Controlling a 3D printer with an ABB Robot YuMi

European Project Semester

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Midtermreport

Abstract

This report outlines the practical and non-practical documentation of the EPS robotics/3D-printer project. The goal of this project is to research the robot capability to perform tasks originally performed by humans, in this case the task to control a 3D-printer.

The method used to research the possibilities for the robot to control the 3D-printer is mainly trial and error. Through trial and error, the robot restraints are being tested, based on the restraint elements are added to the 3D-printer to support the robot with its tasks.

First of all, two cylinders were added to lift the bed of the 3D printer. To hold the cylinders in the correct position a base is printed. This support system enables the robot to pick up the bed. For the robot to be able to turn the 3D printer on and off a tool is designed. The third result thus far is a redesigned button for the 3D-printer. This button ensures that the robot can turn and push the button. Lastly the robot needs to detect if the 3D printer is done printing, therefore a proximity sensor is added. To keep this sensor in place a sensor holder was designed and printed.

The programming was done with the RobotStudio software. The program is composed by two modules, one for each arm. There are different protocols for every step which enable to automize all the system, from selecting the part to print until to recover the printed parts next to the 3D printer.

From this report can be concluded that the ABB robot is easy to program and to adapt to many kinds of project. Nevertheless, supports are needed to perform certain specific tasks such as: turning on the 3D-printer, turning and pushing buttons, lifting the bed and determine when the 3D printer is done printing.

Summary

During this project the capability of a cobot, the ABB robot YuMi, to use a 3D printer, the Prusa MK3, was researched. The vision was to conclude how feasible current cobot technology would be if implemented in ordinary human live. To accomplish the collaboration between the machines a pneumatic system, electrical system, support structure and other specially modified parts for the 3D printer and cobot had to be developed. Because required additional human expertise and engineering to establish an independent functional system. It can be concluded that the present day's available systems are not suitable for one another.

Preface

This project takes place within the context of the European Project Semester (EPS). This kind of study is a real-life project to prepare engineering students for their future career. Each project group is formed with students from different countries. In our case, we are from the Netherlands, Belgium, France and Spain. Each member of the group studies a different degree and every country has a different way of working in a project. Each of us has different skills for this project and we found the way to work satisfactorily together. With the multi-skills of the team members, the project moves in the right direction.

This midterm report has three different parts. The first one is about project management. The terminology of project management and this project situation is described. It is for example the time, the quality, the risk or the cost of the project. Project management tasks were the most important. Indeed, to be efficient, the group needs a clear aim and a good work distribution. The next chapter of this report is a research about the history, evolution and the use of industry of both 3D printers and robots.

During this project, 3D printing is combined with robotics. The aim of the project is to find another way to use a collaborative robot, in this case to program the ABB Robot YuMi to use the 3D printer by itself. To accomplish this, the team had to think about all the objectives and all the steps that we have to go through. This is the last part of the report. Here, the different considerations are explained and how the team has managed each one of them.

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Introduction

1.1 EPS

The European Project Semester is a programme offered by several European Universities (of Applied Sciences) for students that have finished at least 2 years of their higher education studies. The programme consists out of "project related classes" and a project which will prepare the engineering students for the challenges today's industry brings (About EPS, sd).

During the project several engineering students with different nationalities, backgrounds and studies will be placed together to solve a real-life problem. At the beginning of the semester, the different kinds of projects are presented to the students, in which they can choose the project they are most interested in. The teams are based on nationality and studies to get the most out of this international experience. The working language for the project is (academic) English.

1.2 Team

1.2.1 Ares Seuma Perat (21), Spain: Universitat de Lleida.

My name is Ares Seuma, and I come from Spain. In my city, Lleida, I study Electronical Industrial and Automatic Engineering degree. In my Erasmus I am going to study a double degree, the Energy Technology. I have experience with programming, but most of it is Matlab code. I like the topic of robotics, this is why I chose this thesis, because you can program something and then see if it's right through the robot's actions. I also did my internship last summer and I had seen a little bit about the ABB code; I thought that would be interesting if I learn more about it.

If I have to talk about my skills that I can put in the thesis, I will say that I am a responsible person, hardworking and I like to plan my time for all the tasks that I have to do, to do all of them.

About this project, I hope that it contributes me personally to improve my English and my fluency; and also to progress about my embarrassment. I think that it is a good opportunity to do a nice job with all the team.

1.2.2 Yann Rouault (21), France : Ecole Nationale d'Ingénieurs de Tarbes ENIT

I am studying engineering at ENIT in France for 3 years. The aim of this school is to give us multi-skilled field engineers during a 5-years course. My main topic of study is mechanical and industrial engineering, designing and manufacturing. My interest in technical and practical experiences made me want to participate to an EPS. This programme is also the opportunity for me to improve my English by studying with other European students.

1.2.3 Jors de Mot (22), Belgium: Artesis Plantijn University

My name is Joris, I'm from Belgium. I study at the Artesis Plantijn University in Antwerp. The study I'm following in my home country is Process-Automation. This is my second bachelor, before this I studied automation. I like to design different things and love using the programmes I learned at school. A few of the things I learned to program with are: Visual Studio, PLC, DCS and many more. The reason I wanted to do this project was because I wanted to push myself out of my comfort zone. Another reason is to learn new skills. Now that we got the robotics project. I would like to learn more about 3D printing and expand my knowledge about robotic programming, cause there is so much more to learn

1.2.4 Art Wertheim (23), The Netherlands: Haagse Hogeschool

When I am interested in a task that I need to preform, I can get really focused and determined to finish it satisfactory. My other skill that I would say is in good condition is writing. During my board membership I was president and was in charge of leading the group. Here I also learned to give a presentation in a professional manor. My study is applied physics and therefore I'm also quite skilled in physics in general. Because I have had to apply allot of mathematics in my study I got mediocre in it, the same for programming. One of my worst trades is planning. Mostly I just do and see when it is finished.

1.2.5 Renske Voets (19), The Netherlands: Avans University of Applied Science

Currently I am a third year student, studying Industrial Engineering and Management in the Netherlands. I am doing the EPS program instead of an internship and I hope to develop my professional skills as well as myself as a person. Due to the different kinds of projects I have worked on I have experience with different kinds of situations and of course project management. I really like to do presentations and help people. Sometimes I can be a bit straight forward so I hope to improve that a little bit. I also would like to learn more about the technical parts of the project, which I am less experienced in. My main goal for this project is to share my knowledge with the other students and I hope that they will do the same so we all can learn from each other.

2 Project management

To manage and organize the necessary resources, project management is being used to complete a guide a project. It is important to manage a project to ensure the right people do the right things at the right time. There are different tools to guide the project towards a certain goal, for example a clear vision and mission statements, Work Breakdown Structure or a planning. Based on the vision and mission statements objectives are being presented.

2.1 Project mission, vision and objectives

Vision

The vision for this project is to research the ability of robotic arms to perform tasks that are originally performed by humans.

Mission

The mission for this project is to use the ABB robot to operate the 3D-printer like a human, by identifying its restrictions and using the necessary resources to handle accordingly.

Objectives

- Figure out how the 3D-Printer operates and clarify the restrictions and capabilities;
- Figure out how the ABB robot works;
- Use the ABB robot to operate the 3D-printer.

2.2 Project requirements

Listed below are the project requirements. These conditions are set to ensure the success of completion of a project. The requirements also provide a clear list of tasks that need to be done (Project Requirements: Definition, Types & Process Video, sd).

- Starting the 3D printer;
- Turning and pushing the knob;
- Detecting program end;
- Removing the bed;
- Adding a new bed and printing another part;
- Changing material;
- Assembling parts printed.

2.3 Project deliverables and milestones

A milestone is a task without a duration that shows an achievement in a project. Together the different milestones represent a sequence of events that will build up until the project goal is accomplished. Setting clear milestones will help keeping the project on the right track. For this project the set milestones are listed below.

General milestones:

- Midterm report (24th of October);
- Midterm presentation (28th of October);
- Final report (12th of December);
- End term presentation (17th of October).

Practical and research milestones:

- Understanding of the ABB robot and the 3D printer;
- To achieve the objective by manual control;
- To achieve the objective by programming.

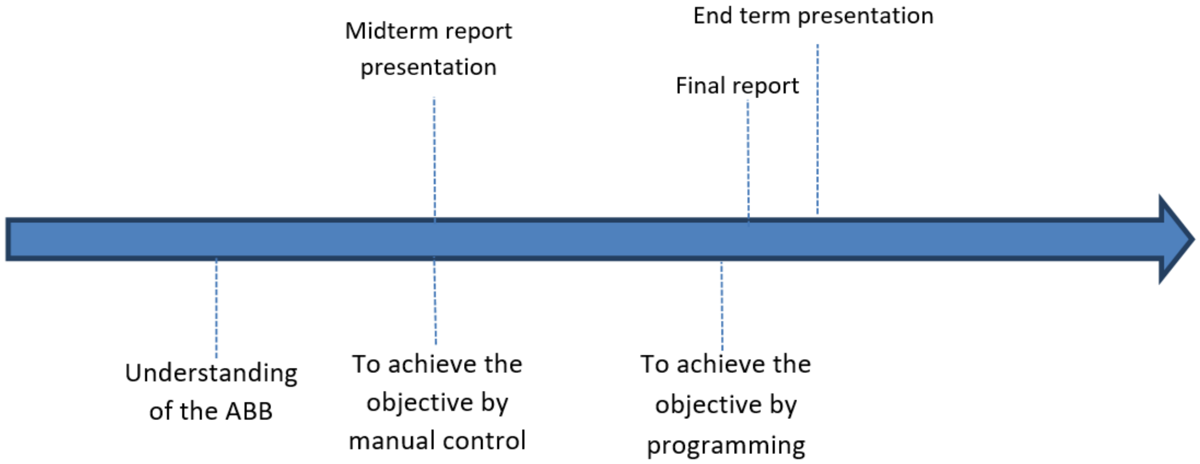

Figure 1: Milestones

2.4 WBS and planning

A Work Breakdown Structure is made to reduce complicated activities to a collection of separate tasks. This is important to do because it is easier to oversee the tasks more effectively. Besides the WBS shows the scope of the project more clearly and it could be used to provide guidance for planning and controlling the project.

In this case the WBS is used as a base for the project planning. Planning a project helps a company or in this case the project group to achieve its aims and goals. In the tables 1 and 2 below the Work Breakdown Structure combined with the project planning for this project is presented.

2.4.1 WBS-planning project management

Table 1: WBS - Project management

	Week 1 (9-9-2019)	Week 2 (16-9-2019)	Week 3 (23-9-2019)	Week 4 (30-9-2019)	Week 5 (7-10-2019)	Week 6 (14-10-2019)	Week 7 (21-10-2019)	Week 8 (28-10-2019)	Week 9 (4-11-2019)	Week 10 (11-11-2019)	Week 11 (18-11-2019)	Week 12 (25-11-2019)	Week 13 (2-12-2019)	Week 14 (9-12-2019)	Week 15 (16-12-2019)	Week 16 (23-12-2019)
Midterm report							24-10-2019									
Midterm presentation								28-10-2019								
Final report														12-12-2019		
Final presentation															17-12-2019	
Preface																
Abstract/summary																
Table of content																
Overview and background																
EPS																
Team																
Project Management																
Project vision, mission and objectives																
Project requirements																
Project milestones																
Work breakdown structure and planning																
Communication Management																
Communication plan																
Stakeholder analysis																
Power/interest grid																
Cost management																
Earned Value Analysis																
Quality management																
Quality plan																
Quality assurance and control																
Risk management																
Risk analysis																
Risk elemination																
Risk monitoring and control																
Human resource Management																
Belbin questionairy																
Change Management																
Trail and error																

2.4.2 WBS-planning practical

Table 2: WBS - Practical

	Week 1 (9-9-2019)	Week 2 (16-9-2019)	Week 3 (23-9-2019)	Week 4 (30-9-2019)	Week 5 (7-10-2019)	Week 6 (14-10-2019)	Week 7 (21-10-2019)	Week 8 (28-10-2019)	Week 9 (4-11-2019)	Week 10 (11-11-2019)	Week 11 (18-11-2019)	Week 12 (25-11-2019)	Week 13 (2-12-2019)	Week 14 (9-12-2019)	Week 15 (16-12-2019)	Week 16 (23-12-2019)
Midterm report							24-10-2019									
Midterm presentation								28-10-2019								
Final report														12-12-2019		
Final presentation															17-12-2019	
1 Finding out how the 3d-printer works																
1.1 Practise printing																
1.2 Write quick manual																
2 Finding out how the robot works																
2.1 Try controlling it with tablet																
2.2 Try controlling it with controller																
2.3 Try controlling it with programming																
2.4 Identify restriction																
2.5 Write quick manual																
3 Check calibration is done																
3.1 Home position; Reed Switch																
3.2 Home position; Proximity sensor																
3.3 Alter home positions; G-code																
3.4 Document information																
4 Check printing is done																
4.1 Home position; Reed switch																
4.2 Home position; Proximity sensor																
4.3 Detect movement bed: Black and White stripes																
4.4 Alter home position; G-code																
4.5 Document information																
5 Selecting file																
G-code																
Document information																
6 Changing/taking out bed																
Look for support lifting bed																
Pisten																
Design base for pistens																
Print base for pistens																
Connect pheumatics with robot																
Electric components																
Document information																
7 Change material																
Design new material holder																
Print material holder																
8 Turning on 3D-printer																
Use pheumatic system																
Stick/tool																
Desing tool																
Print tool																
Document information																
9 Programming robot																
Turning on 3D-printer																
Select file																
Start printing																
Take out bed																
Change material																

3 Communication Management

Communication is a critical factor for a project to succeed, for that reason communication management is used to manage all the channels of communication. To be able to manage the communications channels it is important to identify the involved stakeholders and their interest in the project. Based on that information a communication plan can be developed.

3.1 Stakeholder analysis

A stakeholder analysis is made to identify the parties that are directly and indirectly involved in the project. It is important to clarify which stakeholders are involved to prevent issues that may occur due to the power or interest they have in the project. For this project a brainstorm is used to clarify the stakeholders that are involved in this project. The mind map in figure 2 shows the stakeholders in this project.

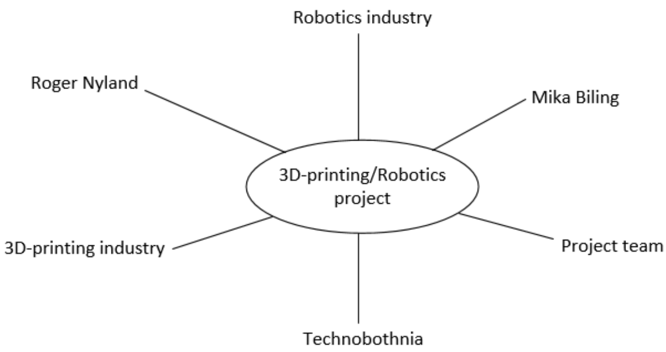

Figure 2: Stakeholder

3.2 Power/interest grid

To keep track of the different kind of stakeholder a power/interest grid is used. This grid helps to categorize the projects stakeholders in four categories: keep satisfied, monitor, manage closely and keep informed. With this grid it is easy to see which key stakeholders needs to be managed closely because they can make or break the project.

Power	Interest: Low	Interest: High
High	***Keep satisfied*** Roger Nyland	***Manage Closely*** Project team Mika Billing
Low	***Monitor*** Robotics industry 3D-printing industry	***Keep informed*** Technobothnia

Figure 3: Power/interest grid

In the power/interest grid above the stakeholders are divided in the four categories based on their power and interest in the project. Both the robotics- and 3D-printing industry need to be monitored to maintain as much (and up-to-date) information. The key stakeholder in this project is the project team. The project team and Mika Billing need to be managed closely because they have a high interest and the highest power in this project and are therefore very important. It is also important to keep Technobothnia informed to be able to receive the resources needed to make this project successful.

3.3 Communication plan

In table 3 the communication plan for this project is presented. It is based on the result of the brainstorm sessions and the power/interest grid.

Table 3: Communication plan

	Communication Plan				
Description	Audience	Goal(s)	Method	Frequency	Responsible
Weekly meeting supervisor	Project group + Mika Billing	- Discuss progress; - Gather new information; - Discuss following steps.	Face-to-face	Once a week	Chairman
Day start-up meeting	Project group	- Discuss progress; - Discuss plans for the day; - Discuss new tasks.	Face-to-face	Every day, every 2 days	Chairman
Brainstorm meeting	Project group	- Come up with ideas; - Select tools/techniques; - Discuss next steps.	Face-to-face	Every week	Project group
General communication	Project group	- Questions; - Share information; - Short updates.	Face-to-face, WhatsApp	Every day	Project group

4 Cost management

Cost management is the process of planning and controlling the budget of a project. It is used to predict costs and helps to reduce the chance of going over budget. For this project the budget is not defined, therefore the expected working hours are used as a guideline to calculate the budget for this project.

4.1 Earned Value Analysis

An Earned Value Analysis is used as a method to measure a project's performance at any given point. The analysis is also used to forecast the project's completion date and final costs, analyse variances in the schedule (SPI) and in the budget (CPI).

The planned value (PV)[1], Actual Cost (AC)[2] and the Earned Value (EV)[3] are plotted in the graph. With the information of these graphs the Scheduled Performance Index (SPI)[4], Cost Performance Index (CPI)[5] and the Estimated at Completion (EAC)[6] can be calculated (Using Earned Value to monitor project performance, 2019).

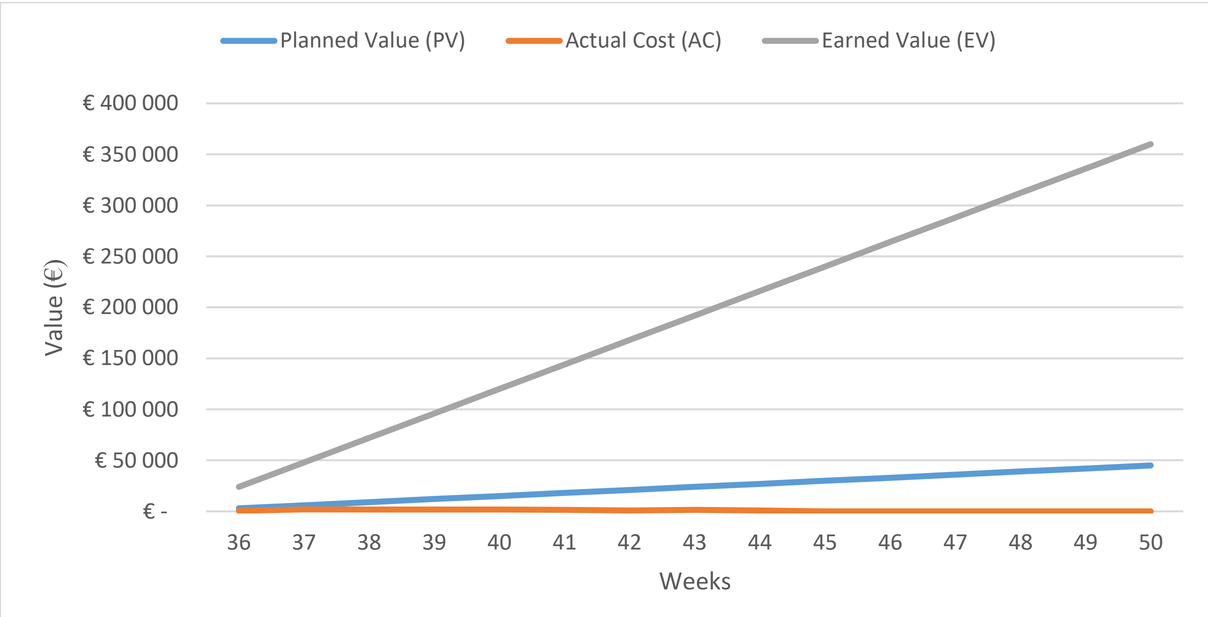

Figure 4: Cost evolution

[1] Planned Value (PV): the budgeted amount through the current reporting period;
[2] Actual Cost (AC): actual costs to date;
[3] Earned Value (EV): total project budget multiplied by the % of the project completion;
[4] Schedule Performance Index (SPI): EV/PV (>1 = good/1< = bad);
[5] Cost Performance Index (CPI): EV/AC (> 1 = good/<1 = bad);
[6] Estimated at Completion (EAC): total project budget/CPI.

	36	37	38	39	40	41	42	43
Hours worked	25,83	98,17	91,48	87,00	87,50	85,33	77,25	170,08
Planned Value (PV)	€ 3.000	€ 6.000	€ 9.000	€ 12.000	€ 15.000	€ 18.000	€ 21.000	€ 24.000
Actual Cost (AC)	€ 517	€ 1.963	€ 1.830	€ 1.740	€ 1.750	€ 1.707	€ 1.545	€ 3.402
Cumulative AC	€ 517	€ 2.480	€ 4.310	€ 6.050	€ 7.800	€ 9.506	€ 11.051	€ 14.453
Earned Value (EV)	€ 24.000,00	€ 48.000,00	€ 72.000,00	€ 96.000,00	€ 120.000,00	€ 144.000,00	€ 168.000,00	€ 192.000,00
Schedule Performance Index (SPI)	8	8	8	8	8	8	8	8
Cost Performance Index (CPI)	46,5	24,4	39,4	55,2	68,6	84,4	108,7	56,4
Estimated at Completion	7750,0	14725,0	9148,3	6525,0	5250,0	4266,7	3310,7	6378,1
Cost Variance (CV)	€ 23.483,33	€ 46.036,67	€ 70.170,33	€ 94.260,00	€ 118.250,00	€ 142.293,33	€ 166.455,00	€ 188.598,33
Schedule Variance (SV)	€ 21.000,00	€ 42.000,00	€ 63.000,00	€ 84.000,00	€ 105.000,00	€ 126.000,00	€ 147.000,00	€ 168.000,00

	44	45	46	47	48	49	50
Hours worked	106,25	86,75	97,50	85,17	97,50	58,92	15,50
Planned Value (PV)	€ 27.000	€ 30.000	€ 33.000	€ 36.000	€ 39.000	€ 42.000	€ 45.000
Actual Cost (AC)	€ 2.125	€ 1.735	€ 1.950	€ 1.703	€ 1.950	€ 1.178	€ 310
Cumulative AC	€ 16.578	€ 18.313	€ 20.263	€ 21.966	€ 23.916	€ 25.095	€ 25.405
Earned Value (EV)	€ 216.000,00	€ 240.000,00	€ 264.000,00	€ 288.000,00	€ 312.000,00	€ 336.000,00	€ 360.000,00
Schedule Performance Index (SPI)	8	8	8	8	8	8	8
Cost Performance Index (CPI)	101,6	138,3	135,4	169,1	160,0	285,1	1161,3
Estimated at Completion	3541,7	2602,5	2659,1	2129,2	2250,0	1262,5	310,0
Cost Variance (CV)	€ 213.875,00	€ 238.265,00	€ 262.050,00	€ 286.296,67	€ 310.050,00	€ 334.821,67	€ 359.690,00
Schedule Variance (SV)	€ 189.000,00	€ 210.000,00	€ 231.000,00	€ 252.000,00	€ 273.000,00	€ 294.000,00	€ 315.000,00

Table 4: Cost description

5 Human Resource management

Human Resource management is used to manage employees within a company, in this case the project members within the project. Managing people in an organisation is important to help a business or project to be more efficient. A method to gain an advantage is for example Belbin tests, to identify and maintain the right "people" for a project, so strengths are being developed and weaknesses managed.

5.1 Belbin questionnaire

To predict how individuals behave in a team environment, a Belbin questionnaire is used. Based on multiple-choice questions the test shows what kind of role a certain person is in a team environment. Each role has its own contribution but also their weaknesses. In the table 5 below the eight different Belbin roles, their contribution and their weaknesses.

Table 5: Belbin roles

Role	Contribution	Allowable weakness
Plant	- **Theorises;** - Creative, imaginative, unorthodox; - *Solves difficult problems.*	- Ignores incidentals. Too preoccupied to communicate effectively.
Monitor	- **Judges impartially;** - Sober, strategic and discerning; - *Sees all options. Judges accurately.*	- Lack drive and ability to inspire others.
Coordinator	- **Generalises;** - Mature, confident, a good chairperson; - *Clarifies goals, promotes decision making. Delegates well.*	- Can be seen as manipulative. Offloads personal work.
Resources investigator	- **Explores opportunities;** - Extrovert, enthusiastic, communicative; - *Develops contacts.*	- Over-optimistic. Loses interest once initial enthusiasm has passed.
Implementer	- **Applies;** - Disciplined, reliable, conservative and efficient; - *Turns ideas into practical actions.*	- Somewhat flexible. Slow to respond to new possibilities.
Completer	- **Perfects;** - Painstaking, conscientious, anxious; - *Searches out errors and omissions.*	- Inclined to worry unduly. Reluctant to delegate.
Team worker	- **Supports;**	- Indecisive in crunch situations.

	- Co-operative, mils, perceptive and diplomatic; - Listens, builds, averts friction.	
Shaper	- **Drives;** - Challenging, dynamic, thrives on pressure. - *Has the courage to overcome obstacles.*	- Prone to provocation. Offends people's feelings.

5.2 Results

The results of the teams Belbin test are summarized below (figure 5 and table 6), the chart shows that all 8 roles are covered in the project group. In table … the overview shows that every role is covered by at least two project members. These roles (implementer, coordinator and finisher) still need more attention than the other roles because there are only two persons who associate with these roles. The team role plant is well covered by four project members.

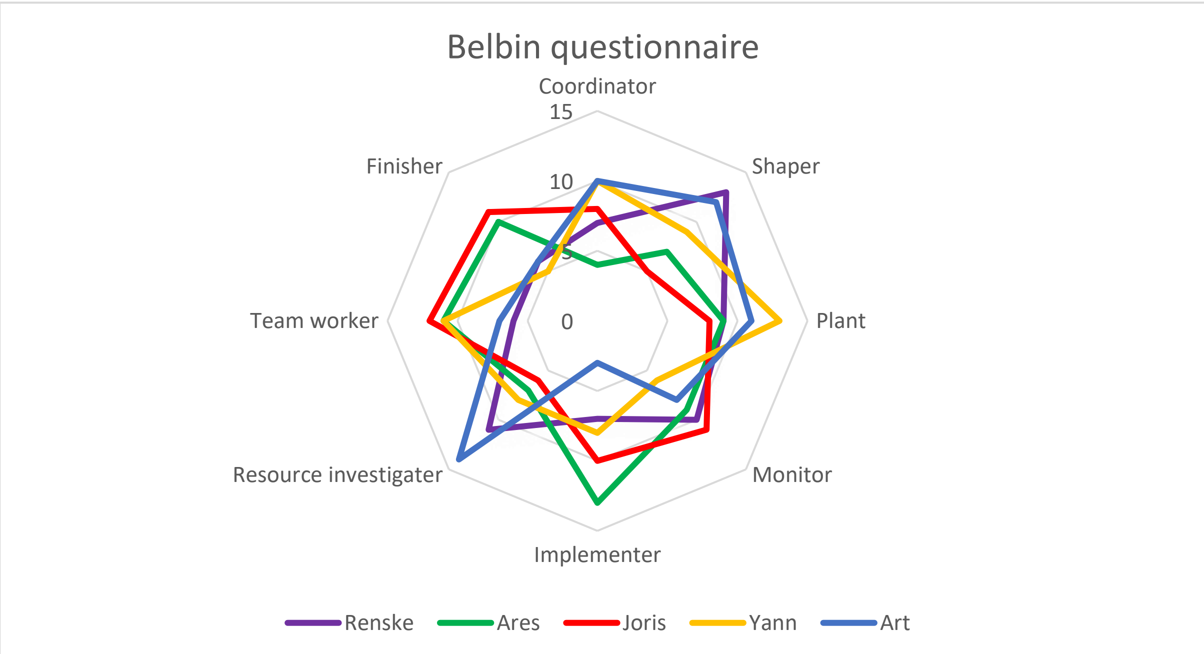

Figure 5: Belbin questionnaire

Table 6: Results Belbin questionnaire

	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
Renske	7	13	9	10	7	11	6	6
Ares	4	7	9	9	13	7	11	10
Joris	8	5	8	11	10	6	12	11
Yann	10	9	13	6	8	8	11	5
Art	10	12	11	8	3	14	7	6

6 Quality Management

Success or failure is dependent on the satisfaction of the customer on the product or service. The satisfaction of the customer gets determined by his expectations of the quality of the product. If the product is cheap compared to its counterparts a low-quality product is expected and on the contrary if a product is expensive a high-quality product is expected. From the perspective of the company the quality of a product is depended on the scope, development and production time and development and production cost. It is important to be able to deliver the quality that the customer expects to get. Because for example if the customer is a manufacturer and is required to work with a minimum quality and he or she cannot rely on your product to always have this minimum quality then it would be better for them to buy somewhere else.

6.1 Quality Management Plan

A quality management plan consists of input, tools and technique and output. The output is a certain aspect of the product that determines the overall quality. The input is the foundation for the output that makes the quality as it is. The tools and techniques are used to know if the right input is used. For example, to do a good research would be the output. In this case trusted sources would be the input. But how you verify the sources are the tools and techniques.

Depending on the sort of project that has to be managed a different kind of strategy is desirable. If it is an ongoing development and production process then a PDCA cycle (Plan, Do, Check and Act cycle) would be beneficial. This means in practice that a production process is monitored constantly to see if it lives up to the expectations. If a new plan is conceived and put in to action the monitoring stage starts over again.

For this project the goal is to research and develop a specific system for a one customer. This requires close communication with the customer and constantly updating the project plan and everything that comes with it. So, in this case a PDCA cycle is most beneficial for the outcome.

In the table below (table 7) multiple aspects that the determine the quality of this project are presented. These aspects were established during brainstorm session with the group. These were based on the interpretation of vision of the group, the desires of the customer, the goal of the project and needs of society. From then on it through research and reasoning the means to achieve the output was conceived.

Table 7: Quality management

Input	Tools and techniques	Output
Trustful sources	- Checking sources; - Compare sources.	- Trustworthy background information.
Good communication	- Weekly meeting with project group; - Weekly meeting with customer; - Reading each other's documentations and give feedback; - Behavioural rules.	- Quality report; - Pleasant work environment.
Work hours	- Keep a logbook of worked hours.	- Active posture; - Evenly divided work effort.

Reaching objectives	- Checklist of objectives.	- Accomplishing customer goals;
Material usage	- Balancing ecological impact and material quality.	- Taking on responsibility for the environment; - Quality product.
Passing on knowledge	- Writing a detailed manual of the system	- Humanity being able to use the acquired knowledge of the project

7 Risk management

Nowadays it is unthinkable for a company, project group or country to be unaware of the possible risks that can occur. Because being unaware can mean bankruptcy, total failure or even human casualties in the worst case. Although being aware and prepared does not guarantee success or the saving of lives, but at least it was tried to be prevented.

This is what risk management is about. Analysing possible future events that can influence the project in a negative manor. There are two important characteristics about risk, they are the impact of the risk and the probability of occurrence. Once these have been determined a plan to mitigate and/or prevent them can be constructed. The difference between mitigation and prevention is depended on the sort risk, if the risk is internal or external. If a risk is external it means that the project group cannot affect the probability of occurrence. With internal risks it is the other way around, the project group can affect the probability of occurrence. In conclusion this means that an external risk can only be mitigated and an internal risk can be mitigated and prevented. In graph on the right (figure 6) an overview is given of the possible risks and their respective impact and change of occurrence.

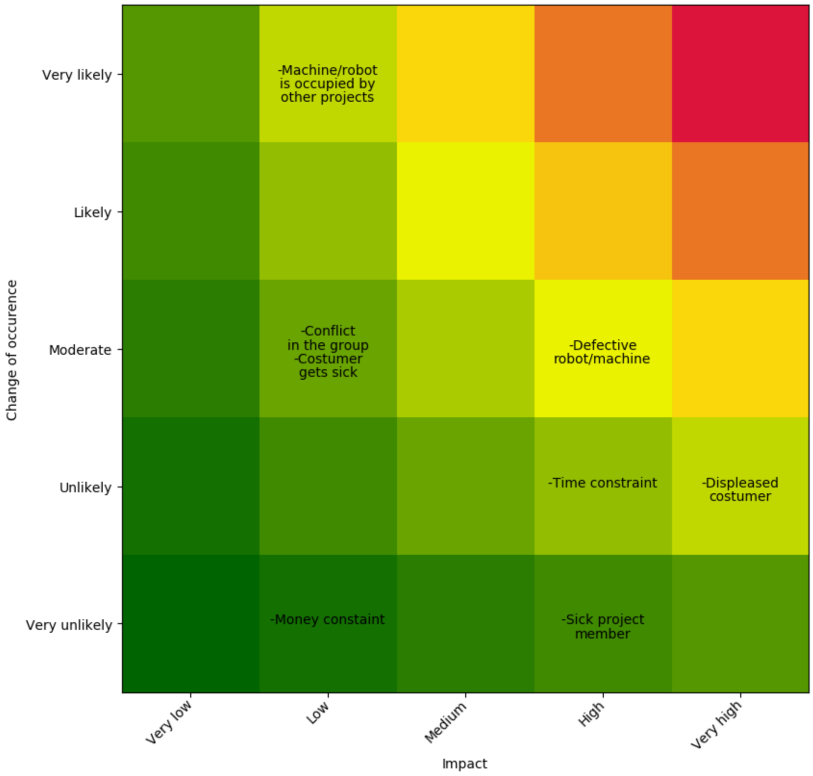

Figure 6: Risk management grid

In the tables 8 and 9 shown below the different internal and external risks for this project are shown. They are based on the understanding of the end product and the development process of the group and came forth from brainstorm session and discussing with the customer.

Table 8: Risk management intern

Risk	Consequence	Prevention	Mitigation
Conflict in the group.	Unpleasant work environment.	Behavioural rules.	Discussing conflict until resolved.
Defective robot/machine.	Cannot continue with practical part of the project.	Being well informed about the system before operating.	Get the robot/machine repaired.
Displeased customer.	Failing the project objectives.	Close contact with the customer about the progress.	No possibility.
Time constraint.	Failing the projects objectives.	Time management.	No possibility.

Money constraint.	Lack of resources.	Cost management.	No possibility.

Table 9: Risk management extern

Risk	Consequence	Mitigation
Sick project member.	Less available working hours.	Other project members take over work or catch up.
Defective robot/machine.	Cannot continue with practical part of the project.	Get the robot/machine repaired.
Machine/robot is occupied by other projects.	Cannot continue with practical part of the project.	Keep informed about the schedule of occupation and plan accordingly.
Costumer gets sick.	No possibility of meetings about the progress.	No possibility.

8 Change management

Change management regulates change within organisations, the broad aspect of change management includes for example change of individuals or production processes. The change process exists out of a sequence of steps or activities to implement and control change, and help employees adapt to change. Which will result in the desired project outcome. Change is important because it allows a organisation or project group to grow, to learn new skills, explore opportunities and exercise their creativity which will result in increased commitment.

8.1 Trial and error

For this project trial and error is used to solve the challenges that are presented to the project group. Trial and error are often used by people that have little to none knowledge in the problem area, in this case limited knowledge about robotics and 3D-printing. Because trial and error are used, change management is very important to be able to continue managing the project.

In figure 7 the process of change within the project is shown. After a challenge/task is presented the possible solutions will be discussed. The next step is to choose the right solution and determine the required tasks. When the tasks are carried out and the solution does not meet up to the expectation an error will occur. Because of the error the change cycle will start again. If the results do meet up to the expectations, the gathered information will be documented.

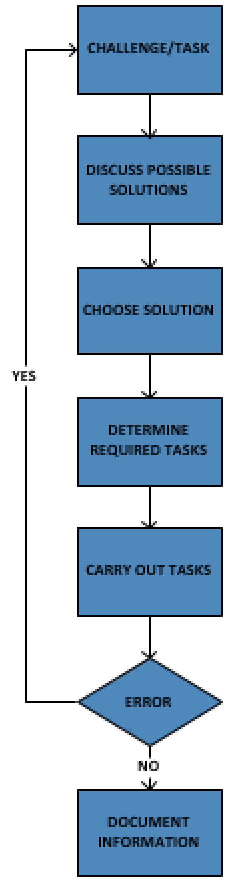

Figure 7: Change management flowchart

9 Research: 3D printing and robotics

This chapter contains general information about 3D-printing and robotics to clarify the background of this project. The information includes for example the history and application of the subjects.

9.1 3D-printing

9.1.1 History

The technical name for 3D printing is additive manufacturing. This means that the desired construction is achieved by adding material instead of the more traditional ways of producing which relies on subtraction. This aspect of the production method is tremendously more ecologically responsible. Another massive advantage is the easiness of producing unique constructions. Normally if a company came up with a new product, they had to have a professional make it by hand. What took time and cost serious money. But there was no sensible alternative. Because if they just went along with their concept and refurbished their factory and the product would not be as desired then all the invested time and money would have been for nothing. But with a 3D printer only a digital designer is required.

It started in 1974 when David E.H Jones wrote a column about what he called "plastic fabrication process". David described the process as "a sort of joyful three-dimensional doodling" based on photo polymerization[7]. The reaction Jones used for polymerization was light. In the column Jones proposed to use a glass container of monomers in a liquid state. Then by using two lasers sources (each half of the required energy) polymerization was stimulated. At the intersection of the laser beams the monomers got linked together. By repeating this process, the desired construction would be completed (E.H., 1974).

Ten years later, in 1984, Chuck Hull filed patent for a stereolithography system. Hull had almost the same concept as Jones but managed to fix one small problem Jones could not fix. The problem Jones had was that two movable lasers would be required. Hull solved this by a plate that can move up and down in the resin, here the construction would be printed on. Then if the lasers can rotate on the other two axes in a fixed position, all of the needed movement is covered. In figure one is a schematic representation off Hull's patent (Stereolithography, 2019).

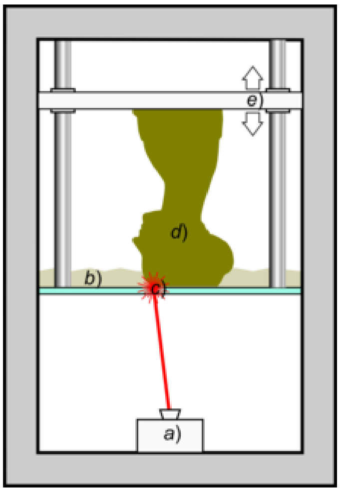

Figure 8: Stereolithography

In the year of 1988 another 3D printing related patent was filed. This patent would expire in 2009 and from then on revolutionize the availability to the public. The idea was plain and simple. Instead of baths of photopolymerizing monomers with ultra violet lasers, just a roll of hardened plastic that can be melted again. It is like a pencil leaving a very thick layer of plastic and once the layer has dried it puts another layer on top of it. This way of 3D printing cost less than the others because of the relatively simple technology that is needed. In general, other techniques offer a better result but they are just too expensive to make up for it compared to this (Fused filament fabrication, sd; Industrial Robot History, sd).

9.1.2 Uses of 3D-printer nowadays

3D printing is one of the most imposing technologies of the last decades. With a strong development and prices getting more and more attractive, people can buy their own 3D printer (starting price at

[7] Linking two or more molecules (monomers) together, which can be achieved by different kinds of reactions.

€200,-) and create their own 3D models. The market value of the 3D printing industry is reaching a value of $23 billion by 2022 (Hooijdonk, 2018). Because of the growing number of companies using 3D printing to produce end-products and prototypes it gets more and more important to understand the trends in the development of this technology.

Plastic is one of the most used materials for 3D-printing but using metal materials will become more popular in the future. 3D printing will never fully replace the traditional ways of manufacturing, but it has a lot to offer (3D printing trends 2019, 2019).

For example, using 3D printed parts in airplanes will decrease the weight of parts, boosting the airplanes horsepower and increasing fuel savings. Expected is that at least three-quarters of new aircrafts will be equipped with 3D printed engines (Hooijdonk, 2018).

Also, the space industry caught up with the technology. In September 2013 Space X made a resupply mission to the International Space Station. On board of the rocket was the first zero-gravity 3D printer that was developed by NASA and Made In Space. From now on not everything has to be delivered by rockets but can be created 400 kilometres above earth surface with a push on the button.

Before, the 3D printing was made only for prototyping but now it can be also used for manufacturing. Because of improvements in this technology, for example: the speed and the diversification of the material, 3D-printing is a viable option for medium sized production runs (3dhubs.com).

9.1.3 Prusa Research and Prusa i3 MK3

Prusa Research S.R.O was founded in 2012 by Josef Prusa. The company started as nothing more than a hobby project. The company started without investors or kickstarter campaigns, just Josef Prusa with a plan. As time went by Prusa started to grow and the Prusa i3 design became one of the most popular 3D printer designs thanks to its open-source nature.

Nowadays Prusa has more than 300 employees and ships over 600 printers worldwide every month. The Prusa Research company became the number 1 fastest growing tech company in Central Europe with a growth rate of 17,12% over the past four years.

The Prusa i3 MK3 3D printer, shown in figure 9, is an open source 3D printer, this means that both hardware and software information are available to the public. This information can be used to build, modify or improve a 3D printer (Best open source 3D printers, 2018).

Prusa i3 MK3 3D printer was chosen as the best 3D printer by MAKE: Magazine and All3DP.com. The most significant features of the Prusa i3 MK3 are:

Figure 9: Prusa i3 MK3 3D printer

- **Removable heatbed:** the magnetic heat bed holds the replaceable steel sheet with a PEI surface. There are two types of sheets, a smooth PEI (polyetherimide) sheet and a textured powder coated PEI sheet.
- **Frame stability:** the Y-axis from aluminium extrusion provides rigidity.
- **Power panic:** with this feature the printer can fully recover a print from the loss of power. It detects power interruption and shutdown the heatbed and extruder heating, after restoring the power, it is possible to continue printing.
- **Filament sensor:** the sensor is using the optical sensor which is triggered by a simple mechanical lever. The sensor does not care about optical properties of the filament and malfunctions cannot occur because of mechanical wear.
- **Bondtech extruder:** the extruder has a Bondtech drive gear, which allows the extruder to grip the filament from both sides. This part increases the push force and makes the printer more reliable. The print fan also cools from two sides increasing overall performance.
- **P.I.N.D.A probe:** the 3D printer has two thermistors. The first thermistor measures the temperature on the electronics to prevent MINTEMP errors. The second thermistor is attached to the P.I.N.D.A 2 probe to compensate for temperature drifts, resulting in a perfect first layer.
- **E3D V6 nozzle:** the metal hotend allows the 3D printer to reach high temperatures which makes it easier to print (Original Prusa i3 MK3 , sd).

All these features are the reason why this 3D printer is used for this project. Especially for the magnetic bed which is easier to move than glass bed as there is among the competitors.

9.2 Robotics

9.2.1 History: Industrial robot evolution

An industrial robot is a robot system used for manufacturing. It is automated, programmable and capable of movement on three or more axis; it is used instead of a person to perform dangerous or repetitive tasks with a high degree of accuracy. There are different types of industrial robots like Cartesian robots, gantry robots, SCARA (Selective Compliance Articulated Robot Arm)[8] robots, articulated arm robot and human-assist robots. To observe the evolution of industrial robots a few examples are given. (Industrial robot, 2019) (Defining The Industrial Robot Industry and All It Entails, u.d.)

Figure 10: SCARA robot

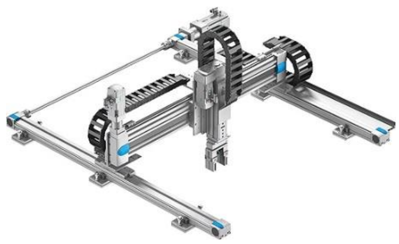

Figure 11: Cartesian robot

Figure 12: Gantry robot

The name "robot" was invented by the Czech writer Karel Capek and it was used in his science fiction stage play in 1920. Between 1956 and 1959 in Danbury (Connecticut, USA), George Charles Devol and Joseph F. Engelberger co-founded the first robotics manufacturing company: Unimation. In 1961, the first industrial robot was born. (Industrial Robot History, u.d.) (Cox, u.d.)In 1962, the company IBM (USA) created a powerful, easily programming language, specifically for robotic applications; engineers could quickly and easily create application programs. A few years later, in 1967 the first industrial robot in Europe was installed in Metallverken, Sweden. (Robot History, u.d.)

Figure 13. Cincinnati Milacron T3 robot

In 1973, at Cincinnati Milacron Corporation, Richard Hohn developed the robot called The Tomorrow Tool (T3). It was the first commercially available industrial robot controlled by a microcomputer. The Cincinnati Milacron T3 robot is an example of a robot arm which is similar to the human arm. The arm consists of several rigid members connected by rotary joints. T3 was controlled using a Hierarchical Control System; it is partitioned vertically into levels of control. The Olivetti SIGMA, a cartesian-coordinate robot, is one of the first used in assembly applications. It was born in 1975 and it was used in Italy for assembly operation with two hands. (Cincinnati Milacron T3 Robot Arm, 2009)

In 1994, Motoman introduced the first robot control system (MRC) which provided the synchronized control of two robots. MRC also made it possible to edit robot jobs from an ordinary PC; it could also synchronize the motions of two robots. (Wallén, 2008)

[8] Selective Compliance Articulated Robot Arm.

ABB developed the FlexPicker on 1998, the world's fastest picking robot based on the delta robot developed by Reymond Clavel. It was able to go to the velocity of 10 meters per second, using image technology. In 2006, on Germany was presented the first Light Weight Robot: KUKA. The structure of the KUKA lightweight robot is made of aluminium; it is highly sensitive and it only weighs 16 Kg. The robot is energy-efficient and portable and can perform a wide range of different tasks.

On 2008, the world's first collaborative robot able to operate safely alongside people enters the market. A few years later, on 2009, ABB launched the smallest multipurpose industrial robot: IRB120. It weighs just 25kg.

Figure 14. IRB120, ABB.

9.2.1 Uses of robots nowadays

With the development of robots during the third industrial revolution, industrial robots are now important for the automatization of the production lines. They have become more accurate, faster and can hold a bigger payload. In some situations it is necessary to have a robot that is able to work with a human, however this requires the robot to be safer. These robots are developed with limited strength and position detectors. They are known as collaborative robots or cobots.

Industrial robots and cobots are not designed for the same type of work. Industrial robots do repetitive tasks or tasks that a human cannot realize because it is too dangerous, too heavy or too complicated. Cobots are capable of learning multiple tasks so it can assist human beings and they are easier to program. These robots are intended for direct interaction with a human worker.

Collaborative robots are important in the current market. They are the future of automation, the market is expected to grow with 150 000 units by 2021. There are a few applications where cobots have a significant presence in the current market: packing, picking, placing, machine tending (it transports the supplies to the machine, interacts with it, and then removes the finished parts), finishing tasks, quality inspection or delete any possible error. (Roehl, 2017) (Neogi, 2018) (Shepherd, 2019)

9.2.2 The collaborative ABB robot: YuMi

ABB (ASEA Brown Boveri) is one of the market leaders in industrial robots and automatization. It originated in Sweden but its current head-quarters is in Switzerland. One of the latest releases from ABB is the collaborative robot YuMi. It is an innovative cobot with easy-to-use double robotic arms that includes flexible hands, location of parts by cameras and state-of-the-art robotic control. YuMi has been designed for the new industrial automation, for example, assembling small parts. To assure the safety of use each is limited to a payload of 500 grams. (ABB Group, 2019) (Technical data IRB 14000 YuMi)

Figure 15. ABB YuMi.

10 Operating the machines

To understand the usage of the 3D-printer and the ABB robot two manuals were made. The written manuals can be found in the appendix. For this chapter a simplified version of the process of using the 3D-printer or ABB robot presented by using flowcharts.

10.1 3D-printing

The company Prusa3D published a general handbook for using the 3D-printer PRUSA MK3. This handbook contains detailed information but does not allow for simple usage. To understand how to operate the 3D printer a simplified manual was made. This manual is presented in the appendix of this report. To give an overview of the 3D-printing process a flowchart is added.

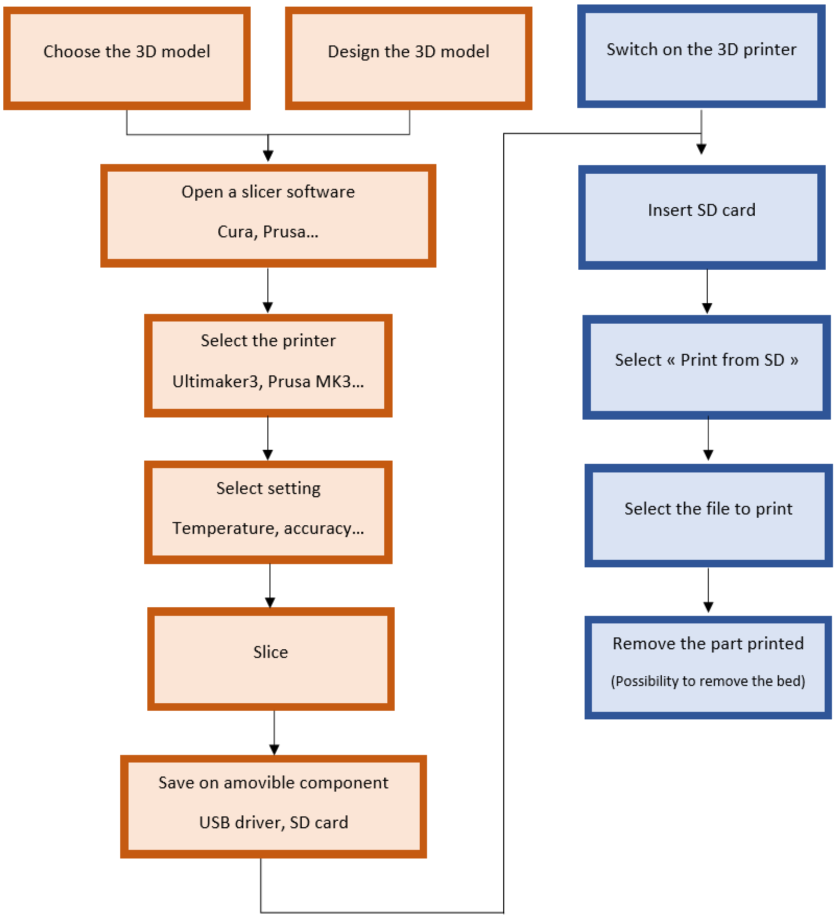

Figure 16: 3D printer flowchart

First of all, a 3D model is needed to print with a 3D printer such as PRUSA MK3. This one can be made with a CAD software or downloaded on specific websites such as Thingiverse. The file has to be a *stl* to be opened in a slicer software which can be downloaded for free. After selecting the 3D printer, some parameters can be modified to optimise the accuracy, the resistance and the velocity of the to be printed part. Next up, the 3D model is sliced to generate the code that can be read by the 3D printer. Saving it on a movable component, SD card or USB driver, enables the data to be transferred to the 3D printer.

Next, switch on the 3D printer and select the command "print from SD card" for the PRUSA MK3. The program is launched when it is selected and a message is written at the end of the printing. Removing the part is easier by taking out the bed when it is done.

10.2 Robotics

The ABB robot is easy to control because it was designed as a cobot. Nevertheless, basic knowledge is required to be able to operate the ABB robot. The ABB manuals and instruction videos are useful sources to acquire this knowledge. To combine the information a manual was made, this manual is given in the appendix. With a flowchart the required steps for using the cobot are explained in the text below.

Figure 17: ABB robot flowchart

Using the 3D robot is not easy thing to do without practical. The main advantage of the ABB robot YuMi is the easy way to learn by practicing. Because it is a cobot, it is possible to test basic command without risk which is very important for the learning. After to switch on the ABB robot, it can be controlled by the FlexPendant. Many possibilities are register to have a basic use but also a more specific one. By opening the jogging window, the arms can be controlled instantly. By opening the production window, position and movement can be registered to create a programme.

11 Practical

In this chapter the process of getting the ABB robot to control the 3D-printer is presented. Based on the requirements the different tasks are defined, these tasks are used as a guideline for this part of the report.

11.1 Introduction

In chapter 10.1 the printing process is defined. Based on the different tasks that a human would need to accomplish to operate the 3D-printer the requirements are stated. These requirements were stated in the beginning of the report. To visualize the tasks a flowchart is presented in the figure 18.

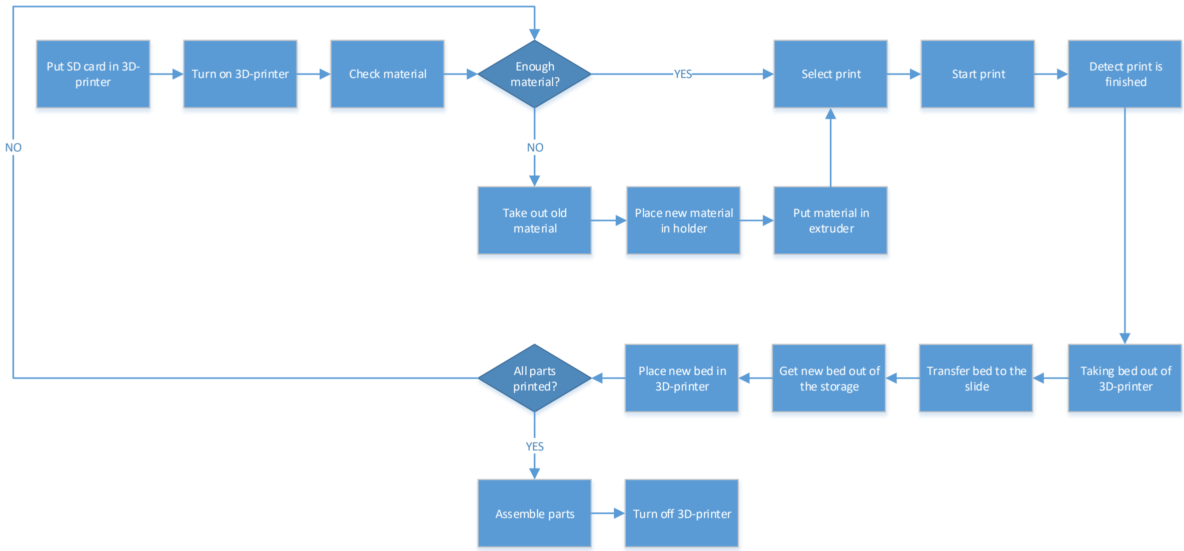

Figure 18: Flowchart process

In table 10 the flowchart steps are stated to give an overview of the content for each step. In addition, the chapter/pages numbers are presented with them for easy excess to the right stages/parts of the project.

Table 10: Overview practical documentation

Flowchart steps	Part and chapter
General	- Position of 3D-printer, slide, storage; - Electrical drawings; - Programming code/UML-diagram.
1. Put in SD-card in 3D-printer	- Design: SD-card holder/tool; - Programming code/UML-diagram.
2. Turn on 3D-printer	- Design: tool; - Programming code/UML-diagram.
3. Change material	- Design: funnel tool and material holder;
4. Select print and start print	- Design: button; - Programming code/UML-diagram.
5. Detecting print is finished	- Design: sensor holder; - Programming code/UML-diagram.
6. Taking bed out of 3D-printer	- Design: cylinder baseplate and valve holder; - Electrical drawings; - Programming code/UML-diagram.
7. Transfer bed to slide	- Design: slide;
8. Get new bed out of storage	- Design: bed storage.
9. Place new bed in 3D-printer	- Programming code/UML-diagram.

11.2 General
In this chapter general information is presented. This information clarifies decisions made further in the project. To start the layout for the different components is discussed, continuing with the general power supply and a general UML diagram.

11.2.1 The position of the 3D-printer, slide and storage
To start this task the 3D printer should be placed in front of the ABB robot. To define the right place for the 3D printer, the following restrictions should be taken in account:

1. ABB robot cannot be moved because it is used for another project;
2. ABB robot can switch on the 3D printer (using a tool is a possibility);
3. ABB robot can pick up the bed with both hands;
4. ABB robot can move the bed next to the 3D printer;
5. ABB robot can reach the top of the 3D printer to replace the material;
6. ABB robot can use the button.

The following layout is chosen:
The 3D printer is placed in front of the ABB robot. In this way, it can perform each task. On the left side a bed storage is placed for easy access to new beds. On the right the slide for the beds that come out of the 3D-printer is placed. The position of the components is marked on the table.

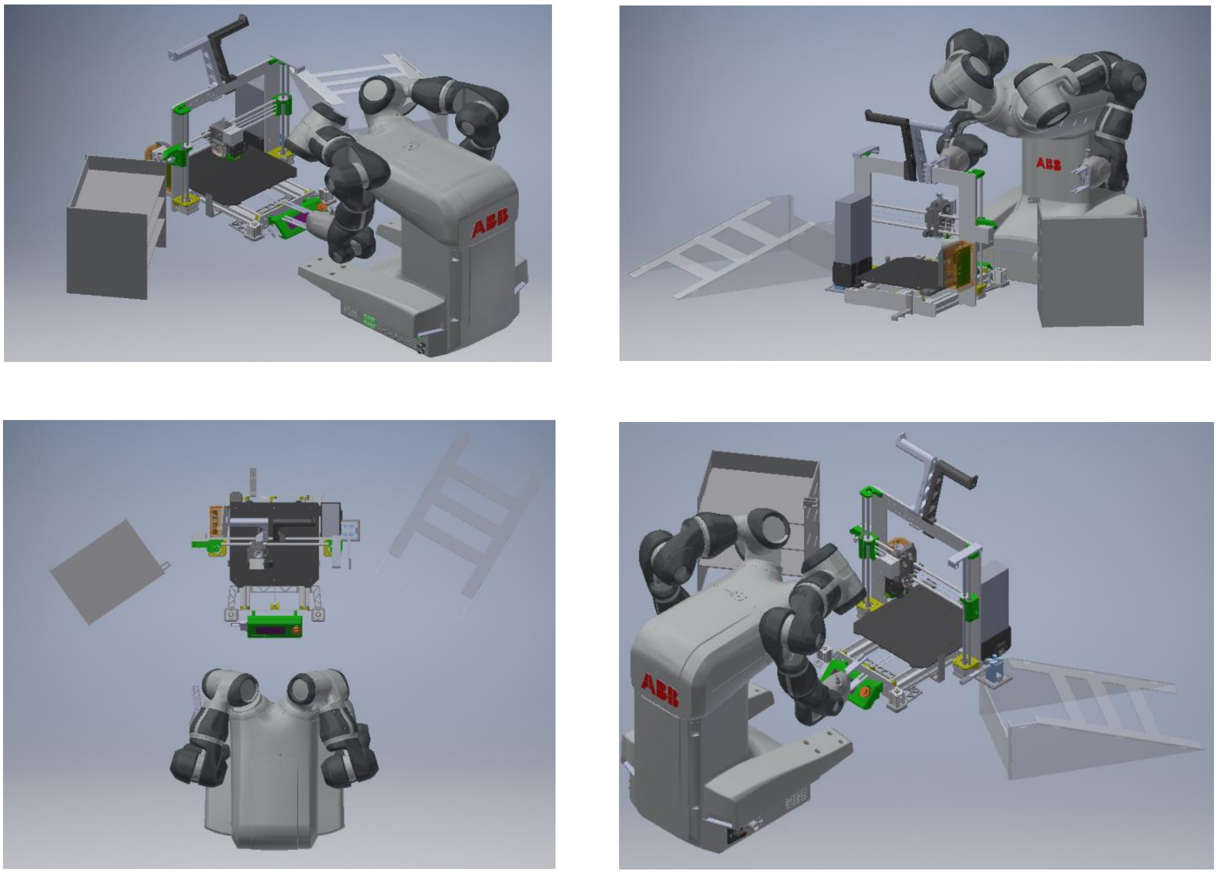

Figure 19: Different views from the set-up

11.2.2 General power supply

To control the modifications of the system that the ABB robot needs to perform the tasks, there are different electrical components introduced, these will be powered by 24VDC. Because the power of the electricity net is 230 VAC, a transformer is used to change the power to 24VDC. How the transformer is connected can be seen on the electrical drawings in the appendix on page 45.

The created power is then used to supply the Remote I/O. This cable is connected to the communication module. Because the remote I/O has different modules there is an internal connection, therefore only the communication module needs power. The connection of the communication module can be found on the electrical drawings in the appendix on page 46

For YuMi to control extra inputs and outputs a Remote I/O is implemented. This Remote I/O exists out of 2 modules. The first module is the communication module which, as said before, gets the power. This module is also connected with an internal Ethernet network, over this cable the signals get send.

The second module is where the input and the outputs are connected. This particular remote I/O has only a digital input (DI) and a digital output (DO). The first row has 8 digital inputs and the second row had 8 digital outputs.

11.2.3 UML-diagram

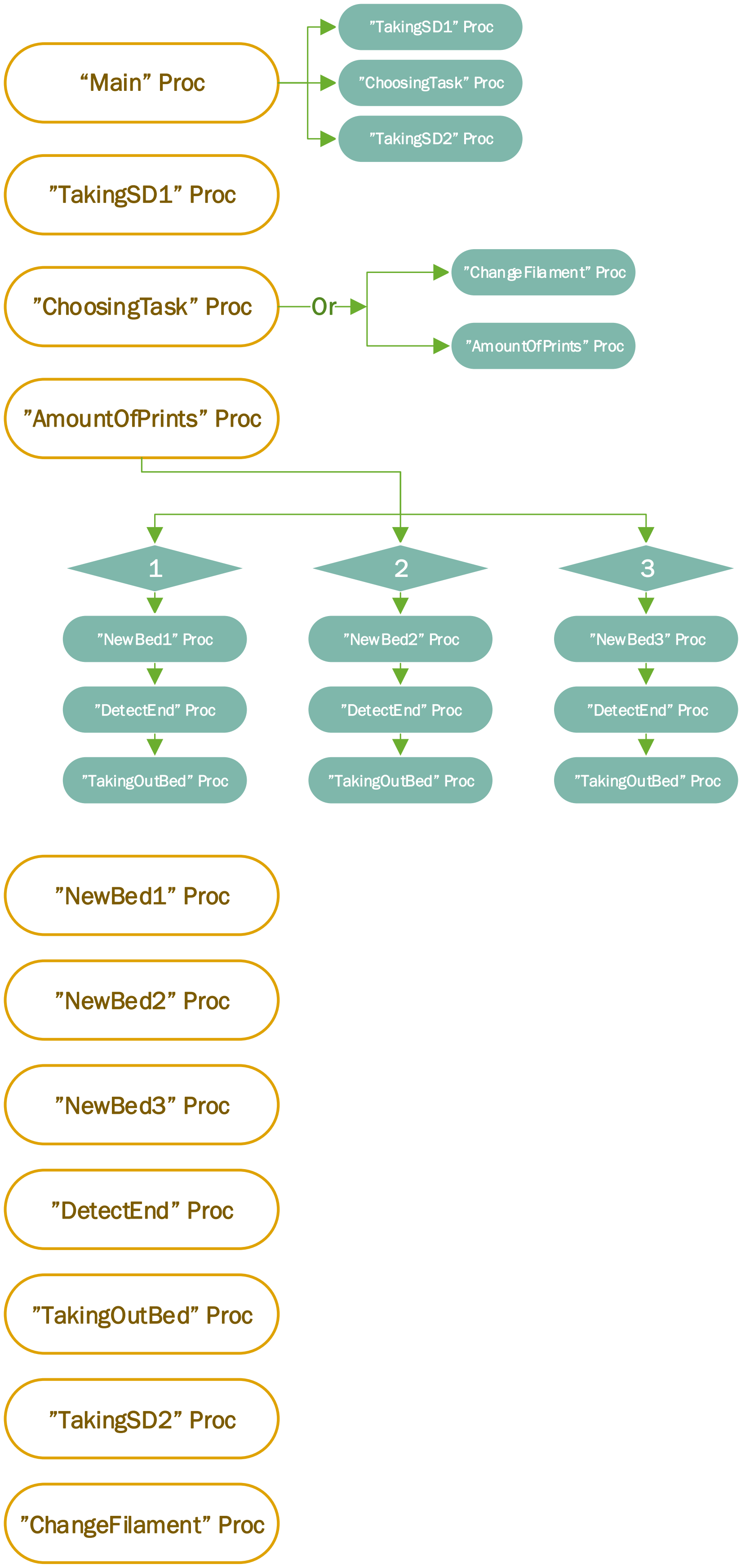

Figure 20: UML-diagram (left arm)

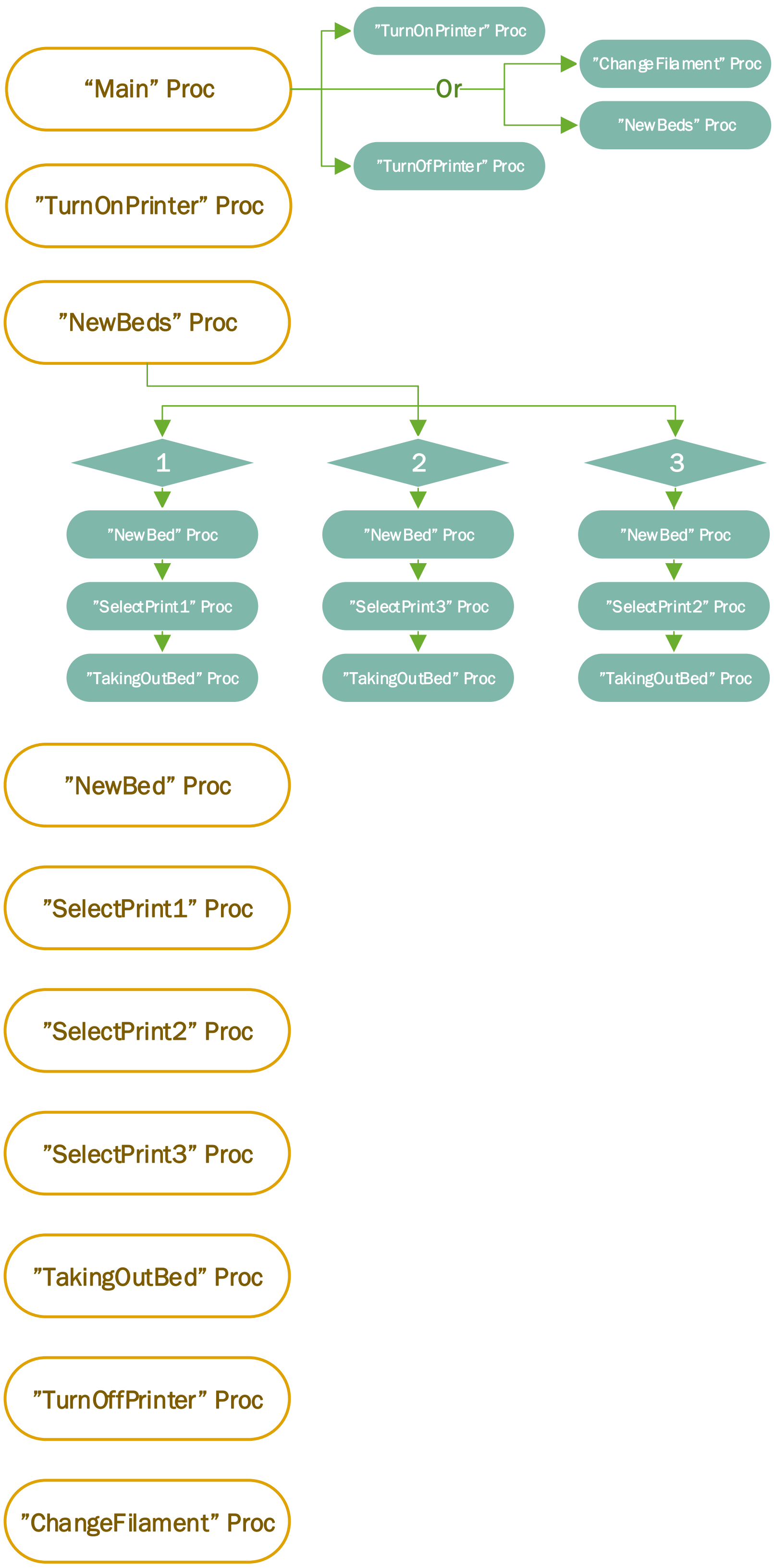

Figure 21: UML-diagram (right arm)

11.3 Put SD-card in 3D-printer (1)

In this chapter the first step of the flowchart will be discussed. This chapter includes the reason why a tool is needed, the design of the tool and the application of the tool. But also, an UML-diagram is presented to clarify the programming code.

11.3.1 Design: SD-card holder/tool

As said before the first step that the robot needs to fulfil is inserting the SD-card in the 3D-printer. There are several issues concerning this step. First of all, the SD-card port from the 3D printer is too close to the table therefore the griper is not able to reach to SD card completely. Secondly the angle of the SD-card port is off causing problems for the robot to grab the SD-card. To solve these problems a tool was designed. This tool is placed around the SD card like a 'sleeve', making the object (SD-card) bigger and easier for the robot to grab. The SD-card with the holder are stored in the SD-card holder. This holder is attached to the bed storage for easy access for the robot. The technical drawings are presented in the appendix on the pages 12 and 13.

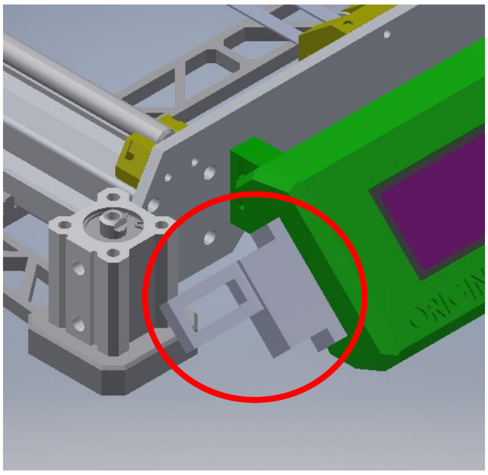

Figure 22: SD-card holder in 3D printer

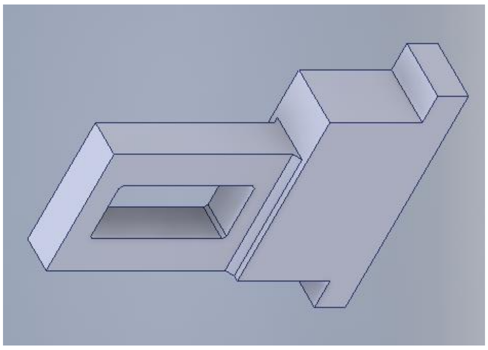

Figure 23: SD-card holder

11.3.2 UML-diagram

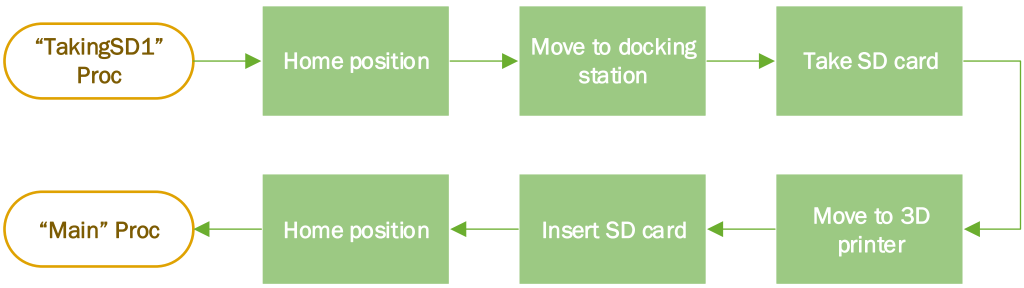

Figure 24: UML-diagram 'Put SD-card in 3D-printer'

11.4 Turn on 3D-printer (2)

The second step in the flowchart is turning on the 3D-printer. This needs to be done without any electronic connections. The solution developed, uses a stick and a support. With the same tools but a reversed procedure the printer can also be turned off.

11.4.1 Design: tool

The robot is not able to reach to the back of the 3D-printer to switch it on. Therefore, a tool is needed that in some way 'extends' the switch and makes it easy for the robot to switch on. By using the designed tool (showed below) the robot can turn on the 3D-printer with a rotation movement. The designed tool is printed with the 3D-printer. Detailed drawings of this tool are presented in the appendix on pages 13 until 19.

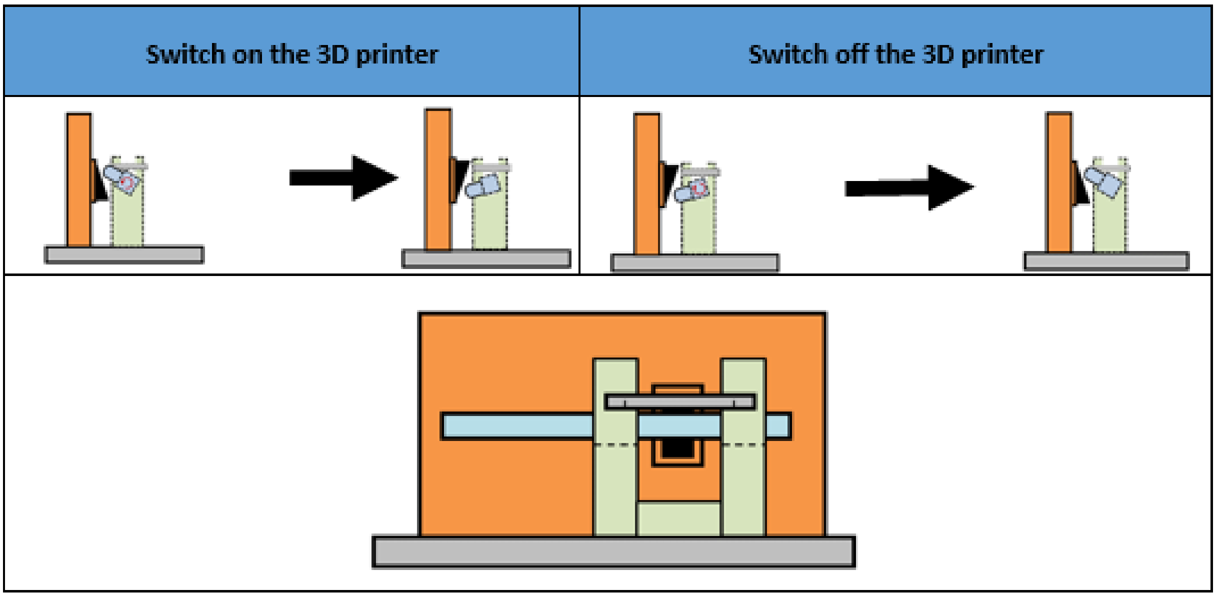

Figure 25: Design switch tool

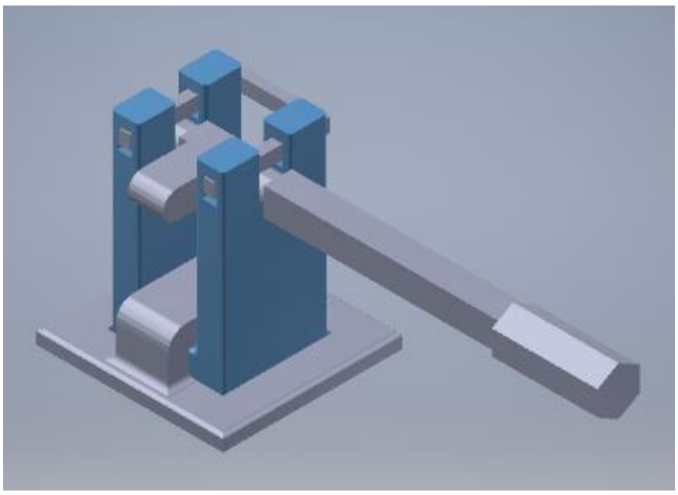

Figure 26: Switch tool

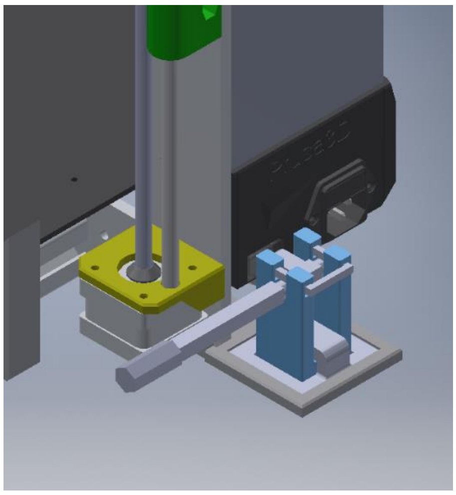

Figure 27: Switch tool beside 3D printer

11.4.2 UML-diagram

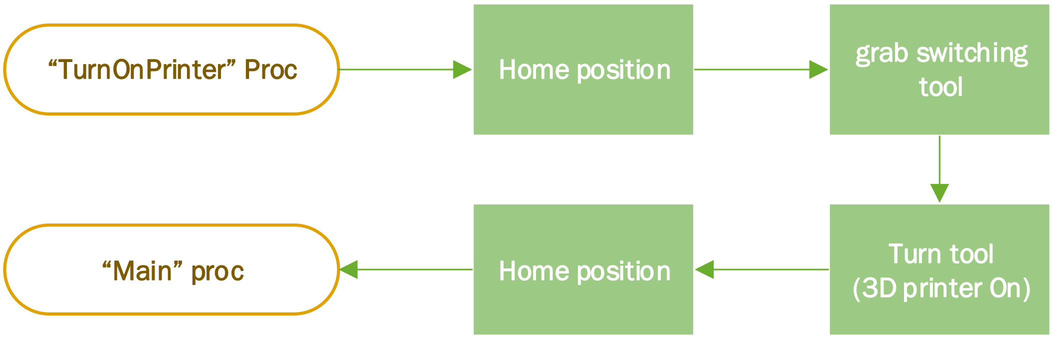

Figure 28: UML-diagram 'Turning on 3D-printer'

11.5 Change material (3)

It might occur that during the print jobs the 3D printer will run out of filament. To counter this, modifications have been designed and added to the system. But after trying to program the robot to change the filament it became clear that this is not desirable. Because when the extruder is preheated to change the filament a residue falls from the extruder somewhere on the heat bed. The shape and position of this residue cannot be predicted which makes it hard to grasp with a preprogramed movement. Therefore, it cannot be assured that the residue will be removed by the robot before the print is selected or continued. This situation is not desirable because it might ruin a print.

11.5.1 Design: funnel tool and material holder

The original material holder from the 3D printer is copied and mirrored. Because of the extra material holder, there is more material available to print multiple parts. As for the funnel tool, this tool is used to guide the material in the extruder. Making it easier for the 3D printer to change the material by itself. The technical drawing of the funnel is presented on page 20 of the appendix.

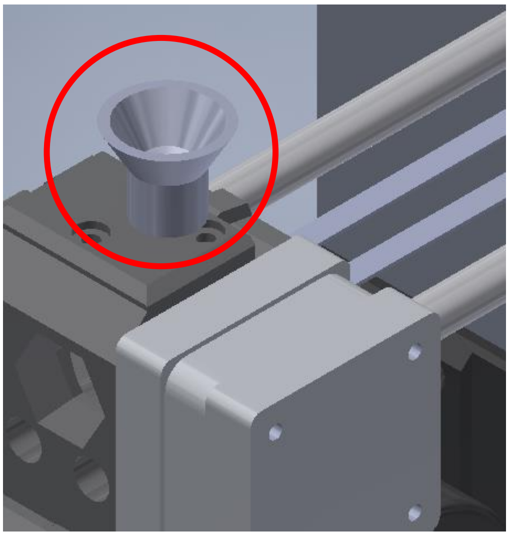

Figure 29: Funnel tool on extruder

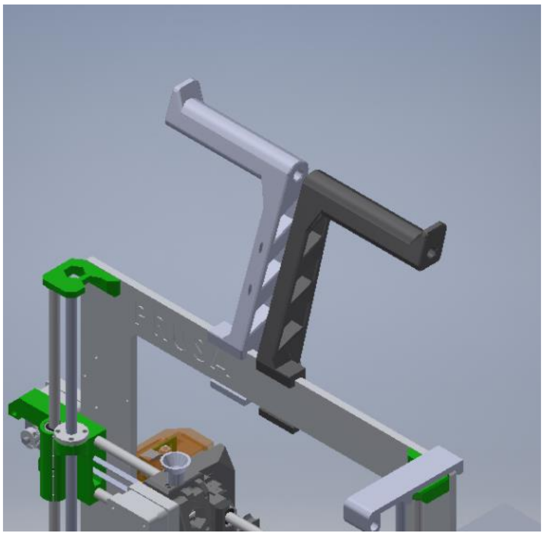

Figure 30: Material holders on 3D printer

11.6 Select print and start print (4)

11.6.1 Design: button

To control the 3D printer the ABB robot needs to be able to turn and push the button. With the original button, it is hard for ABB robot to grab, that is why a new button is designed. The technical drawings of the new design made for the ABB robot can be found on page 21 of the appendix and has two main characteristics.

1. Hexagon: better grip;
2. Two levels: easier to push the button without changing the position of the hand.

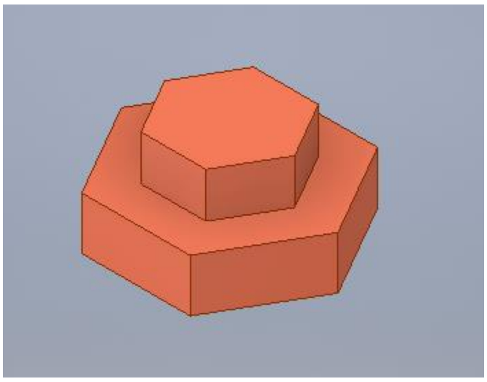

Figure 31: Button

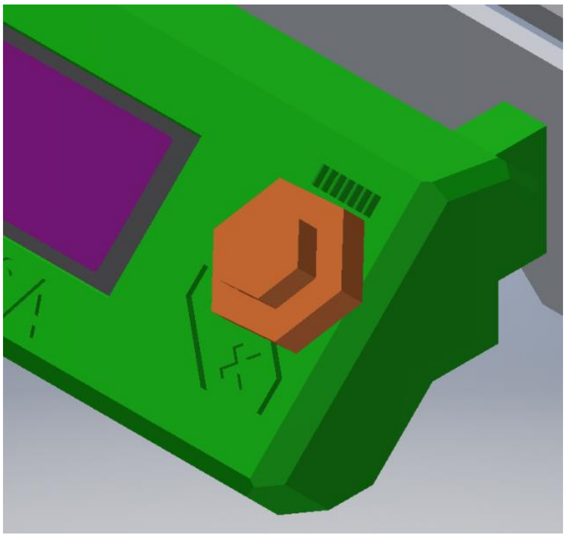

Figure 32: Button on 3D printer

11.6.2 UML-diagram

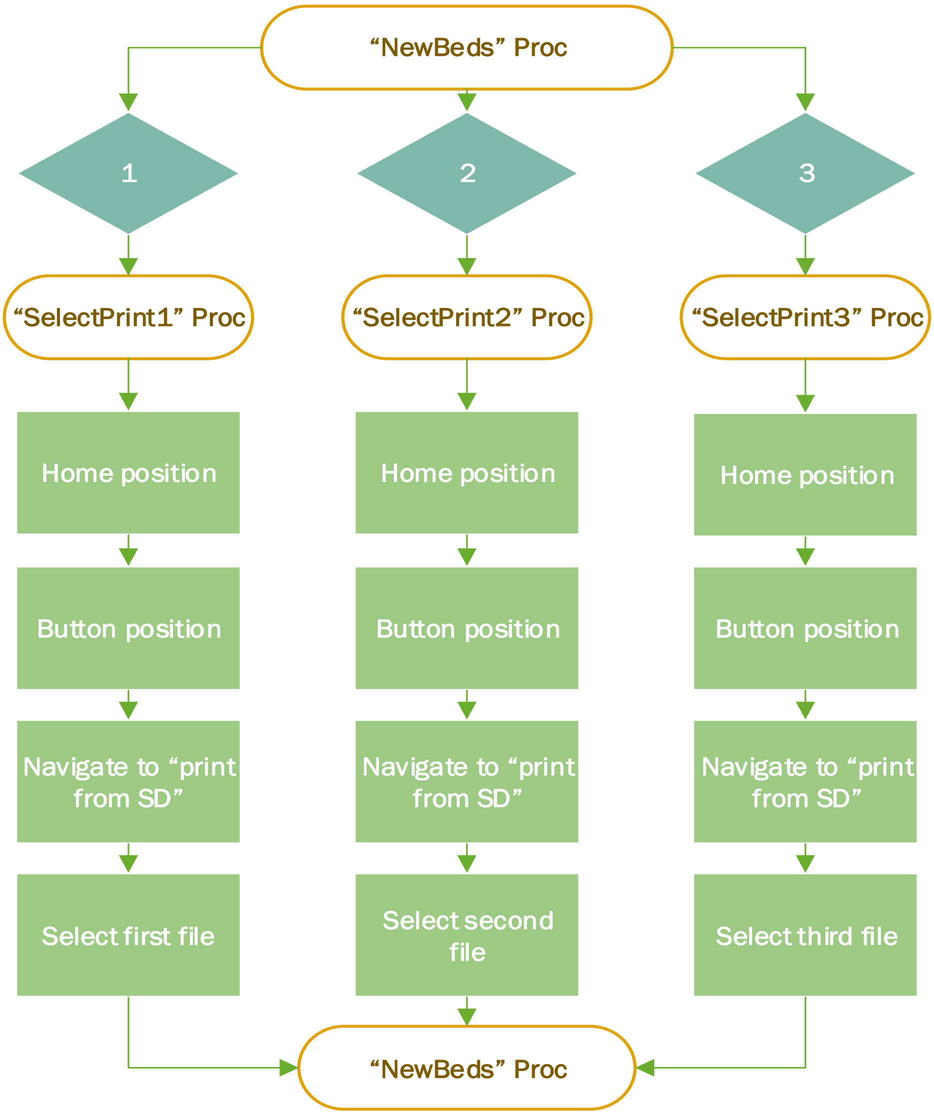

Figure 33: UML-diagram 'Select print and start print'

11.7 Detecting print is finished (5)

Before removing the bed, the ABB robot has to know when the printing is finished. It was considered to use industry 4.0 for this, but that did not align with the vision of this project. More on industry 4.0 in the chapter Research of the appendix. Eventually it is done by the usage of a sensor. There are different kinds of sensors to detect movements or positions of certain objects. Sensors are divided in two main categories, inductive and capacitive sensors. For this project a proximity sensor was used to detect when the print is finished.

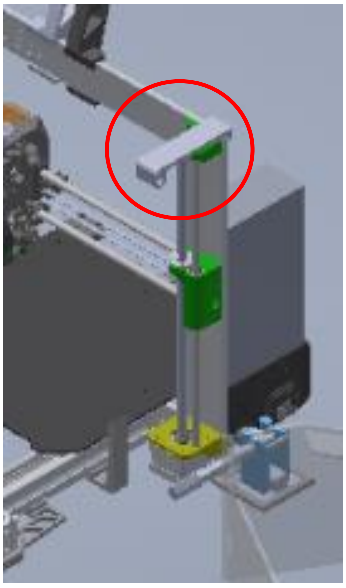

Figure 34: Sensor holder on 3D printer

11.7.1 Design: sensor holder

To hold the sensor in place a holder was designed. The holder is attached to the top of the 3D printer. This placement was chosen because it does not interfere with the extruder while printing. The proximity sensor reacts to magnetic fields, because of the magnetic parts in the extruder there is no need to attach magnet to the extruder. The technical drawings of the sensor holder can be found on page 22 of the appendix.

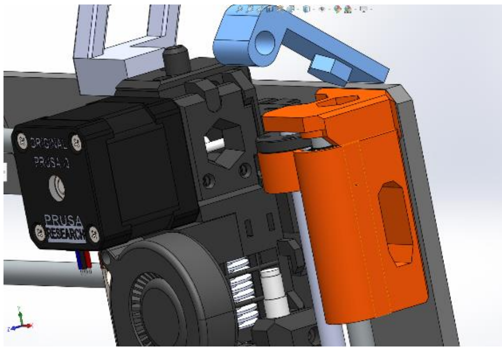

Figure 35: Sensor holder lose from 3D printer

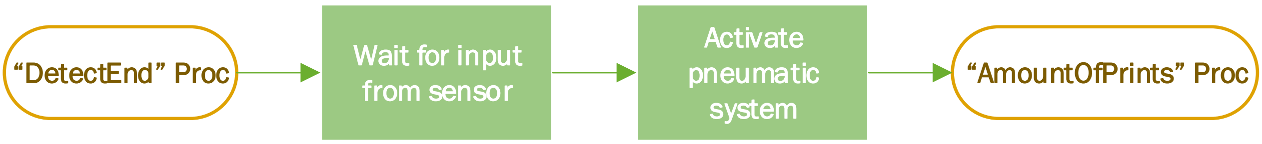

Figure 36: UML-diagram 'Detecting print is finished'

11.8 Taking bed out of 3D-printer (6)

Continuing with the sixth step, taking out the bed of the 3D-printer. Because the of the magnetic bed and the weight restriction of the robotic arms, extra help is needed. It was thought at first that by adding a pneumatic system with cylinders, the magnetic attraction is lowered enough. Then when the ABB robot detects that the printing is finished, a signal is sent to the pneumatic system to lift the bed and the ABB robot can put its fingers underneath. The grips close, a synchronized move upward is done and the printed part can be put on the side. However, after the addition of the pneumatic system the magnetic attraction was not reduced enough for the robot to take out the bed.

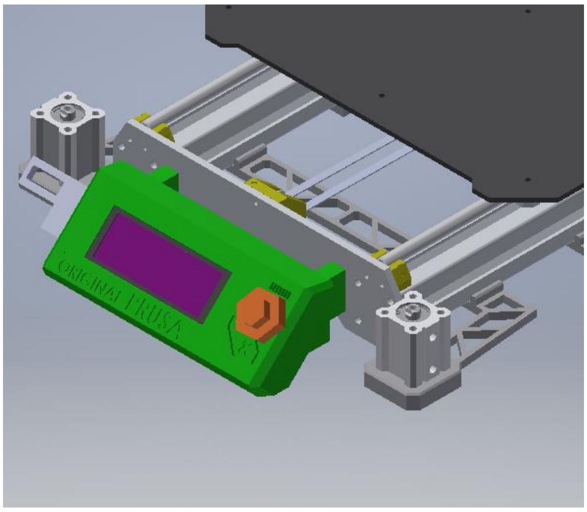

Figure 37: Cylinder baseplate underneath 3D printer

11.8.1 Design: cylinder baseplate and valve holder

To keep the cylinders in place a base was designed. This base can be attached to the bottom of the 3D-printer. The base can be removed if any changes need to be implemented. Besides the base plate, a valve holder is attached to the back of the 3D-printer to clean up the working area by organizing the air tubes. The technical drawings of the base can be found in the appendix on page 23 and of the valve holder on page 24. Additional research on the pneumatic system is presented in chapter 4 of the appendix.

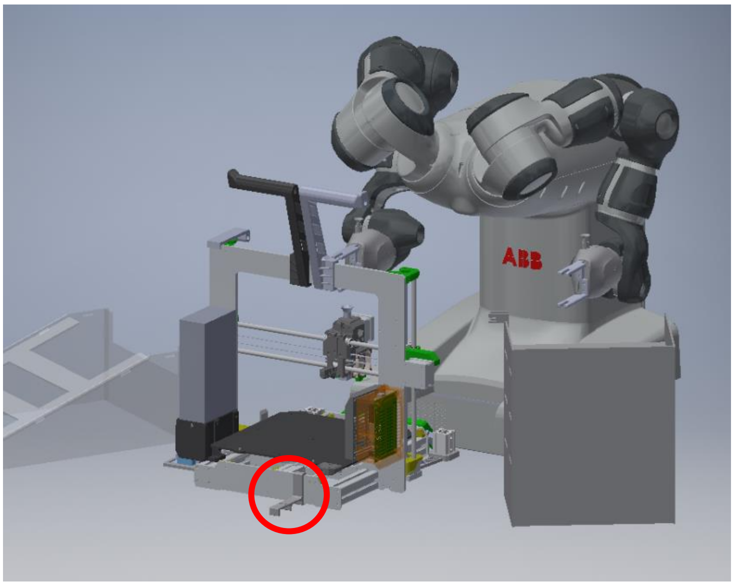

Figure 38: Valve holder on 3D printer

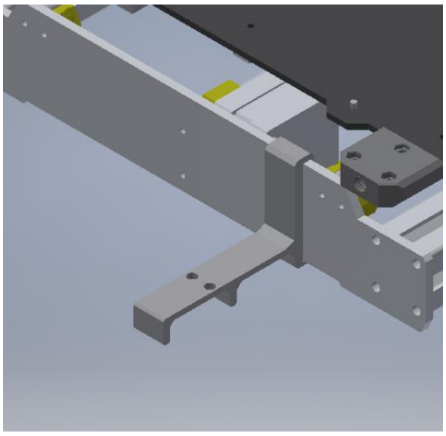

Figure 39: Valve holder on 3D-printer zoomed-in

11.8.2 Electrical drawings

In this project two valves are used, these will be used to control the airflow to the cylinders. Like said before the current from the remote I/O is not high enough to power the valves directly. The relay on page 48 of the appendix is a normal open (NO) contact. Once the relay is switched on the power will go directly from the transfer to the valves.

11.8.3 UML-diagram

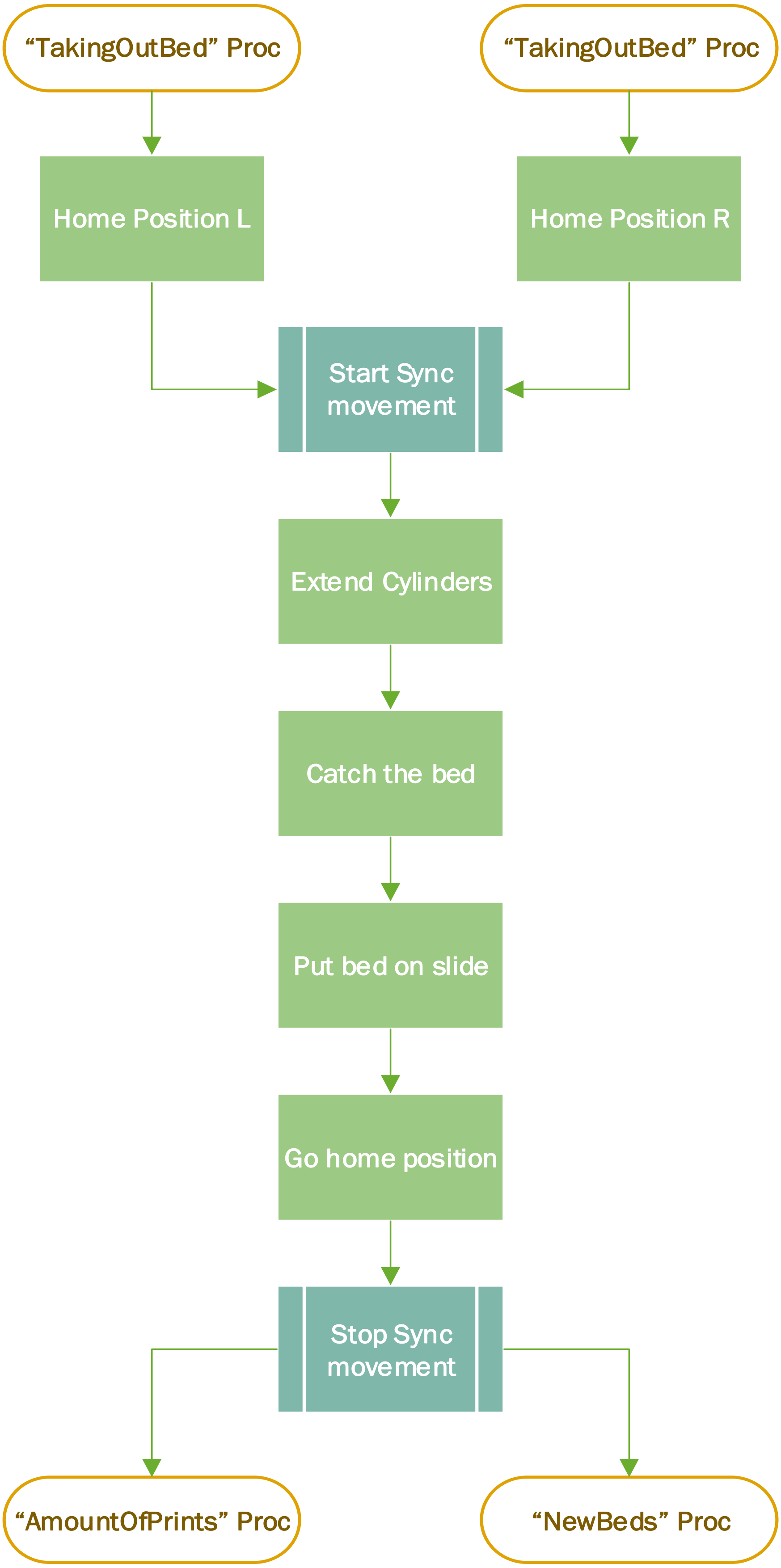

Figure 40: UML-diagram 'Taking bed out of 3D printer'

11.9 Transfer bed to slide (7)

The seventh step from the flowchart is placing the removed bed on the slide. The slide is, as said before, located on the right-hand side of the robot. By using the slide, the removed bed can be discarded and make place for a new bed to start printing again. Using the slide has its limitations, when the bed slides of the slope the robot is not able to recover the printed parts for assembly.

11.9.1 Design: slide

To make the slide, laser cutting technology was used instead of 3D-printing. The slide is specially made for the size of the beds. The parts are too big to be 3D printed, therefore the laser was used. Each part of the slide can by assembled though dovetails, using glue to be more resistant. The technical drawings of the slide are presented on the pages 25 until 28 of the appendix.

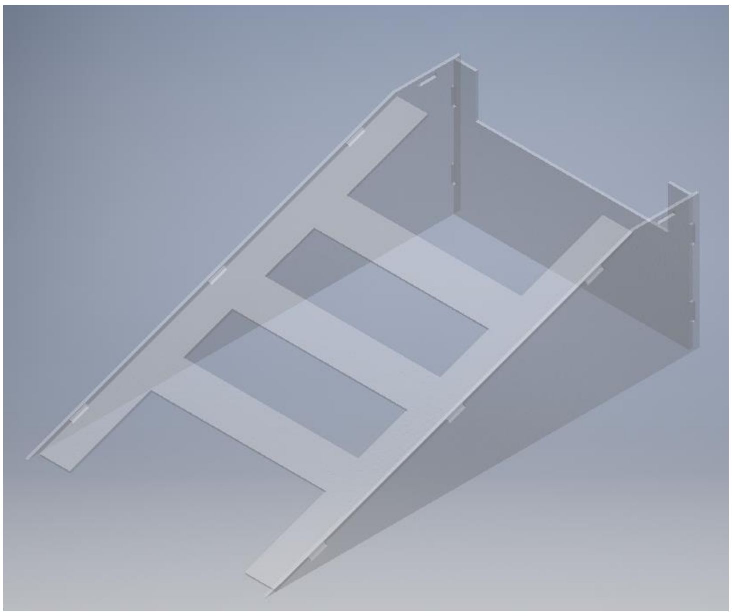

Figure 41: Design slide

11.10 Get new bed out of storage (8)

To be able to print multiple parts extra beds are needed to switch from beds. To store these extra beds a storage rack is designed. This rack is situated on the left of the 3D printer.

11.10.1 Design: bed storage

The rack has 3 levels, this means 3 print jobs can be done. The rack was produced with the same technology as the slide, by laser cutting. On the pages 29 until 32 of the appendix are the technical drawings of the bed storage.

If there is not a bed in each level, the top has to be completed before to the bottom. In this way, during the process, the robot will catch at the first bed at the top, secondly the one at the middle and will finish with the one at the bottom. Under the same conditions as removing the bed, the two arms are synchronized to have a better grip.

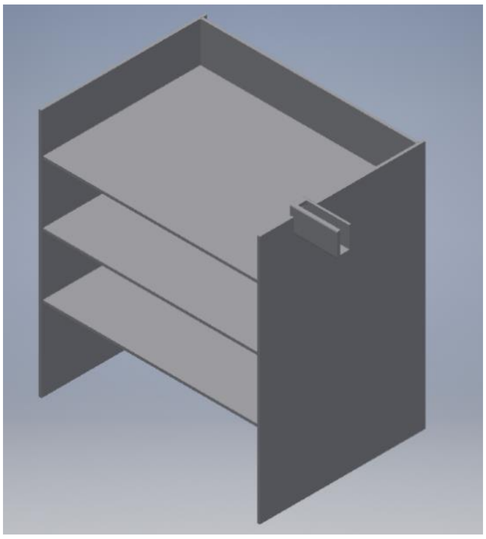

Figure 42: Design bed storage with SD-card

11.11 Place new bed in 3D-printer (9)

The idea developed to put the new bed is to place the bed in front of the 3D printer, to lean in to have contact and then push it to the back. The last moves for the robot are to go down and to withdraw. To make it easier, the cylinders are kept at the top during this task.

11.11.1 UML-diagram

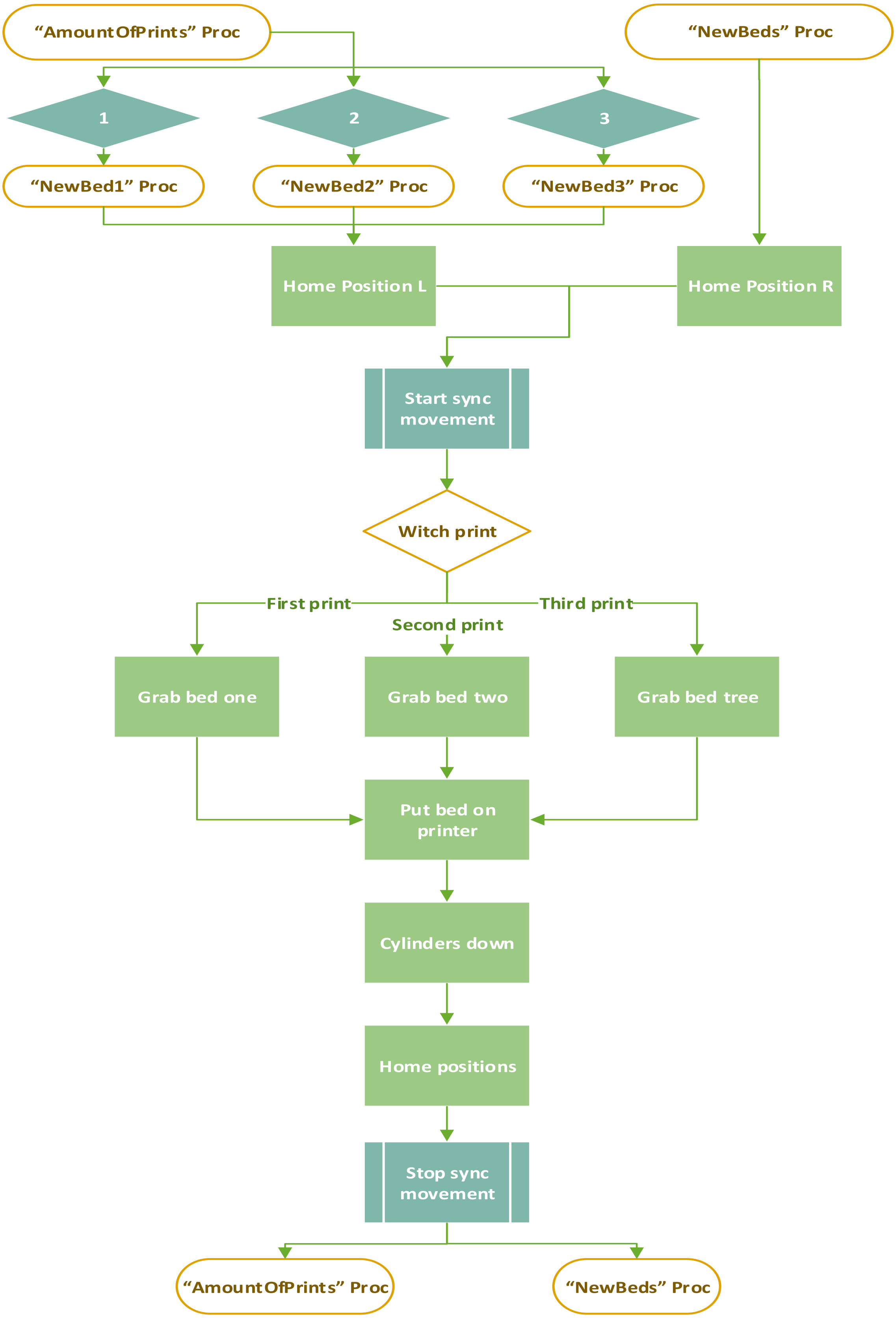

Figure 43: UML-diagram 'Placing new bed in 3D printer'

12 Conclusion

The mission of this project is to use the 3D printer with the ABB robot. To be able to do this a broad understanding of these machines was necessary. Therefore, the first part of this semester primarily consisted of researching and clarifying the objectives. The second part of the semester was focused on the programming the ABB robot and perfecting the use of the 3D printer. Because the machines are not designed to be cooperating together, multiple supportive systems had to be added. To turn on the printer a mechanical system with support was needed. The SD card required a sleeve and storage area. A modified button that the ABB robot could turn and push to go through the menu of the printer. To detect when a print was finished a sensor with holder had to be added. A pneumatic system with support and an electrical connection with the ABB robot to help with taking out the bed of the 3D printer, which still wasn't enough. And finally, a slide for depositing of the used beds. Furthermore because of the accuracy that is required for all the tasks it is important that everything stays in the exact same position once it is calibrated. The slightest movement of one of the components can incapacitate the entire system. However, the ABB robot is capable of performing everyday household tasks if everything necessary is in reach and in the correct position.

13 Recommendations

An important recommendation has to do with possible error during the print. It might happen that the one of the first layers fail and the print becomes detached from the heat bed. Therefore, it is recommended to always stay near the printer in the beginning to see if these layers are successfully printed. However, the robot does not have the ability to recognize such an error. Furthermore, even after the implementation of the pneumatic system the ABB robot was not able to take out the bed from the printer because of the magnetic attraction. The idea was developed to cut the end of the beds to reduce the force. This modification is expected to have enough impact for the wanted result. However, this could not be tested because of the lack of beds. In addition, as stated in the conclusion a high accuracy is needed for the system to perform. Which means that everything has to stay in the exact same place. This could be countered by implementing recognizable points on the storage area, 3D printer and slide that the ABB robot would identify with its camera. Then all the necessary positions of the objects can be in relative positions from these predefined points.

14 Bibliography

3D printing trends 2019. (2019, January 25). Retrieved from Makrforged.com: https://markforged.com/blog/3d-printing-trends-2019/

ABB Group. (2019, 11 23). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/ABB_Group

About EPS. (n.d.). Retrieved from europeanprojectsemester: http://europeanprojectsemester.eu/concept

Applications of 3D printing. (n.d.). Retrieved from wikipedia: https://en.wikipedia.org/wiki/

Applications of 3D printing. (2019, September 20). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/ Applications_of_3D_printing

B., H. (2014). NASA just emailed the space station a new socket wrench. *UPI*.

Best open source 3D printers. (2018, April 22). Retrieved from 3dinsider: https://3dinsider.com/open-source-3d-printers/

Cincinnati Milacron T3 Robot Arm. (2009, 9 30). Retrieved from At The Turning Point: https://lakshmimenon.wordpress.com/2009/07/26/cincinnati-milacron-t3-robot-arm/

Cox, B. (n.d.). *The Evolution of industrial robotics*. Retrieved from Sutori: https://www.sutori.com/story/the-evolution-of-industrial-robotics--ESrMeSubei76BonChmqmtgkr

Defining The Industrial Robot Industry and All It Entails. (n.d.). Retrieved from Robotics Industries Association: https://www.robotics.org/robotics/industrial-robot-industry-and-all-it-entails

E.H., J. (1974). Ariadne. *New Scientist*.

Flow regulation valves - spool valves. (n.d.). Retrieved from hafner: http://www.hafner.pl/en/general-informations-about-pneumatics/spool-valves

Fused filament fabrication. (n.d.). Retrieved from wikipedia: https://en.wikipedia.org/wiki/ Fused_filament_fabrication

H., L., & M., K. (2014). *The new world of 3d printing.* John Wiley Sons.

Hooijdonk, R. v. (Ed.). (2018, December 26). *These Trends Will Shape 3D Printing Moving Into 2019*. Retrieved from Fabbaloo.com: https://www.fabbaloo.com/blog/2018/12/26/these-trends-will-shape-3d-printing-moving-into-2019

Industrial robot. (2019, 11 20). Retrieved from wikipedia: https://en.wikipedia.org/wiki/Industrial_robot

Industrial Robot History. (n.d.). Retrieved from RobotWorx: https://www.robots.com/articles/industrial-robot-history

Industriële automatisatie. (n.d.). Retrieved from a-vt: https://www.a-vt.be/nl/automation.aspx

Is industry 4.0 really the next industrial revolution and what does it mean for the future of work? (2018, April 2018). Retrieved from paysa: https://www.paysa.com/blog/is-industry-4-0-really-the-next-industrial-revolution-and-what-does-it-mean-for-the-future-of-work/

J.T., Q. (2013). Chinese scientists are 3D printing ears and livers with living tissue. *The diplomat*.

MES and ERP. (n.d.). Retrieved from eazyworks: https://eazyworks.com/ez-mes-and-erp

Neogi, S. (2018, 11 5). *Servitization in Manufacturing: Collaborative Robots - Cobots*. Retrieved from HCL Technologies Limited: https://www.hcltech.com/blogs/servitization-manufacturing-collaborative-robots-cobots

Original Prusa i3 MK3 . (n.d.). Retrieved from Shop.prusa3d.com: https://shop.prusa3d.com/en/3d-printers/180-original-prusa-i3-mk3-kit.html?gclid=CjwKCAiAqqTuBRBAEiwA7B66hSyWkcgQAwZGQS-jDVeX7HgE4v0uCRGPkbqqwYx-3VNxy_oB6Fkg9RoCF00QAvD_BwE

Project Requirements: Definition, Types & Process Video. (n.d.). Retrieved from Study.com: https://study.com/academy/lesson/project-requirements-definition-types-process.html

Robot History. (n.d.). Retrieved from IFR International Federation of Robotics: https://www.ifr.org/robot-history

Roehl, C. (2017, 10 12). *Know your machine: Industrial robots vs. cobots*. Retrieved from Universal robots: https://blog.universal-robots.com/know-your-machine-industrial-robots-vs.-cobots

S.J., G. (2014). Koenigsegg is triving to make the worlds dastest car with 3D printing. *3D printing industry*.

Shepherd, S. (2019, 2 6). *Welcome to the age of cobots*. Retrieved from Universal Robots: https://blog.universal-robots.com/welcome-to-the-age-of-the-cobots

Stereolithography. (2019, September 23). Retrieved from wikipedia: https://en.wikipedia.org/wiki/Stereolithography

Technical data IRB 14000 YuMi. (n.d.). Retrieved from ABB: https://new.abb.com/products/robotics/industrial-robots/irb-14000-yumi/irb-14000-yumi-data

Using Earned Value to monitor project performance. (2019, August 21). Retrieved from Insight: https://help.insight.com/app/answers/detail/a_id/116/~/using-earned-value-to-monitor-project-performance

Wallén, J. (2008). *The history of the industrial robot.* Automatic Control group.

Wanneer inductieve/capacitieve sensoren en wanneer magnetische. (n.d.). Retrieved from Docplayer: https://docplayer.nl/10728890-Wanneer-inductieve-capacitieve-sensoren-en-wanneer-magnetische.html

What are Single Acting & double acting hydraulic cylinders? (2017, December 19). Retrieved from medium: https://medium.com/@vcompmississaug/what-are-single-acting-double-acting-hydraulic-cylinders-817d6e6f30a8

What is a Reed Switch and How does it work? (2018, augustus 14). Retrieved from arrow.com: https://www.arrow.com/en/research-and-events/articles/the-reed-switch-ingeniously-simple-sensing

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