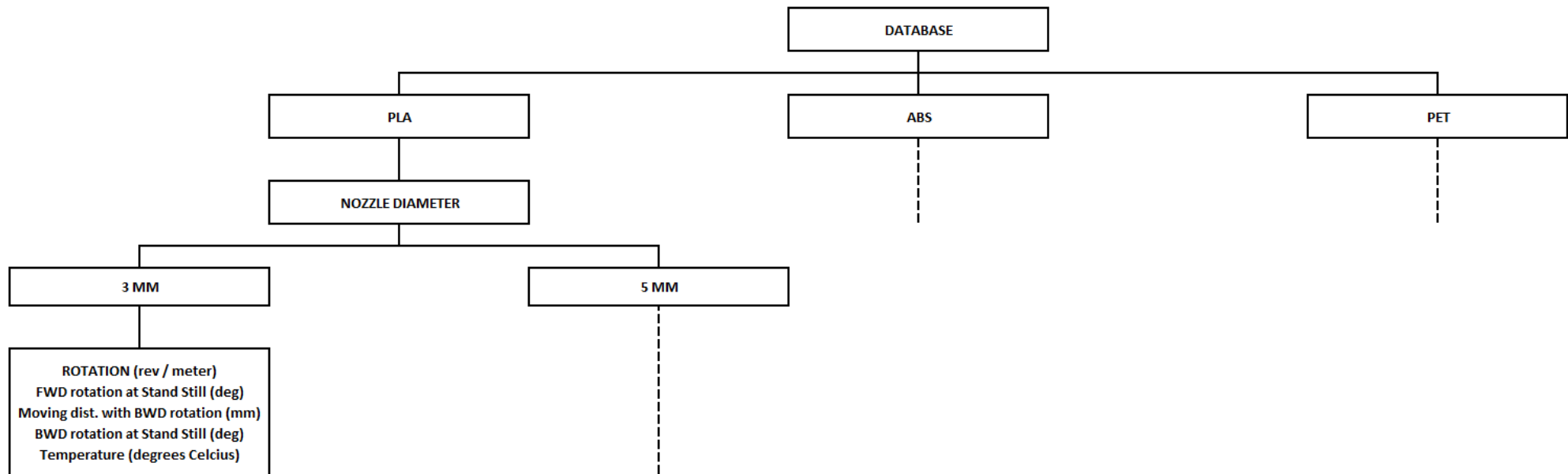


Figure 59: Example of Database

CONCLUSION

The European Project Semester offers a unique experience and a new way of working within a multinational group. Our team was composed by Ben Cardwell from Scotland, Frédéric Demarbaix from Belgium and Mathieu Gonzalez from France. Under the supervision of Mika Billing, we had the chance to work on a multidisciplinary project which was:

“DESIGN A 3D-PRINT TOOL FOR AN INDUSTRIAL ROBOT USING AN EXTERNAL AXIS EXTRUDER”.

Humanely speaking, it was really important to create a cohesion in the group by trying to know each other better and doing some extra scholar activities together really helped in this process. Throughout this project, and especially because we were only three people in the team, we never had difficulties and on the contrary, we had a great time working together including Mika.

Professionally speaking, the team had the chance to realize a complex but still really interesting project. To this end, we divided the latter in two distinct missions:

- **The project Management:**

With the precious help and education from Roger Nylund, we studied the project from different angles and aspects: objectives and goals, time analysis, risk analysis, economic analysis or tasks analysis.

This long process allowed us to set clearly all the stakes of the project and to start working on the best way possible.

- **The Project itself:**

The team first decided to understand better the project by doing loads of researches about for instance robots, 3D printing or extruder.

Once this step over, we quickly ordered our printing head: an extruder composed by a barrel, a plasticizing screw, heating elements, a breaker, a hopper and two nozzles.

Unfortunately, the pandemic situation slowed down the production and the delivery time so we never received this extruder in time.

Instead of giving up, we managed to pull ourselves together by changing our goals in agreement with our supervisor. The team designed and 3D printed a complete prototype which portrayed the real extruder. We also created a working solution by programming and simulating the extruding process on the software Robot Studio.

As a conclusion, even if the project did not go as expected mostly because of the current situation, the team met the expectations set at the very beginning. We provided a working solution and all the necessary upstream work for the next person in charge of this project.

This experience is a one-in-a-lifetime experience. We all individually grew up as a person but also as a professional.

Thank you again to all the people who made it possible!

EXPECTATIONS

The aim of this project was to attach a printing head to a robotic arm in order to 3D print a chair.

Throughout the project, the team had some unforeseen that made us change our initial instructions. Because of the pandemic situation we did not receive the extruder. Therefore, we were not able to assemble it and install it on the ABB – IRB – 1200 robot.

After a discussion with our supervisor, we decided to write a manual listing all the steps that will need to be done once the extruder will be received:

- Assemble the extruder: weight it and measure its length
- If too long, design a new table
- If more than 5-6 kg, redesign the barrel by using aluminium instead of steel. This must save around 700 grammes
- Create a bigger feeder for material
- Then install the heating elements on the barrel and check their temperature
- Install the whole extruder on the robot and try to move it to see how it behave
- Insert some material (maybe only focus on PLA first) and check how it go through the nozzle without moving the robot
- Try different rotation speeds (revolutions per meter) to find the best one
- Repeat the same last two points while moving the robot (linear movement) and maybe try different movement speed

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APPENDIX

APPENDIX A: OBJECTIVES AND WORK BREAKDOWN STRUCTURE

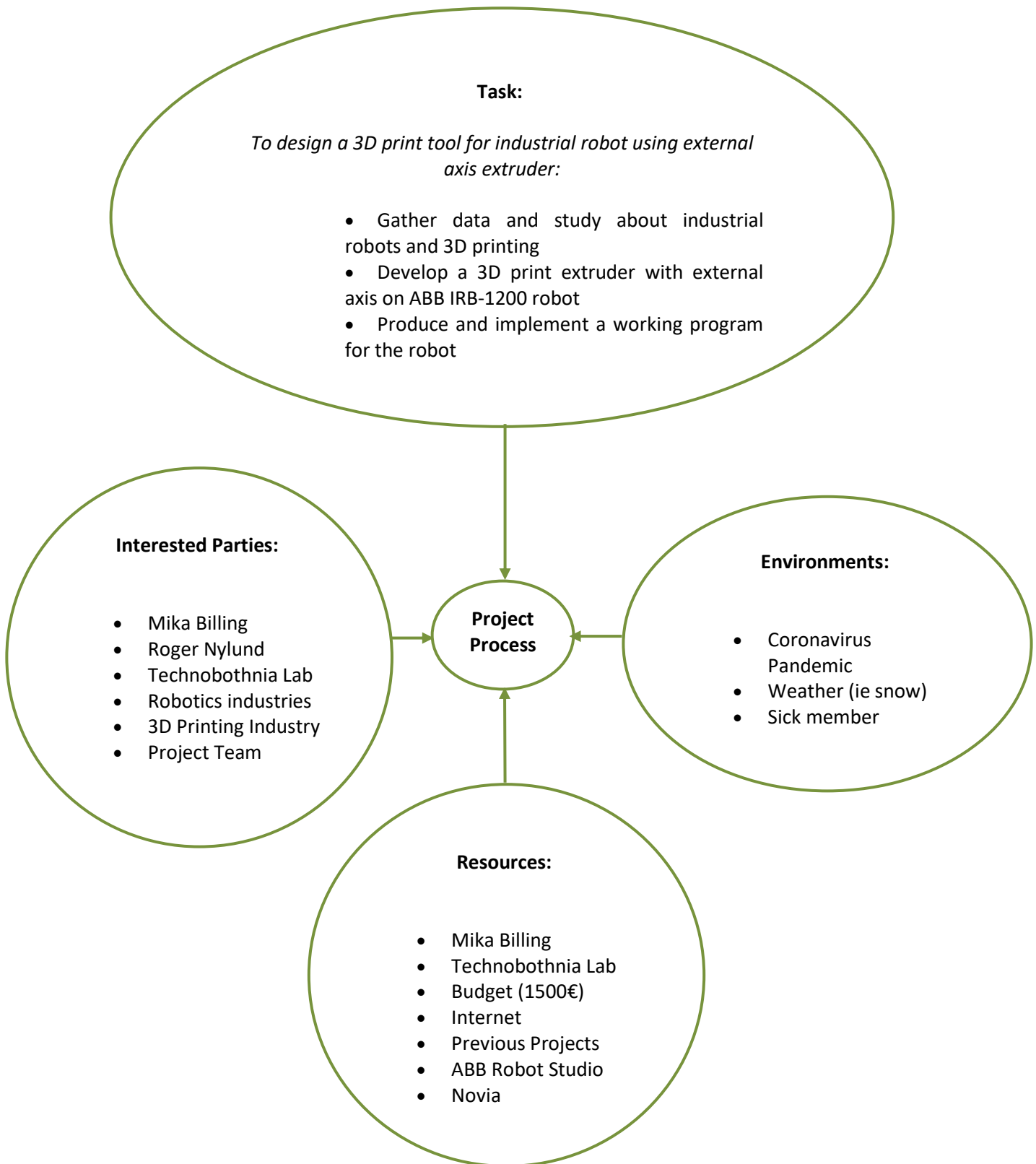


Figure 60: Project Management introduction

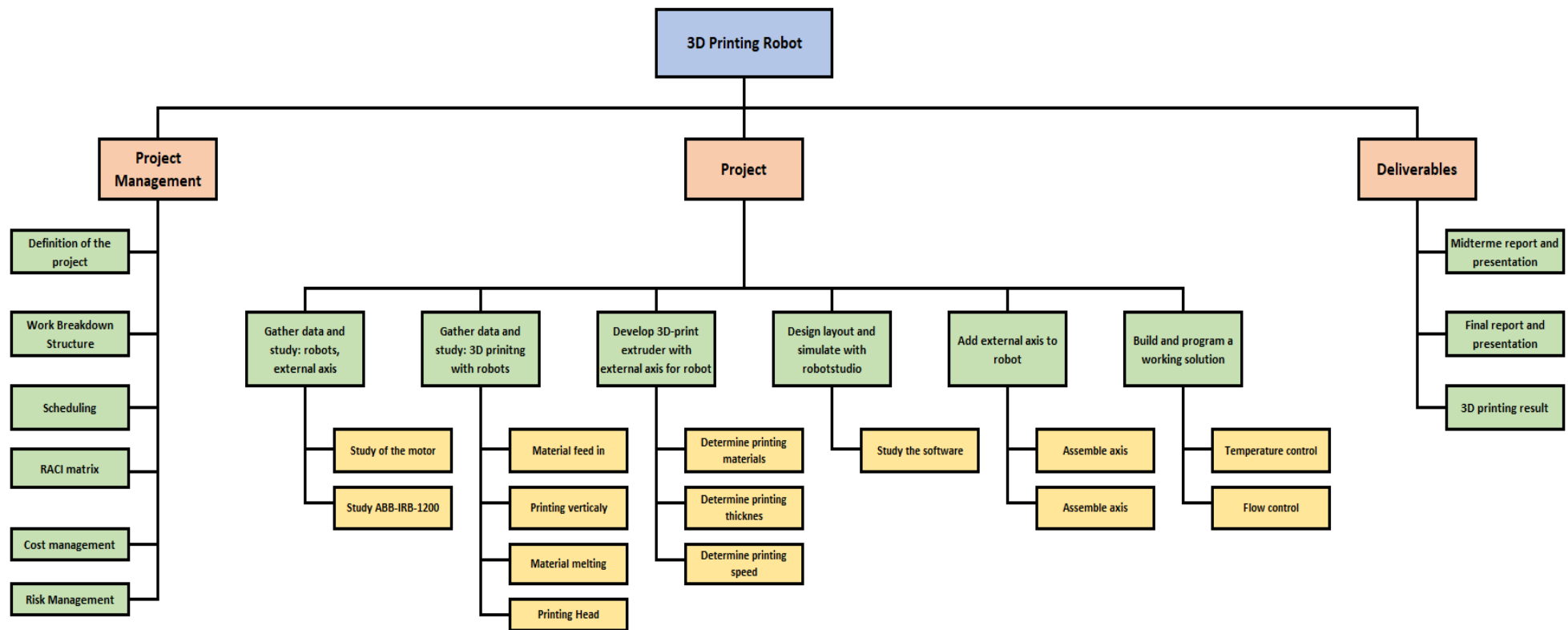


Figure 61: Work Breakdown Structure

APPENDIX B: TIME MANAGEMENT

Once the Work Breakdown Structure realized, we started to work on the schedule to organize and plan our project.

Indeed, the Work Breakdown Structure is used to list every task that need to be done in order to succeed in a project but it does not say in which order they need to be executed.

Thanks to this scheduling task, you can have a global vision of the planning by sequencing the activities in the order they are to be realized.

To this end, we decided to use a well-known tool called “bar chart” or also “Gantt chart”.

A Gantt chart, named after its inventor Henry Gantt, represents a project schedule by organizing vertically all the tasks of a project. This visual tool offers a simplified vision of the duration of each activity and the sequence that need to be respected in order to have a successful project.

Different levels of Gantt charts can be used; for example, modern ones can show the dependency between two tasks: if a task need to be completely finished before the start of another one, it will be represented as an arrow between these two activities.

While organizing and scheduling all the tasks from the Work Breakdown structure, we tried to be as precise as possible but we still had in mind that it was only a theoretical time organization. It will not necessarily be the same in real life but it still helps getting started in the best way possible.

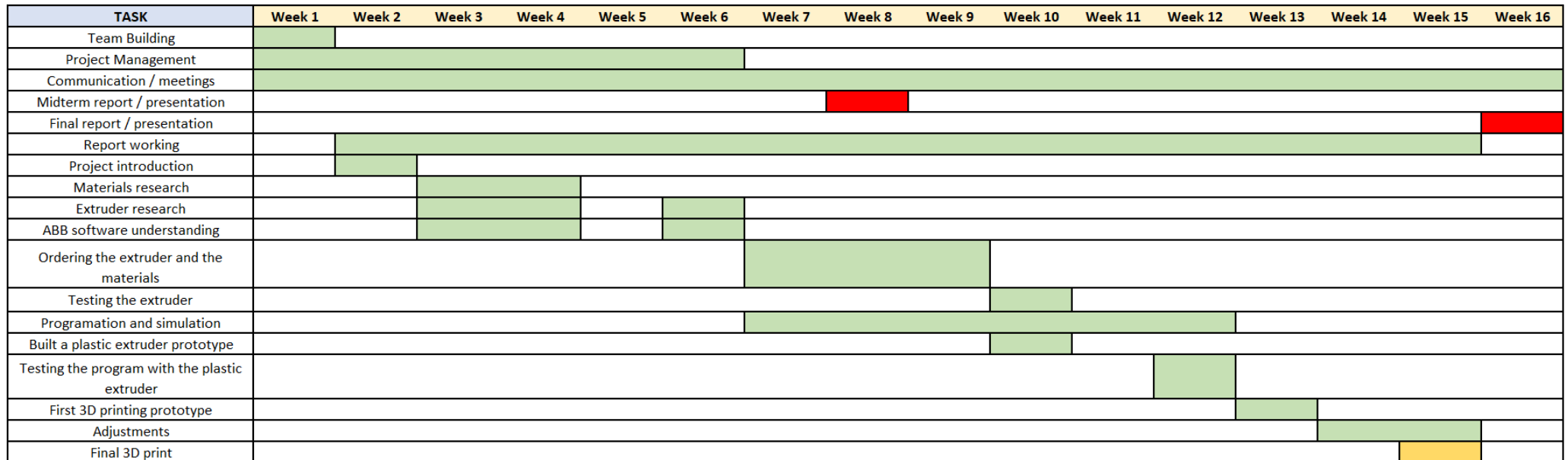


Figure 62: Gantt Chart

APPENDIX C: COMMUNICATION MANAGEMENT

In everyday problem, or in our case, for an engineering mission, communication is one of the most important skill for a project to succeed or for a problem to be solved. This project management tool is used to organized all the different ways of communication with every stakeholder involved within the project.

In a mission like this one, we are not only working for ourselves but we had to provide results for different people involved in this project: Mika BILLING or Roger NYLUND for instance. That is the reason why we first started to identify all the stakeholders involved or interested in this 3D-Printing project.

APPENDIX C.1: STAKEHOLDERS ANALYSIS

A stakeholder analysis is a method used to identify people involved or interested in a project whether it is a direct or indirect connection. Each stakeholder is then classified according to their concern and impact on this project so we can easily determine the best way to communicate with each one of them.

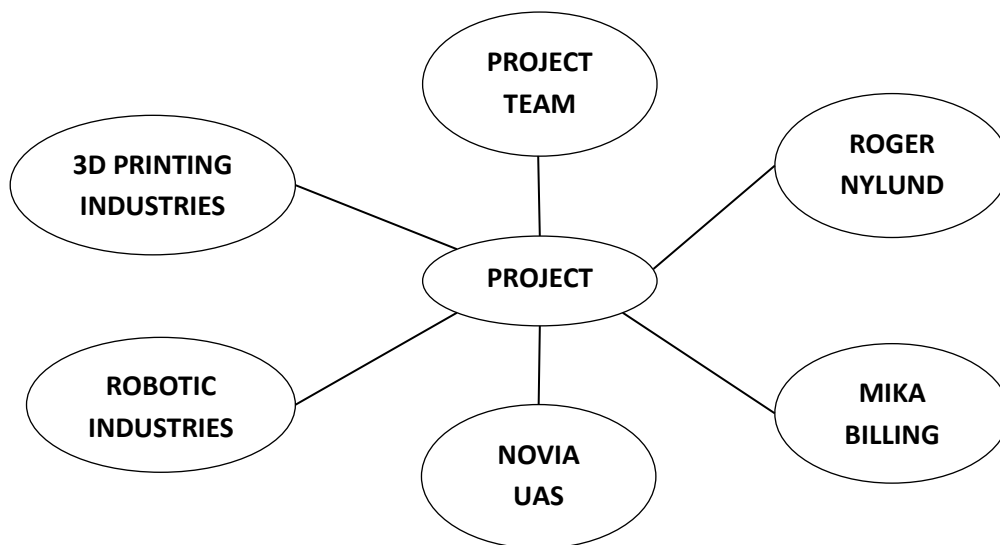


Figure 63: Stakeholder's analysis

APPENDIX C.2: POWER / INTEREST GRID

The management of every stakeholders is made by using a Power / Interest matrix that divides all the interested parties into four categories: *Keep satisfied*, *Manage Closely*, *Monitor*, and *Keep updated*. (*Stakeholders Analysis, MindTools*):

- **Manage closely:** You want to regularly communicate with these people and try to meet their expectations.
- **Keep satisfied:** you want to give them news of the project progression but try to avoid an overcommunication.
- **Keep informed:** You want to update these people to prevent major issues to happen.
- **Monitor:** As for the “Keep satisfied” category, you do not want to bother them with an excessive communication.

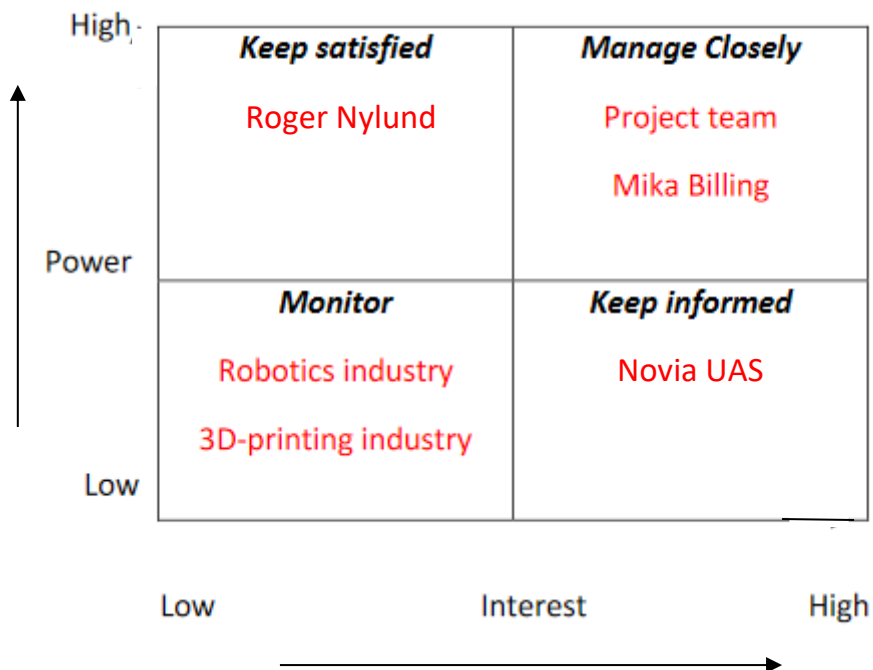


Figure 64: Power / Interest grid

APPENDIX D: RACI MATRIX

A RACI matrix is a project management tool that is employed to assign each project member to a task according to their role realizing this mission.

RACI is an acronym standing for *Responsible, Accountable, Consulted, and Informed*.

Because we are only a three people group, we decided only to use two roles to define everybody's responsibility:

- **Responsible:**

Responsible people are the one working to realize the task. In a project group, most of the time there is one person responsible for each task (you can also have multiple responsible roles for the same task) and then there are few people helping by assisting the work.

- **Accountable:**

Within a project, there must only be one accountable person for each task. As the name suggests, the accountable person is the one you go for to validate the work and to ensure that all the expectations are completed.

This person is also here to dispatch the work that need to be done between all the *responsible*. (*Responsibility assignment matrix, Wikipedia*)

TASK	Frederic	Ben	Mathieu
Team Building			
Project Management			
Communication / meetings			
Midterm report / presentation			
Final report / presentation			
Report working			
Materials research			
Extruder research			
ABB software understanding			
Ordering the extruder and the materials			
Testing the extruder			
Programation and simulation			
Built a plastic extruder prototype			
Testing the program with the plastic extruder			
First 3D printing prototype			
Adjustments			
Final 3D print			

Accountable

Responsible

Figure 65: RACI matrix

APPENDIX E: EARNED VALUE ANALYSIS

Earned Value Analysis is a Project Management tool used to control and measure all the work and progress done for the project.

This base can be used later for determining the global cost of the project or the value created during its realization. (*Earned Value Analysis, Wikipedia*)

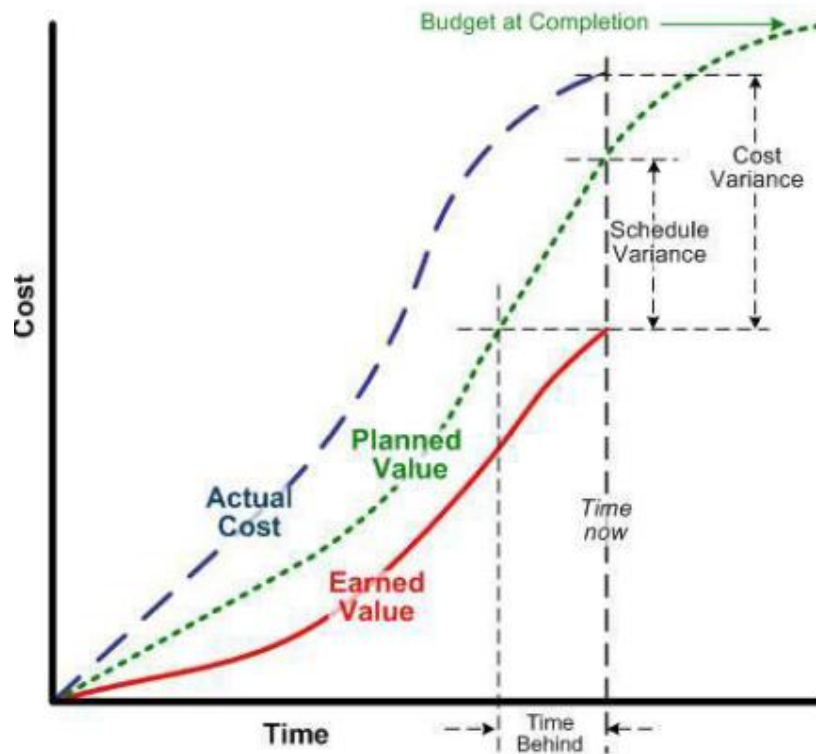


Figure 66: Earned Value Analysis

- Budget at Completion is the global cost of the project
- Actual Costs is evaluated throughout the project and is based on the total working hours
- Planned Value is the prediction (quantity of work, project cost ...) made at the beginning of the project
- Earned Value is all the work that has been done by the team so far

APPENDIX F: Drawings

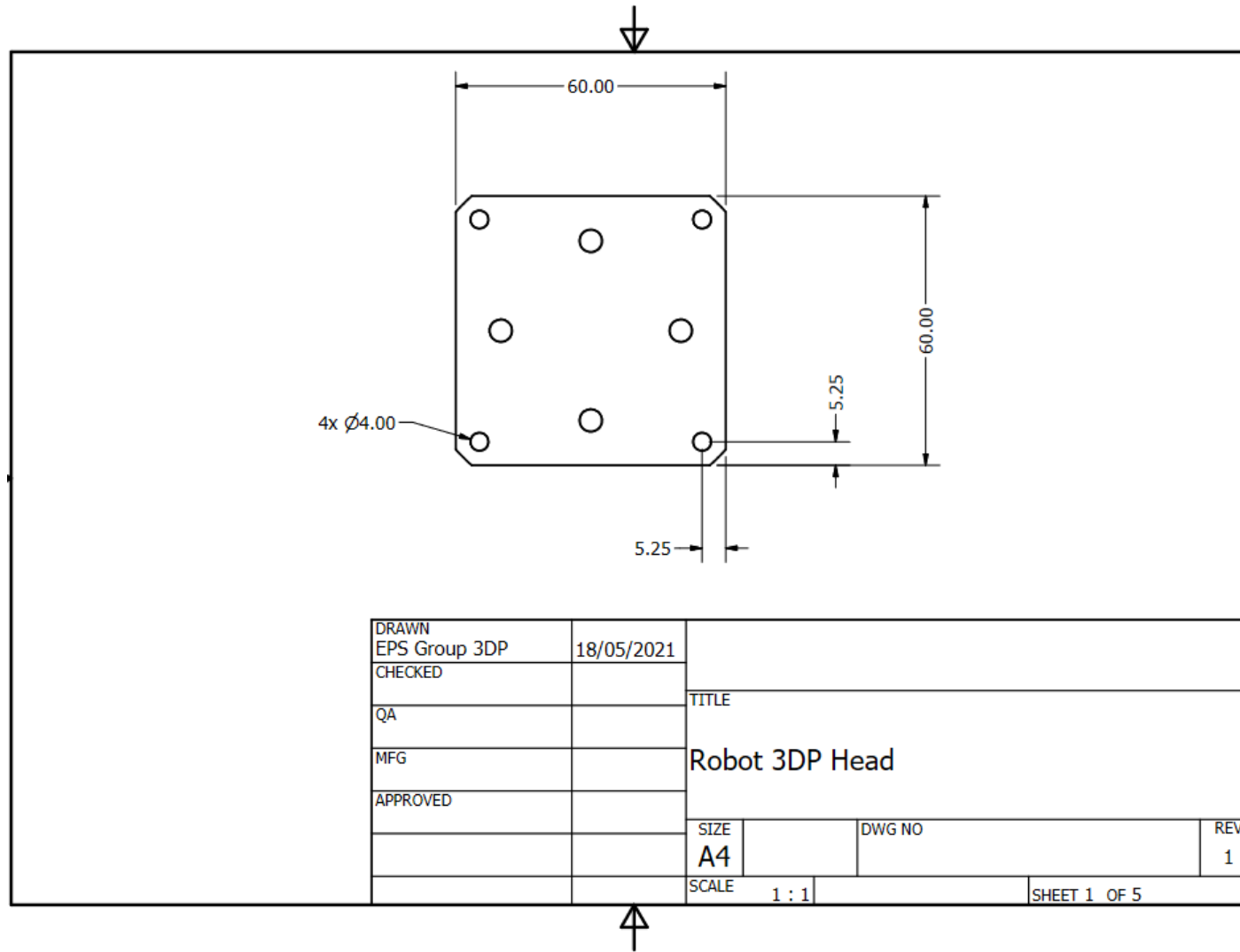


Figure 67: Metal plate drawing

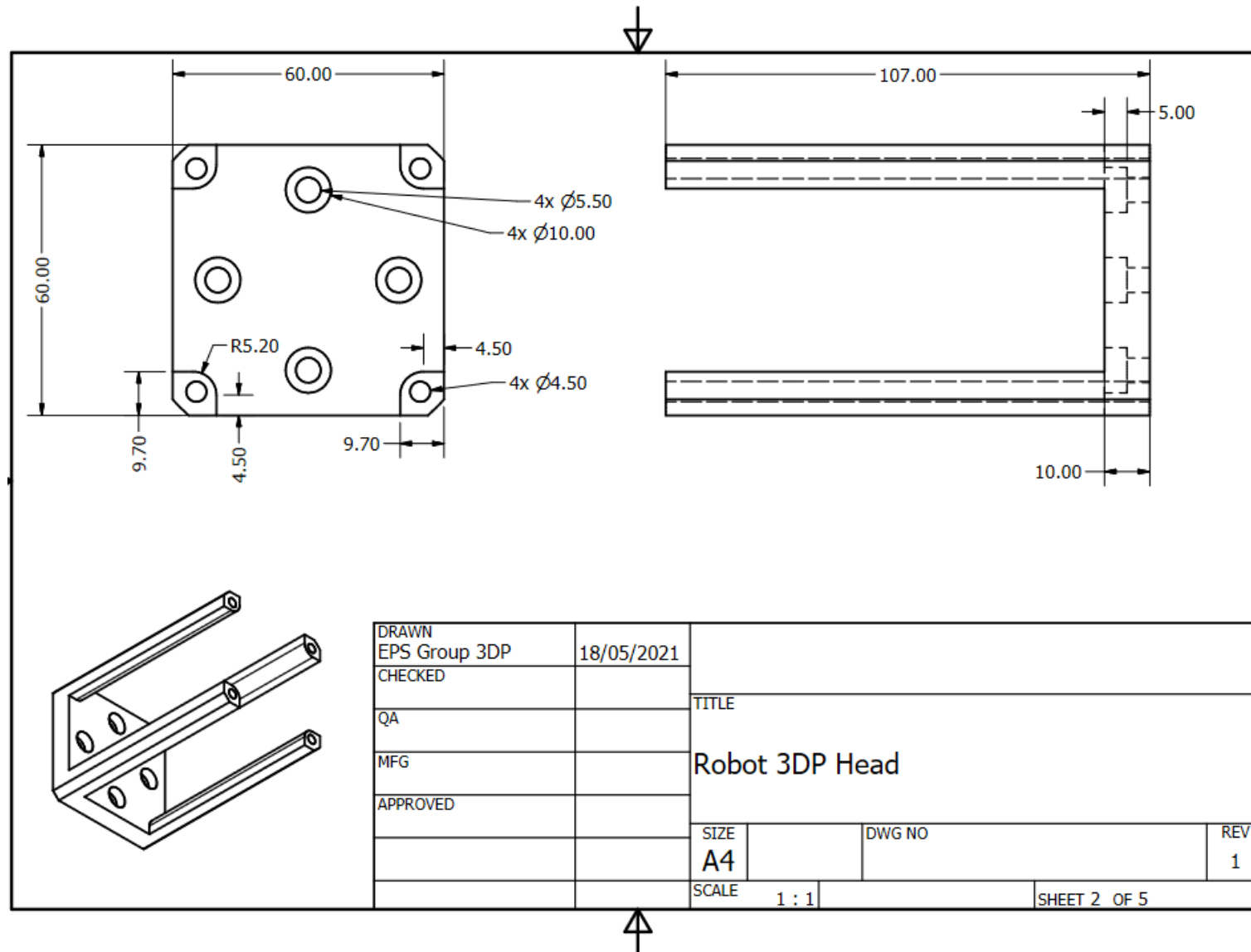


Figure 68: Holder drawing

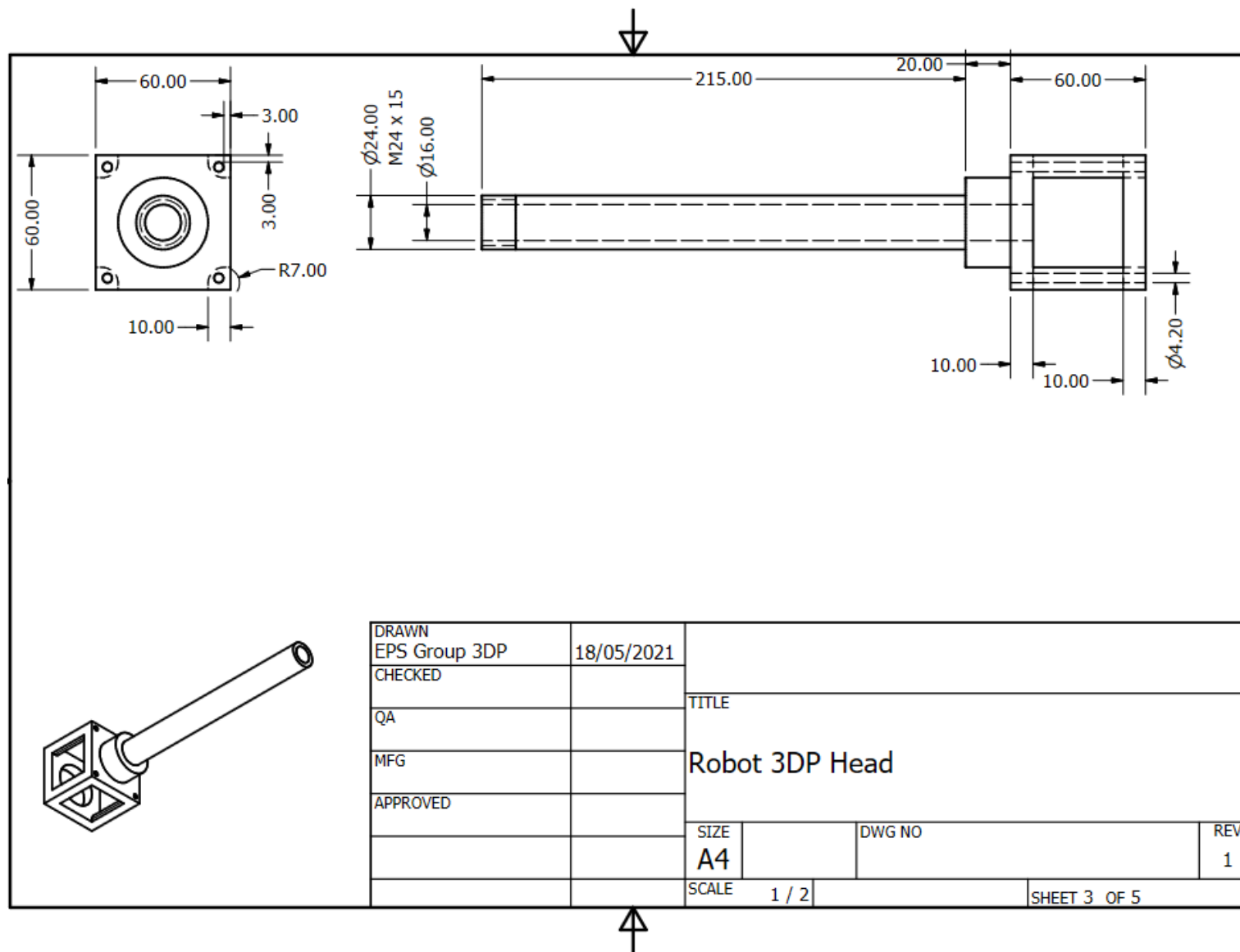


Figure 69: Barrel drawing

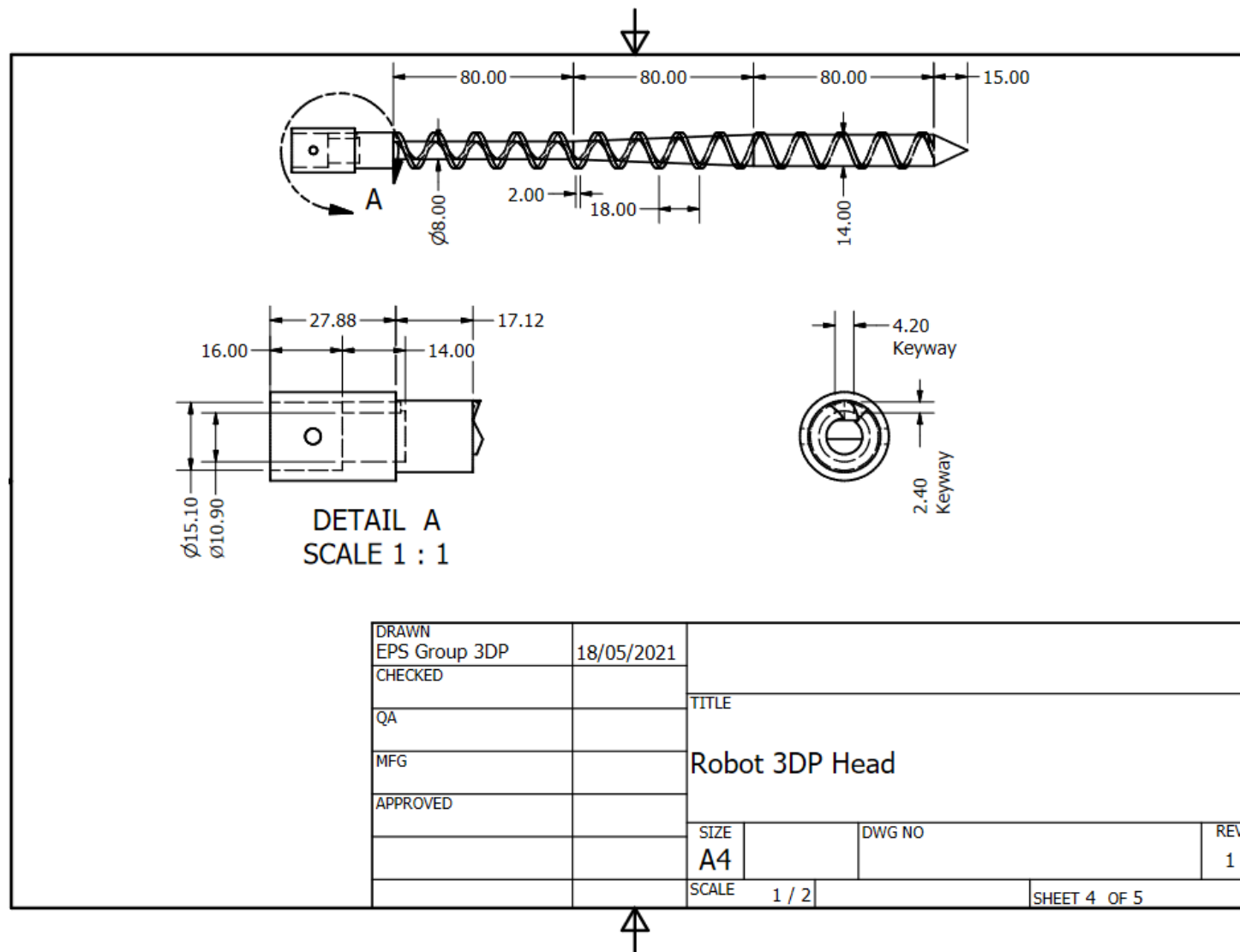


Figure 70: Screw drawing

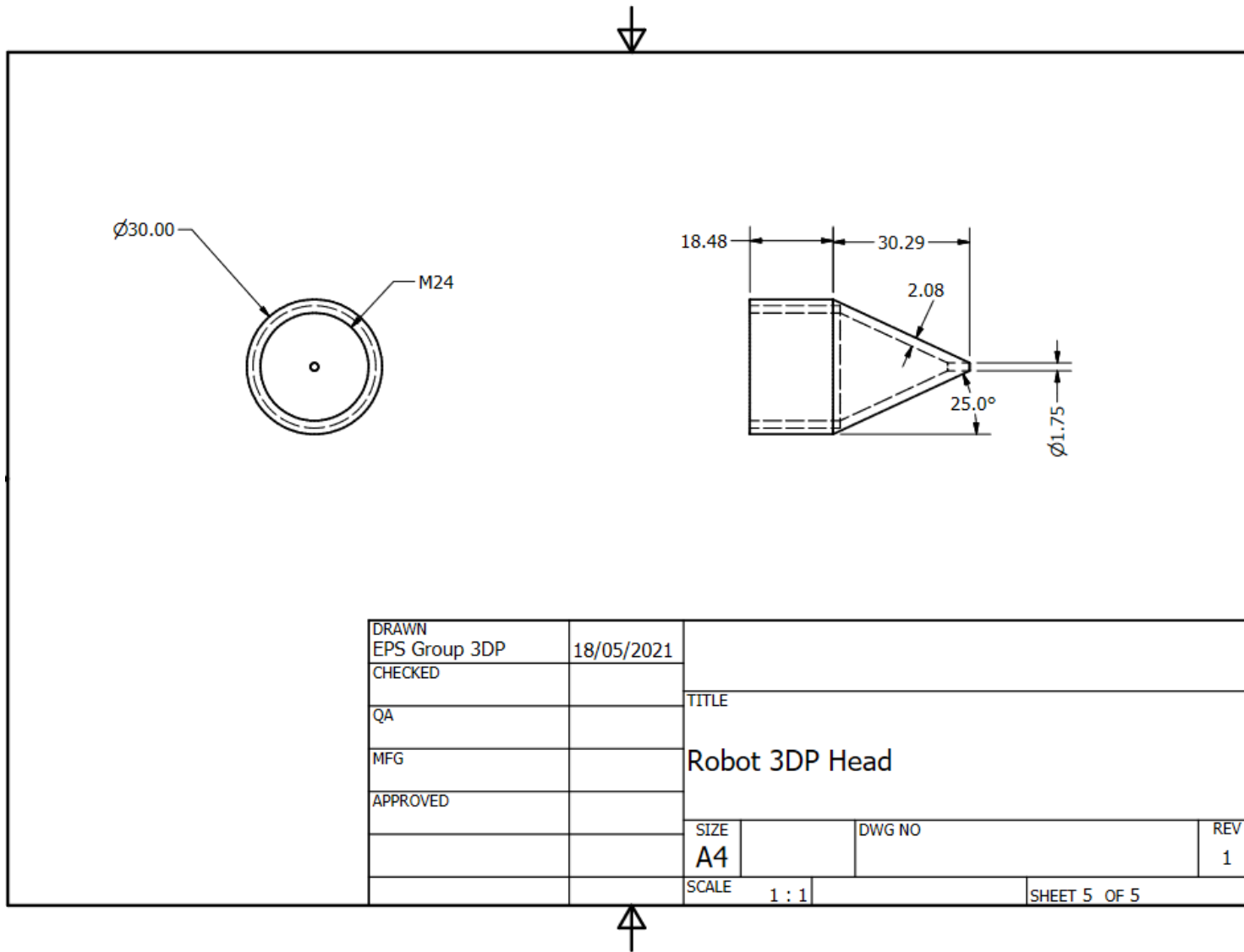


Figure 71: Nozzle drawing