Internship Report

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Systems (MS3)
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1 Preface

During my internship I've had the pleasure to work in an organisation that strives to improve its most valuable capital good: the knowledge and skills of the employees. I would like to thank Daniël Brummelman for his guidance and assistance in his role as personal supervisor, Marc Schreiber as project lead in the development of a new brew chamber, and everyone else at PCV Group for their support. I've experienced the organisation as able, always willing to help, and aimed at learning to achieve results as efficiently as possible.

2 Summary

This internship consisted of two parts. One individual project on which 50% of the time was spend was on the development of a new prototype coffee brewing mechanism for project Carlo. The other 50% of the time was spent on several projects in project teams for clients and other activities.
These other projects include development on a new electric paint sprayer, medical ear sensor, an alternative to PUR foam, and a cow milk sampler. Other activities include a Solidworks course, internal engineering courses and a visit of the Hannover Messe Industrie fair.
Project Carlo is a modular experimental setup for a fully automatic espresso coffee (EC) machine. The performance of EC machines can be improved by improving the homogeneity of the ground coffee bed used for making coffee in a process called percolation. The goal of the project was to develop and integrate a mechanism to improve the quality of the coffee made by automatic EC machines by improving the brew chamber. From a pre-analysis it followed that the main problem is that in current machines the coffee bed is not properly homogenised with respect to the local thickness of the coffee bed, resulting in an uneven extraction and thus bad tasting coffee. By using a tool used within PCV Group for problem analysis the requirements were set by performing a Critical to Quality (CTQ) analysis. Subsequently concepts solutions were created by utilising TRIZ. The most promising concept utilising a specifically designed mixing impeller was worked out using a design methodology of "fail fast learn fast". This was done by making three prototypes with increasing complexity produced with rapid prototyping technologies. A functional prototype was realised that could produce an even coffee bed and meet most of the requirements set by the CTQ analysis. The results and recommendations were presented to the organisation including management and perceived as successful.

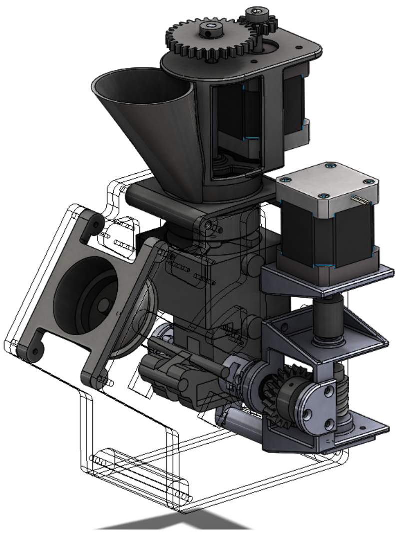


Figure 2.1: Final prototype CAD

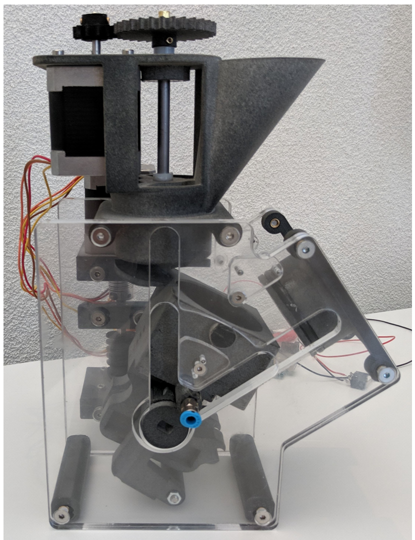


Figure 2.2: Final prototype

Contents

3 Introduction

Figure 3.1: "Villa van Heek", head office of PCV Group [4]

PCV Group

PCV Group is an independent end to end product and technology development consultancy firm established in Enschede. PCV Group stands for People Creating Value. The engineers and managers of PCV Group invent, develop and design components for a wide range of appliances and devices in medical, consumer and industrial markets. The firm is an expert in dispensing and dosing systems, embedded systems and mechatronics. With this skill set the company is a product and development partner for many global multinationals and other large manufacturers. Currently PCV Group employs about 45 full time employees locally in Enschede supported by a shell of specialist network partners and of equal size. In addition the company houses about four internship students that work on various stand-alone and assisting projects.

About this internship

This internship consists of a multitude of aspects. In the search for my internship I was not looking for a company which could provide more than just an interesting internship assignment. Besides the assignment itself the company should provide a broader view with regard to the industrial working field not provided by the university. Some examples include the contact with industrial partners and project management. Besides that PCV Group insisted on setting learning goals and picking assignments based on those. This way I was convinced that PCV Group could provide a broad and informative internship by providing a varied set of assignments.
One of these assignments concerns project 'Carlo' which PCV Group started in 2017. Carlo is a modular experimental fully automatic coffee machine setup intended to showcase the knowledge and technology of PCV Group in dispensing and dosing systems. Since the start various interns have worked to improve parts of Carlo and Carlo would be my project to work on when there is no other business going on. Other projects and assignments were taken on as they appeared.

About the report

This report starts with the formulation of general learning goals and intended outcomes. This part should serve as a guide throughout the internship to pick projects that match the intended learning goals. The report then continues with various sub-reports for each project. In each of these sub-reports the project itself is described as well as the intended learning goals and outcomes.

4 Learning goals

In order to provide guidance during the internship the formulation of learning goals is considered. These goals are both industry 'hard' skills and 'soft' skills. It should be noted that these learning goals served more as a wish-list rather than a hard requirement and that therefore the possibility exists that not all learning goals can be achieved within this internship. The learning goals are reflected on in the Reflection report in appendix

Soft skills

- **Stakeholders:** I would like to gain a broader view of industry beyond academics by gaining experience in which stakeholders and people are involved in all phases of product development from the viewpoint of consultancy. Stakeholders and people include clients, employees of PCV Group, PCV Group as an organisation and external experts.
- **Phases of product development and development tools:** I would like to gain experience with the different phases of product development and the development tools that are used in these processes. This includes brainstorm sessions, project scope definition, time planning etc.
- **Type of work:** I would like to obtain experience in as many different ways of working as possible to asses which 'type' of work suits me best. Do I like to work solely on a problem or in a team? Do I prefer a more academic or hands on approach? Do I like to work at the start phase or end phase of product development? Do I like to work on the fundamental basis of a principle or the integration of this principle into a end product?
- **Time management:** I would like to gain experience in product and prototype development with regard to time management. How do you tackle problems which should have been solved yesterday? How to approach a problem within a limited time effectively? How to quickly asses the dilemma between thoroughness and speed?

Hard skills

- **CAD:** I would like to improve my CAD drawing skills to a level suitable for product development. This means that I should be able to make models of prototypes to an extend that they can be produced and function as intended.
- **Testing:** I would like to improve my ability to perform experimental tests. These tests should provide relevant results within a certain time an have an academic basis.
- **Coding:** I would like to gain experience an unknown coding language or development environment relevant for the project goal.

- **Field of expertise:** I would like to broaden my field of expertise and work on subjects not strictly related to mechanical engineering. Examples could be Electrical engineering or Industrial design engineering.

5 Project Carlo: Design of a brew chamber with uniform coffee bed technology

5.1 Introduction

Project Carlo is an internal project at PCV Group aimed at acquiring knowledge and technology in a specific area of dispensing and dosing machines, namely fully automatic espresso machines. An example of a fully automatic consumer oriented espresso machine is shown in 5.1. Carlo is a modular demonstrator coffee machine of which parts can be interchanged to improve Carlo's performance. In this project a brew chamber of a fully automatic espresso machine is considered with the goal to improve the performance of the brew chamber by enabling the use of new technology that is implementable into future fully automatic espresso machines.

Figure 5.1: A typical fully automatic espresso machine by Krups [7]

5.2 Project charter

As a starting point, a project charter is created to set the outlines of the project. The charter can be found in Appendix **??**. The project charter is frequently used as a tool within PCV group which defines the global project description, goals, budget (financially and time-wise), scope, stakeholders, Key Performance Inidices (KPI's), project team, attention points and communication plan. The charter is as a composition made from various talks with core stakeholders. The clients for example are asked what their main goals of the project and focus points are regarding PCV Group. Whereas the project manager sets the budget. The rest of the project team consists of technical experts on the subject of system architecture and coffee technology.

5.3 Pre-analysis

First, a pre-analysis regarding Espresso Coffee technology is conducted to identify relevant parameters and physics of the brew chamber and the percolation process. Besides literature the internal research and knowledge of PCV Group is consulted. In the pre-analysis the definition of Espresso Coffee and the scientific background is looked into with the goal of identifying relevant parameters of EC. Ultimately the subproblems that concern the brew chamber are defined. The full pre-analisis can be found in Appendix B.

Main problem

The development a prototype brew chamber with functionality to produce a uniform coffee bed aimed at fully automatic espresso coffee machines for consumers.

Subproblems

In the pre-analysis a number of subproblems have been identified which are related to what a "uniform coffee bed" is. These are related to the ground coffee cake dimensions and particle distribution:

1. The variance of **global cake permeability** is often caused by the varying particle size distribution and ground volume dependent on the grinder and used coffee beans. Most automatic EC machines compress the coffee bed up to a certain height rather than a certain compression force. It is therefore important to control the amount ground coffee volume which is dependent on the grinder settings. The grinder setting also influences the particle size distribution as it can be set for finer or courser grinds. Both variances occur when a new type of coffee beans is used. This variance can be controlled by manually by adjusting the grinder setting for fineness en grind time.
2. The variance of **local cake permeability** is often caused by a local difference in density which can be caused by a height difference of the coffee bed before compression. As the uneven bed of ground coffee is compressed locally the density and therefore porosity and permeability changes. This variance can be controlled by minimising the local density differences and height difference of the coffee bed.
3. The variance of **local particle distribution** is caused by handling of the ground coffee. During shaking motion courser particles migrate to the middle and top of the grind while finer particles migrate to the bottom and sides. This variance can be controlled by minimising the unmixing of particles, or by maximising the homogeneity of the mix.

Subproblem 1 is only dependent on grinder setting in most current automatic EC machines and therefore left out of scope. Subproblem 2 and 3 are caused by handling of the ground coffee inside the brew chamber before percolation and therefore subjects of interest. Subproblem 3 is assumed to be of lesser interest as in most EC machines the coffee directly falls from the grinder into the brewer. Because of this unmixing of particles is assumed to be minimal.

Verification of subproblem 2: variance of local cake permeability

Simple tests are conducted to verify and determine the significance of subproblem 2, a difference caused by height distribution. The test is given in Appendix C. A conclusive result based on the measured variables (TDS, yield, and visual parameters of the flow below the portafilter) was not obtained. However taste testing did indicate that local under- and overextraction was more significant with an uneven height distribution.

An expert, Hedzer van der Kamp, is interviewed. He states that the observed visual parameters (jets and center of outflow) are dependent on many variables and cannot be attributed to a single variance in height distribution. Therefore the visual parameters are unfit to determine the significance of a different height distribution. He suggests that this also holds for the measured variables TDS and yield. The difference in height distribution however is very likely to have a significant effect on on local under- and overextraction.

The interview underlines the need for a different method of measurement to quantify homogeneity of the coffee bed with regard to height distribution.

5.4 Problem definition

As indicated by an initial test (Appendix C) and an expert interview: Subproblem 2 is the subproblem of interest for the development of a brew chamber with new technology to reduce the differences in local cake porosity. This new technology should therefore minimise the height difference of the coffee bed before compression in order to create and equally dense coffee bad with minimal permeability differences to enable an even extraction of the coffee bed.

5.5 Requirements: CTQ flowdown

With the problem defined the next step is to define the project requirements. For this, the Critical To Quality (CTQ) flowdown in figure 5.2 is constructed. A CTQ flowdown serves the purpose to define the specific and measurable requirements which are part of a SMART (specific, measurable, acceptable, realistic and time bound) approach to projects. These requirements follow from a strategic focal point with underlying project objective and corresponding top line user requirements.
The strategic focal point is that PCV Group strives to be a specialist partner in system and dosing applications in the coffee business. Project Carlo fits within this strategic focal point as it is aimed at acquiring knowledge and technology in a specific area of dispensing and dosing machines. Logically, the acquired know-how can be of great value for follow-up projects and clients.
With regard to this strategic focal point the project objective is defined as: the development of a prototype brew chamber with functionality to produce a uniform coffee bed aimed at fully automatic espresso coffee machines for consumers.
Within PCV Group various stakeholders can be identified. The Research and Development department has its focal point on the development of core coffee competences and technology. The Marketing and Sales department has an interest in selling these competences to clients and therefore require that the prototype can be used as a demonstrator in the current market. The CTQ flowdown ultimately leads to the requirements that are critical to the quality for the project objective. The CTQ's are subdivided into requirements which must be met and 'nice-to-haves' that are indicated by dashed lines.

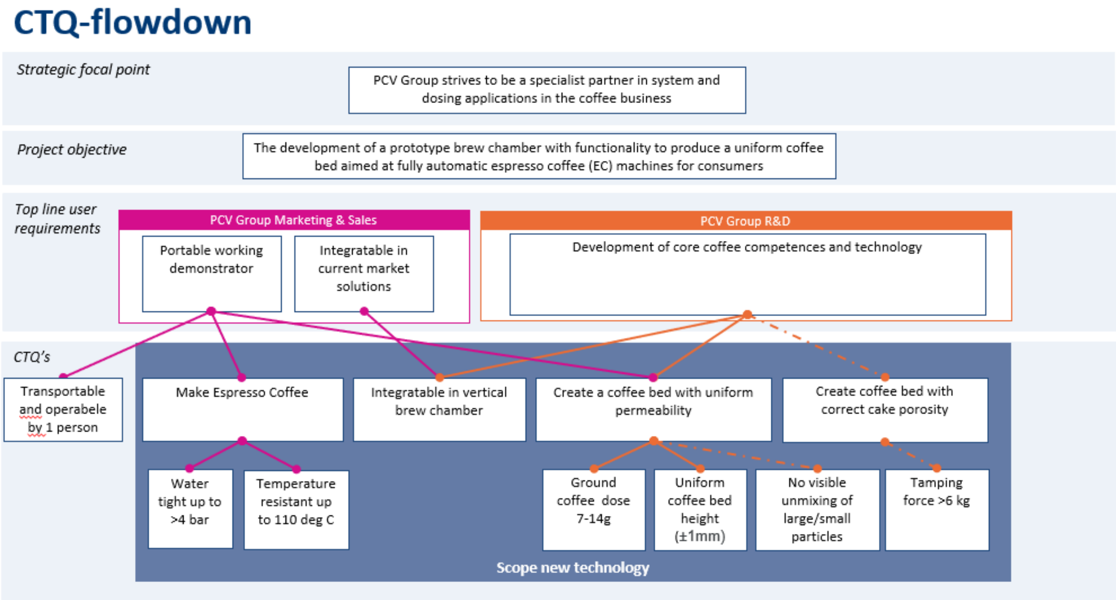


Figure 5.2: CTQ flowdown

5.6 Concept Generation

With the requirements set, concepts can be generated for a prototype brew chamber with added functionality. This is done by using concepts from TRIZ, the theory of inventive problem solving.

Function analysis

First, a function analysis of the brew chamber of a fully automatic espresso machine is made. A distinction is made between system architectures with 1 station and 2 stations. In a 1 station system the system fills and percolates the coffee in the same position whereas in a 2 station system these functions are done in separate locations. The remaining functions can be performed in whichever position.
The functions of the brew chamber are:

- **Main functions**
  - Hold coffee ground.
  - Compress coffee ground with force F.
  - Percolate the coffee ground by letting water with temperature T and pressure P flow from one to the other side of the coffee bed.
  - Remove used coffee ground from the brew chamber.
- **Added functions**
  - Equalise the coffee bed height before compression.
  - Mix the ground coffee with a mixing device.
  - Actuate the mixing device.
- **Architecture dependent functions**
  - Move cup from and to second position

Concept solutions for a uniform coffee bed permeability

Various devices can be used to create a more homogeneous coffee bed height to enable a uniform permeability. Baristas in general use various tools to produce an even coffee bed. Techniques include distributing the coffee with a slide of the finger or using a 'distribution tool', as shown in figure D.3, to produce an even coffee bed. Various other methods and tools used by baristas or found in industry can be found in Appendix D.

Previous testing by J. Bogers suggests two methods for creating a uniform coffee bed that are promising. Namely a concept with pins and one with blades [2] shown in figures 5.3 and 5.4. Around these two concept solutions the other concepts are generated.

Figure 5.3: 'Blades' concept [2]

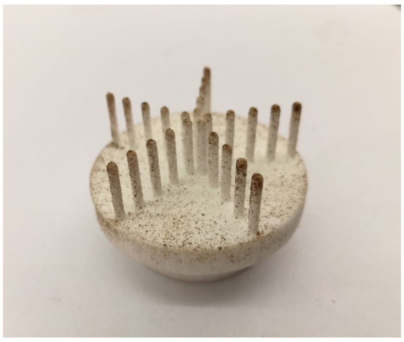


Figure 5.4: 'Pins' concept [2]

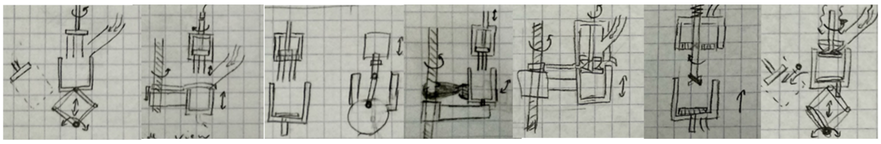
Concepts

For each function a morphological overview is created depicting different partial solutions to perform the functions. These partial solutions are created using the TRIZ Effects Database that provides numerous basic mechanisms for a given function [13]. Combining different partial solutions 7 concepts are created. Concepts 1-4 are based on the pins concept where concepts 5-7 are based on the blades concept. The morphological overview and concepts can be found in Appendix E.
Concept selection All concepts must comply with the CTQ's given previously. These CTQ's however are unsuitable for concept selection since they result in "yes it complies" rather a relative measure for how good it is when compared to the other concepts. Because of this concept selection criteria are defined as follows:

- **Complexity** takes into account the required number of motors, seals and parts.
- **Dimensions** takes into account the assumed system size. Note that the size of the brew chamber itself is mostly predefined as it must be a common size, meaning 40-60mm in diameter.
- **Prototype flexibility** takes into account how easy the subfunctions can be integrated into separate subsystems and how adjustable main dimensions are.

Concept selection

The concepts are scored together with the project team based on these selection criteria, which is shown in table 5.5. A large version can be found in Appendix E. Based on the score chart it is decided that concept 7 will be further developed.



Concept selection	1	2	3	4	5	6	7	Weight
	Pins 2 station	Pins 1 or 2 station	Pins 1 station	Pins 1 or 2 station	Helix 2 station	Blades 1 station	Helix 2 station	
Motors	3	3	3	3	3	3	3	15
Seals	3	3	2	3	2	2	3	15
Parts	3	2	3	3	2	3	3	20
Complexity	3	2,6	2,7	3	2,3	2,7	3	50
Dimensions	3	2	4	2	2	4	3	20
Prototype Flexibility	4	2	2	3	3	1	4	30
	3,3	**2,3**	**2,75**	**2,8**	**2,45**	**2,45**	**3,3**	

Figure 5.5: Concept score chart

Concept 7

In concept 7, the brew chamber is filled with ground coffee in the upright position while the 'blades'mixer is on the bottom of the brew chamber. Then, the mixer is actuated while moving the brew chamber down using a transnational motion. This essentially moves the mixer up through the coffee bed which mixes and slightly compresses the ground coffee creating a uniform coffee bed. Then, the brew chamber is rotated and subsequently translated over the percolation head where the coffee bed is compressed before percolation. After percolation, the coffee bed is removed by extending a piston inside the brew chamber. This concept is largely identical to concept 1 with the main difference being the end effector. In the design the possibility of changing the end-effector is taken into account.

5.7 Brew chamber design

Approach

Due to the limited time available and the numerous technical challenges that have to be faced in the design of a complete brew chamber prototype a "learn fast fail fast" design methodology is carried out by designing 3 prototype designs. The main requirements are given by the CTQ in 5.2. The problems and improvements made in each iteration are tracked with a function status overview that scores the main functions of the system. In each iteration an overview of the function status is given. A more extended function status overview is given in Appendix F.

5.7.1 Design iteration 1

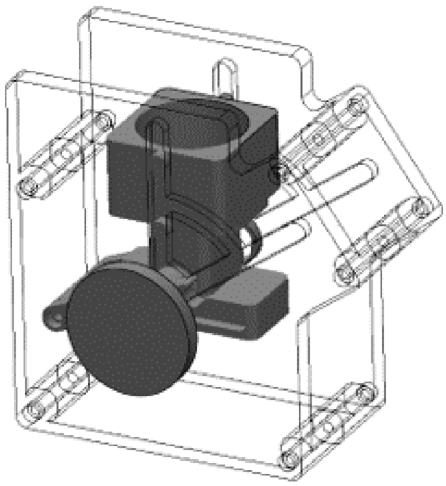


Figure 5.6: Iteration 1 CAD

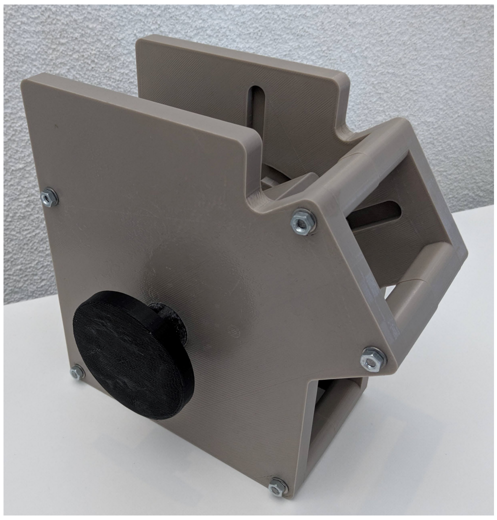


Figure 5.7: Iteration 1 prototype

Goals

In design iteration 1 the main goals are to:

- Define main system dimensions
- Verify function of movement mechanism

When the movement mechanism works within the main system dimensions this can be used to quickly evaluate the design and identify further areas of improvement for the next iteration. Moreover, when the movement mechanism functions, complexity can be added to the design.

Design

Using hand calculation the main system dimensions are calculated. Simple tests are conducted to define the density and compression ratio of coffee ground and thus find out how much volume and translation is required in the system.
Additionally a mechanism is designed which can make two translations and one rotation when actuated by one motor only. This mechanism is in parts based on a conventional

brew chamber design found in other fully automatic espresso machines shown in figure 5.8. It functions as follows. The brew group is filled with ground coffee when the cup is in upright position. Then, the main axle (yellow) is rotated which rotates the cup. After rotation a slider-crank mechanism realises a translation which moves the cup over the percolation head where the coffee is compressed and percolated. After percolation the used coffee is removed by a lever-piston mechanism inside the cup which is engaged when the cup translates downwards.

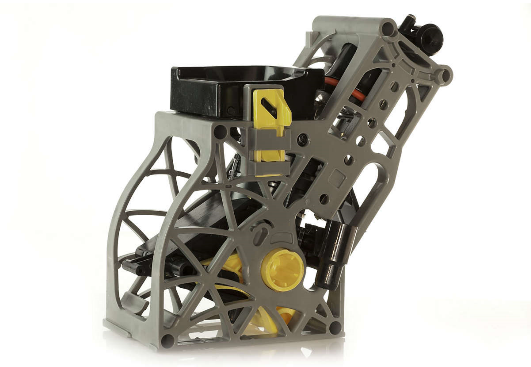


Figure 5.8: Philips brew group [15]

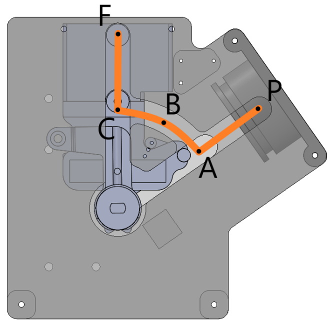


Figure 5.9: Movement schematic

The new mechanism is also driven via a main axle which can move the cup up and down, essentially a slider-crank mechanism. The addition to this mechanism is that the slider-crank can function in two locations by rotating the slider, which in this case is the cup. This mechanism function is depicted in figure 5.10. For the function status overview the full movement is subdivided as depicted by figure 5.9. The mechanism moves as slider-crank from F(ill) to C where it is engaged by the nock to rotate from C to B and from B to A. At A the nock is disengaged and the slider-crank now moves from A to P(ercolate). Moving back to F occurs in reverse order. Please note that the movement mechanism is not the main goal of the project but rather one of many ways to realise two translations and one rotation which seemed easy to implement.
Also, it should be noted that the cup diameter is a trade-off between the ideal height over width ration of the coffee bed, which is 0.2, and the resulting forces on the system. A larger cup diameter would result in higher resulting forces due to the pressure inside the system as it is essentially a pressure cylinder. The cup diameter is chosen to be $5cm$, resulting in a ground height over width ratio of $0,22 - 0,44$ for $7 - 14g$ of coffee respectively. This diameter is larger than conventional fully automatic systems, but smaller than conventional EC machines.
The prototype is manufactured using Fused Deposition Modeling (FDM) 3D printing.

Learnings

- Cup can rotate such that it locks in the guidance slots.
- Nocks can rotate inside their guiding slot.

Function status overview

The movement system works yet requires improvement.

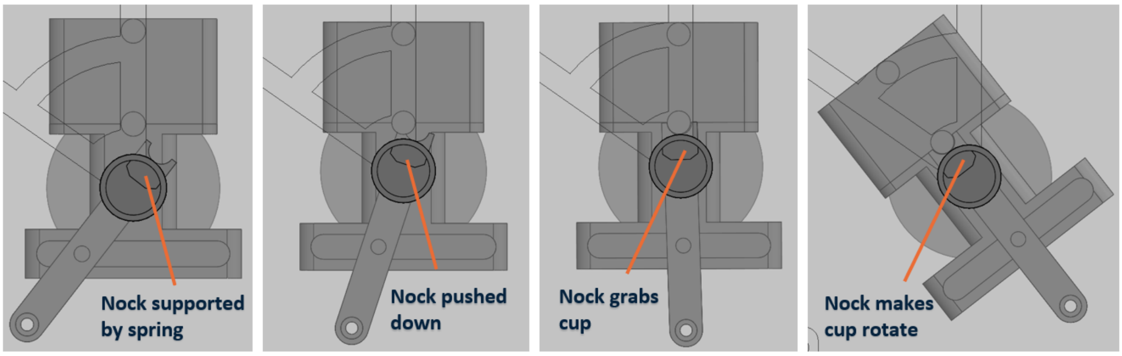


Figure 5.10: Movement mechanism

Function status	Prot. 1
I. Basic function	1,0
II. Movement	3,0
III. Equalising and tamping	1,0
IV. Percolation	1,0
V. Used coffee removal	1,0

5.7.2 Design iteration 2

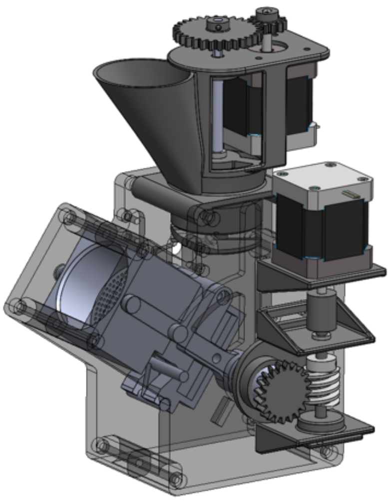


Figure 5.11: Iteration 2 CAD

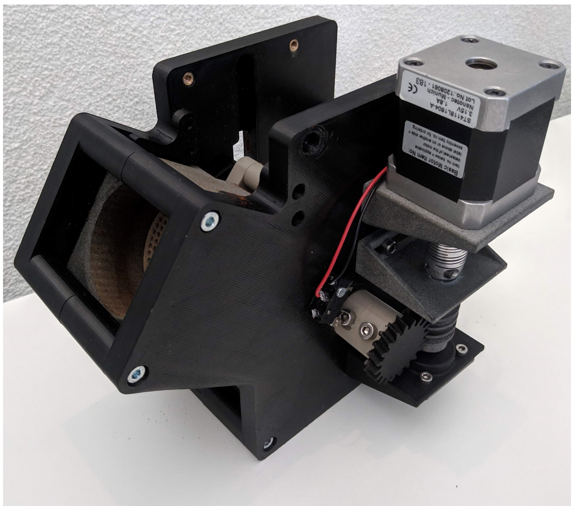


Figure 5.12: Iteration 2 prototype

Goals

With the basics of the movement mechanism defined and the overall dimensions determined complexity can be added to the design. This means that the basic functions have to be added and tested to prove that the prototype can actually produce an even coffee bed. Additionally the basis for percolation is laid out in the form of seals. The used coffee removal is also considered. All this added functionality should be realised in a smaller form-factor comparable to current brew chamber solutions. The main goals are:

- Implement motors and control for movement and tamping auger

- Implement used coffee extractor
- Implement sealing
- Reduce system size

Design

Two NEMA 17 stepper motors are used in combination with an Arduino Uno and a switch used for determining the 'null' position by homing the stepper. One stepper drives a worm via a flexible coupling that rotates a worm-wheel connected to the main axle of the system. The other stepper drives the tamping auger via a gear setup. The movement mechanism is now designed such that the forces caused by pressurising the system do not cause a moment on the main axle put rahter push down straight on it.
When the cup moves down from the percolation position a lever bumps into a protruding block in the housing. This lever than pushes the extraction bed upwards causing the coffee bed to be extracted. This mechanism is shown in figure 5.13. This is essentially the same mechanism as applied in a conventional brewer shown in figure 5.8. The main challenges here is the available space and system integration in the new design which has an additional translation.

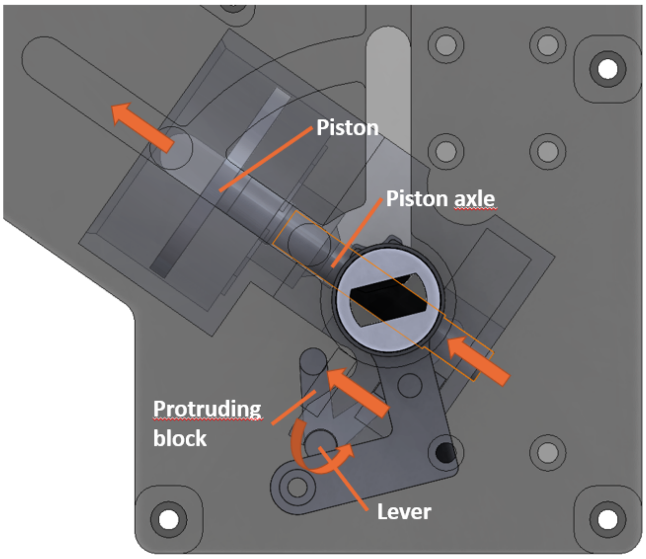


Figure 5.13: Extraction mechanism

The prototype now also has a slide through which coffee can be filled. Inside the brew chamber a seal is inserted between the rod of the piston and the brew chamber. Also, the overall system size is reduced by integration a redesign of many parts to take up less space.
The prototype is constructed using Multijet Fusion 3D printing, which is a selective laser sintering (SLS) type of rapid prototyping by Hawlet Packard in combination with FDM 3D printing. Other parts such as axles are made in house.

Learnings

- Worm and worm-wheel drive train causes elastic deformation causing backlash, play and in the worst case locking of the main axle.

- Nocks sometimes loose grip on the cup assembly during rotation.
- The tamping auger dimensions are such that coffee residue remains on top. Shown in figure 5.15.
- The lever is unable to move the internal piston of the extraction bed, most likely due to friction issues of the bearing of the lever and sealing of the piston.
- When rotating the lever for extraction comes into undesired contact with the protruding blocks.
- Various tolerances have to be optimised further.

Function status overview

Function status	**Prot. 2**
I. Basic function	5,0
II. Movement	4,3
III. Equalising and tamping	3,6
IV. Percolation	1,0
V. Used coffee removal	1,8

All basis functions are satisfied, coffee can be put into the brew chamber and is kept in place properly. The brew chamber can also perform the required transnational and rotational motion most of the time. The transition from translation to rotation and fails sometimes, presumably due to friction issues caused by deformation and locking of the main axle. Additionally, it is expected that the nocks of the movement mechanism can be optimised further.

The system is tested with the amount of coffee ground ranging between 7 to 14 grams of coffee to find optimal movement settings of the system. These settings are currently hard-coded into the Arduino code and depend linearly on the amount of ground coffee. This enables an easy integration in future systems for which the amount of coffee ground can be chosen steplessly. It is shown that design iteration 2 shows can reliably create a coffee bed with an even height for any amount of coffee ground between 7 to 14 grams of coffee. The resulting coffee bed is shown in figure 5.14. The exact height of the coffee bed is not measured as it is visually perfectly flat without any visible chunks or significantly larger particles. This satisfies the coffee bed requirements set by the CTQ flowdown. The tamping force is not measured and scored accordingly.

The extraction of the used coffee bed does due to friction issues in the lever and sealing and it is decided to leave this system out of scope for now.

Figure 5.14: Coffee bed result

Figure 5.15: Coffee residue on auger

5.7.3 Design iteration 3

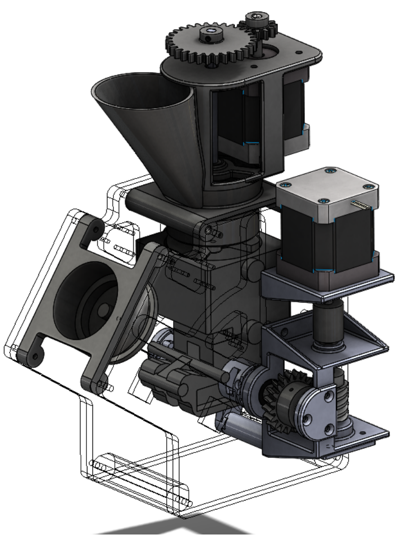


Figure 5.16: Iteration 3 CAD

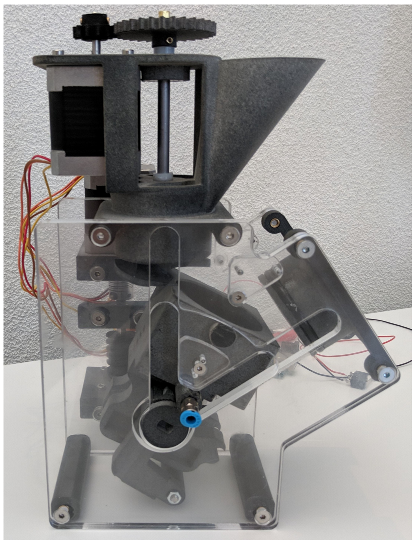


Figure 5.17: Iteration 3 prototype

Design iteration three is the final prototype that should serve as a demonstrator. As such the goals are aimed to finalise the design:

Goals

- Implement learnings from iteration 2:
  - Auger dimensions
  - Drive train optimisation
  - Tolerance optimisations
  - Adjustable nock design
- Make prototpye visualle appealing
- Implement sealing

- Make coffee

Design

Various seal slot dimensions are tested by making two rods by turning them manually. One has the same dimensions as the brew chamber and the other has the piston axle dimension. Both rods have varying slot dimensions in order to test their performance. Subsequently the required force for moving the rod is evaluated and the corresponding dimensions chosen. Final added features for percolation are Festo couplings to connect a water inlet and outlet.
The drive train is optimised such that the worm to worm wheel transmission functions properly by using shaft bearings of all axle ends. This is shown in figure 5.18. Tolerances are further optimised such as tolerances on the fitting of bearings, sliding parts and more. Furthermore, the nock system is designed such that nocks can be easily exchanged for nocks with slightly different dimensions to find the optimal geometry. This is shown in figure 5.18. To make the prototype visually appealing the housing is made of transparent PMMA to show the inner workings and screws are laid flat on the outer surface of the housing. The other parts are again made using MJF or handmade steel parts. The used components can withstand temperatures up to 110 deg to meet the requirements.

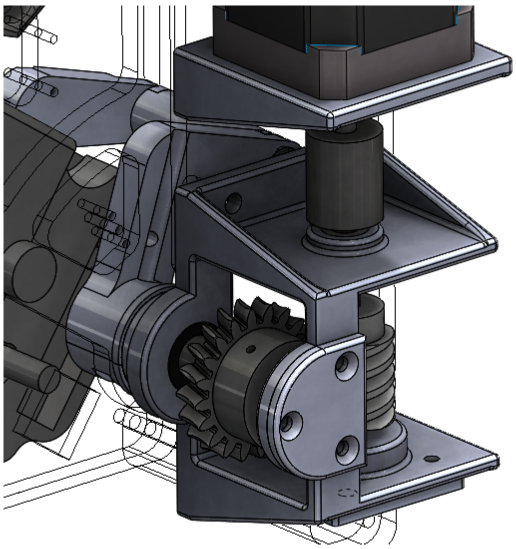


Figure 5.18: Iteration 3 drive train

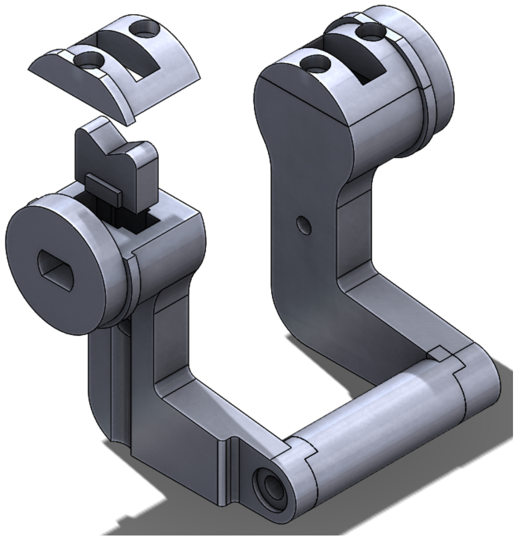


Figure 5.19: Exchangeable nocks

Learnings

- The main axle is out of center of the PMMA housing bearing hole. The tolerance of the axle and PMMA should be reduced or the cutout in the PMMA part reduced. This does not effect the movement however.

Function status overview

The movement mechanism now functions properly with minimal backlash and unwanted deformations. The tamping force is not measured as proper equipment is not available. The mixing auger performs better than iteration 4. Percolation could not be tested as the test setup required for pressurised water could not be used in time and thus percolation performance is unknown. Depressurised testing did show that the system is watertight. As coffee removal was left out of scope this function has not been improved.

Function status	**Prot. 3**
I. Basic function	5,0
II. Movement	5,0
III. Equalising and tamping	4,3
IV. Percolation	3,0
V. Used coffee removal	1,8

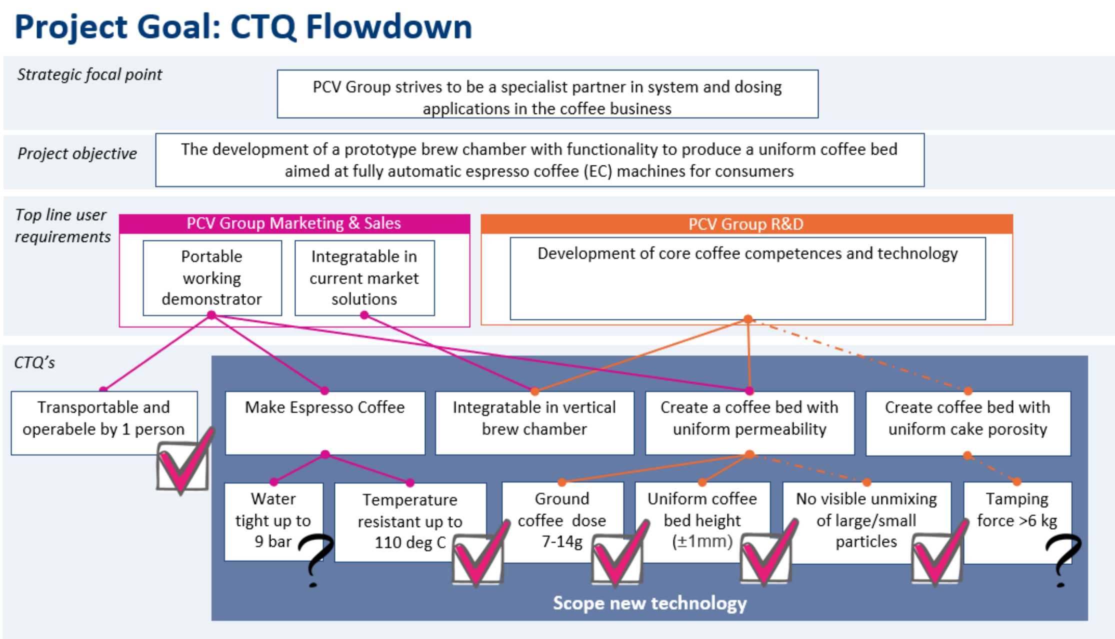


Figure 5.20: CTQ results

5.8 Conclusion

From the pre-analysis it is concluded that a more even coffee bed can improve espresso coffee quality in fully automatic espresso coffee machines. This is because extraction occurs more evenly in the coffee bed. The technology used for creating a more even bed is a type of mixing impeller/auger that proved to produce an even coffee bed heigth [2]. Three prototypes are developed with the goal to ultimately give proof of function of said technology.
To conclude if the project goals are achieved the CTQ flowdown is assesed. In the final prototype, version three, it is shown that it satisfies the CTQ's for temperature, coffee dose, uniform bed height and unmixing properties.
Some CTQ's are unknown however. As the tamping force of the system is not measured it is unknown if this requirement is met. This also holds for the requirement for water tightness.

5.9 Recommendations

CTQ validation

First, the remaining CTQ's should be verified. The tamping force of the system should be measured. This can be done by placing a pressure gauge in place of the percolation head and moving the brew chamber such that is pushes against it. It should be checked whether the required force is reached and that the system does not deform in any undesirable way. The water tightness of the system should be assessed. This is to be done by connecting a source of pressurised water to the inlet of the system and a pressure valve to the outlet. Then, with the brewer in the percolation position pressure can be increased with care to asses the water tightness properties of the system. It should be noted that in this load case the resulting forces on the system exceed those of the tamping force load case. Lastly, the operation by one person is questionable. The final prototype electronics are not embedded on a soldered board and not plug-and-play ready as a PC is required to communicate with the Arduino. To improve this, a small box for the electronics could be made with some control buttons and a small screen to control the prototype.

Espresso coffee quality improvement validation

From the pre-analysis it is concluded that a more even coffee bed height distribution can improve espresso coffee quality because of a more even extraction of solubles into the brew. This statement is not validated and could be done qualitatively and quantitatively.
A quantitative test could be done by assessing the amount of extraction of the coffee bed locally. By taking a part of the coffee bed and fully extracting any remaining solubles with a fluid, one can measure the TDS of said fluid and thus asses how many solubles are left in the coffee bed. The amount of remaining solubles should be uniform over the coffee bed. This way, the results between an equalised coffee bed and uneven coffee bed can be compared. A qualitative test could be taste testing. By evaluating tasting done by an expert the difference between an equalised and not equalised brew can be compared.

Movement mechanism optimisation

Occasionally, the movement mechanism fails to rotate the brewer from position A to B to C and vice versa. See figure 5.9. This could be due to the nocks disengaging from the cup. The optimal geometry of the nocks of the mechanism shown in figure 5.10) could be optimised further. Alternatively, another mechanism of realising two translations and one rotation can be designed for this application. Advanced designs of moving an axle through a slot can realise such motion reliably. This knowledge exists within PCV Group.

Grinding and mixing integration

To reduce preparation time, mixing and pre-tamping of the ground coffee can be done while grinding. Doing the mixing and grinding operation simultaneously also gives rise to other opportunities.
In current applications the amount of ground coffee is not accurately measured. It is known that a variance in amount of coffee significantly influences the percolation process and thus taste. Adding a torque or pressure sensor to the mixer could be done to give a feedback signal to measure the amount of ground coffee. Many types of sensors, for example a strain gauge, could be used for this.
Alternatively a mechanical clutch coupling could be used to activate a switch or to mechanically disengage the grinder. By being able to disengage the grinder, one could drive both the grinder and mixer with the same motor to reduces costs.

Brew chamber separation

In most current fully automatic espresso machines the brew chamber is removable from the machine for cleaning purposes. To make cleaning of the developed brew chamber concept easier the mixing part of the brew chamber could be separated from the brew chamber as illustrated in figure 5.21. As long as the mixer part only comes into contact with dry ground coffee the amount of residue on the mixer will be minimal. This eliminates the need for manual cleaning and thus the part no longer needs to be removable, reducing complexity.

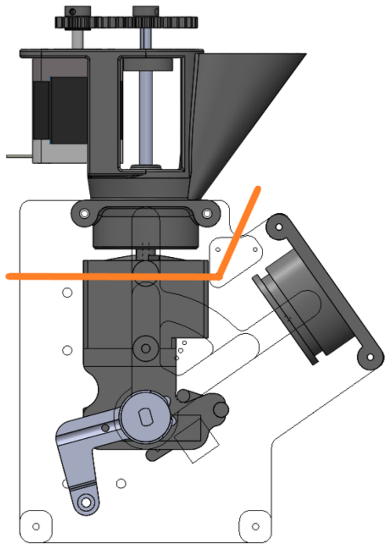


Figure 5.21: Illustration of brew chamber separation

6 Other projects

Since other projects are performed for clients of PCV Group information regarding these projects is kept to a minimum.

6.1 Milk Sampler

For a client specialised in technological agricultural automation and information systems a small feasibility project of a new product is conducted. The goal of the device is that it can be used during milking of dairy cows to take milk samples for lab research in-line with minimal work. Instead of continuously sampling a certain constant percentage the milk flow, a concept with a fast switching valve is proposed.

6.2 Ear Sensor

For a client a re-design of the mechanical aspects of an ear monitoring system for health-care use is conducted. The current design features a clamping mechanism around the patients ear to press a sensor against the inner ear of the patient. This design looks similar to a hearing-aid device.
The current hinging solution however is inadequate. The sensor is not kept in place with the correct applied force to allow for accurate readings of the sensor. The hinge mechanism of the ear sensor is therefore redeveloped. Free-body-diagrams of concept hinge solutions to calculate global system requirements are worked out. After that, some 'functions as real' concepts are further worked out into CAD models to present various concept solutions to the client.

6.3 Paint Sprayer

For a client their current paint spray product is compared to a competitors paint sprayer to asses performance differences and advice on areas of improvement. Work included the development of a test setup, developing an experimental test plan focused on reliability and repeatability, performing various experiments, relating test results to fluid mechanics calculations and reporting suggestions for improvement to the client.

6.4 Pur foam alternative

For a client an alternative to pur foam is researched. Tasks included testing foaming performance of various mixtures and the development and testing of a foaming setup to find the optimal system configuration.

7 Other activities

Engineering training sessions

In PCV Group I was lucky to be able to take part in a carousel of courses in weekly training sessions. In these training sessions the most important principles of certain areas of expertise, and ways of working within PCV Group are explained to (mostly new) employees. Training sessions themes include: coffee, milk foaming, sealing, pumps, CAD principles and guidelines etc.

CAD Course

In order to improve Solidworks drawing skills, an online Solidworks course was followed. This allows me to work in large assemblies in an organised and integrated way, using advanced features, and being able in producing prototypes effectively.

Hannover Messe Industrie

Together with three colleagues I've been part of a team to explore the Hannover Messe Industrie for new opportunities in technology and exciting market trends with regard to PCV Group. In exchange for the trip I was tasked with ensuring that the things we learned and saw were passed on to PCV Group as an organisation. This was done by presenting the relevant opportunities and trends at PCV Group during a 15 minute talk. As a direct result, many prototypes within PCV Group now make use a new production method, namely Multijet Fusio (MJF), instead of Selective Laser Sintering (SLS). This is because of improved mechanical properties, reduced cost, heat resistance and water tight properties.

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A Project Carlo: Project Charter

Project charter: Carlo – Uniform coffee bed implementation brew chamber

Project name: Carlo - brew chamber uniform coffee bed implementation Date: 5-02-2019	Client: PCV group Project manager: Daniel Brummelman
Project description:	Project goal and financial impact (business case)
Carlo has been developed as a dispensing and dosing platform that is constantly being developed so that it can be used both internally and externally to show which competences and technologies PCV has in house. The Carlo will be improved by the implementation of new technology in the brew chamber. This is done in the form of a method to prepare the coffee bed more uniformly for percolation. This method performs automatically what professional baristas do manually to homogenise the coffee bad and this will improve the espresso quality. The implementation of this technology in Carlo can be used as a showcase for the implementation in commercially available fully automatic machines.	The development of a brew chamber for Carlo with the functionality for uniformly producing the coffee cake for percolation. - 2019: Improvement of Carlo's performance through integration of an improved brew chamber. Budget: - 14 weeks < €1000
Project scope (and delimitations):	Stakeholders:
In scope 2019 – Prototype of a brew chamber for Carlo with added functionality. Out of scope 2019 – Production method and implementation in current machines on the market.	• PCV Marketing & Sales - Demonstration model • PCV Group general - Technology and competence development • PCV Employees - Learning and challenging project • PCV Internship - Internship assignments on level, guidance and support
Project results (most important deliverables, KPI's):	Most important activities, timing:
• Aantonen van kwantitatie verbetering uniformiteit in Carlo • Praktische kennis voor het ontwikkelen van een volautomatisch espressomachine met technologie voor het verbeteren van de uniformiteit van de cake.	February 2019: start development prototype
Total project team members:	Attention points:
• Clients: Fred and Bart • Project manager: Marc • Quality control: Daniël • Internship supervision: Daniël (personal), Jelmer (technical) • Intern: Sjoerd • System architecture / Coffee specialists: Jelmer and Hedzer) • External specialists: n.a.	• Attention to a good system architecture • Enough progress despite all other priorities • Sufficient quality for the intended purpose (Experience that often a complete redesign must be made at the end)
Review- and communication plan:	Approved by:
Internal: Bi-weekly core team meeting tussen stagiar en opdrachtgever en project manager	Name: Daniël Brummelman Position: Quality control Paraph: Date:

1

Figure A.1: Project charter: Carlo

B Project Carlo: Pre-Analysis

Fully automatic coffee machines

A fully automatic coffee machine consists of many different parts to mimic all operations a barista would do by hand to produce Espresso Coffee (EC). These parts are schematically depicted in B.1 First, coffee beans are transferred from a hopper to a grinder to process the beans to ground coffee. This ground coffee is than transferred into the brew chamber in which the ground coffee is compressed to a coffee bed. A water reservoir connected to a pump and heater then forces pressurised hot water through the coffee bed. This process is known as percolation which is the stage that is crucially contributing to the beverage's qualities [5]. During percolation extraction of the coffee bed occurs after which the extracted fluid, now called coffee, flows into a cup.

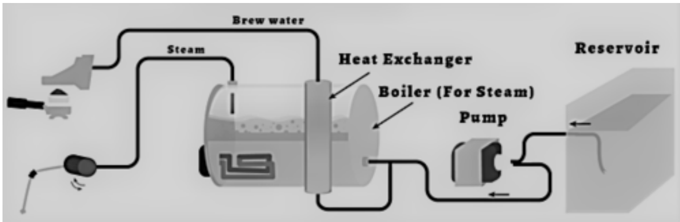


Figure B.1: Heat exchanger coffee machine schematic

Definition of Espresso Coffee

Espresso is coffee of Italian origin, brewed by expressing or forcing a small amount of nearly boiling water under pressure through finely ground coffee beans. Espresso is generally thicker than coffee brewed by other methods, has a higher concentration of suspended and dissolved solids, and has crema on top (a foam with a creamy consistency). [5] As a result of the pressurised brewing process, the flavors and chemicals in a typical cup of espresso are very concentrated.

The Science of Espresso Coffee

Scope

The scientific principles behind the art of coffee making is a topic readily discussed in forums, books and scientific papers. Ultimately EC quality is influenced by the entire trajectory from soil to cup in which the plant, raw bean, roasting, packing, grinding, percolation and even the cup itself play a role. This research will be limited to the science influencing a cup of Italian Espresso Coffee in the percolation phase.

Percolation

During the process of percolation pressurised hot water flows through the coffee bed extracting soluble and insoluble particles from the ground coffee resulting in brewed coffee. In an EC machine this process takes place in the brew chamber where ground coffee is compressed to a coffee bed, wetted and subsequently percolated. In this process various parameters play a role.
The process parameters of Italian EC are bound according to Illy and INEI (Instituto Nazionale Espresso Italiano) by the parameters in table B.

	Illy	INEA
Portion of ground coffee [g]	6.5 ± 1.5	7 ± 0.5
Water temperature [°C]	90 ± 5	88 ± 2
Water pressure [bar]	9 ± 2	9 ± 1
Percolation time [sec]	30 ± 5	25 ± 5
Volume in cup [ml]	25 ± 5	25 ± 2.5

Table B.1: Italian Espresso Coffee process parameters [5][10]

Quantifying flavour

The solubility of various flavour molecules in an important scientific principle for Espresso Coffee. There are two main concepts involved in solubility, referred to in the industry as Total Dissolved Solids (TDS) and Extraction Yield [6].

- **Strength**: Solubles concentrate. The strength of the brew is indicated by the percentage of Total Dissolved Solubles (TDS) in the coffee. A higher TDS value indices more solubles and therefore stronger coffee. Levels that are too high or too low indicate overextraction or underextraction respectively.
- **Extraction**: Solubles yield. The extraction yield refers to the percentage of coffee material that has been removed from the coffee ground.

Together these two parameters can be used to form a the brewing ratio chart in figure B.2. Here, the grey area indicates the general sweet spot for a cup of espresso. One could assume that a strong coffee is also overdeveloped. This is a misconception, as the brewing chart shows that an espresso can be strong yet underdeveloped. In general smaller particles have a larger contact area per unit mass and are therefore more easily extracted.

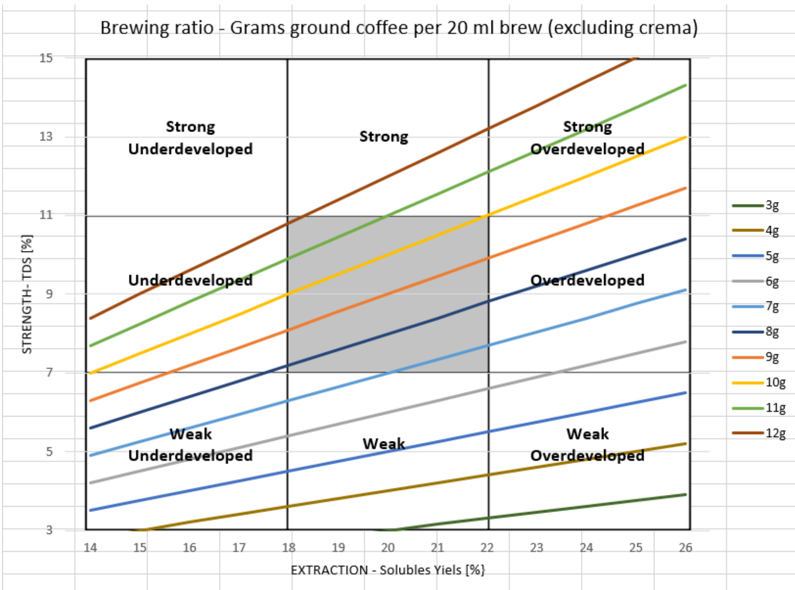


Figure B.2: Espresso brewing chart

Over- and underextraction can be related to flavour of the espresso. Ted Lingle [8] grouped the solluble coffee flavours by molecular weight.

- **Fruity Acids** With floral and fruity aromas are the lightest flavour molecules and extracted first.

- **Maillard Compunds** By-products of the roasting process with a nutty, toasted grain or malty flavour are extracted second.
- **Browning Sugar/Caramel** In the roasting process most of the sugars are caramelised. These introduce sweet vanilla, chocolate and caramelised flavour and take longer to extract.
- **Dry Destillates** These are more prominent in darker roasts and give a ashy, smokey, carbon or tabacco like flavour. Slowest to become soluble.

Crema

Espresso brewing produces a by-product unique to the method used for extraction: crema. Due to the high pressures in combination with the outgassing of carbon dioxide that occurs in freshly roasted beans, non-soluble fats inside the coffee ground are emulsified.

Relevant percolation parameters

Extraction is influenced by many parameters. Controlling these parameters is of upmost importance to ensure a consistently well made EC. The most important are listed shortly.

- Cake parameters
  - **Ground coffee weight**[w] The total weight of ground coffee influenced by the grind process.
  - **Cake dimensions** height and radius [h, w]. Ideally $h/w \approx 0.2$.
  - **Cake porosity** expressed as fraction void [ϵ]. Influenced by the particle size and compacting force.
  - **Particle size distribution**. Influenced by the beans, grinding method and post handling.
  - **Cake permeability** [Q]. Influenced by the particle distribution, cake porosity and dimensions.
- System parameters
  - **Water pressure** [p]. Although pressurised by a pump the cake water resistance strongly influenced the water pressure.
  - **Water temperature** [T]. Solubility of the solubles is highly dependent on water temperature.
  - **Water flow velocity** [v]. Ideally kept as constant as possible.
  - **Percolation time** [t]. Ideally around $25s$

Relating percolation parameters and flavour

Now that most parameters and their influence on the flavour is known globally. A so called 'Espresso Compass' given in figure B.4 can be constructed to help baristas. This is used for finding the correct parameters of the complex system in order to make good EC.
When the percolation time is set ($\approx 25s$) with the desired volume of EC $\approx 25ml$ this gives the ideal needed flow velocity. This flow velocity however depends on the water pressure in combination with the water resistance according to Darcy's law for fluid flow in the pore space given by:

$$v = -\frac{Q(\epsilon, d_p)}{\mu} p \tag{B.1}$$

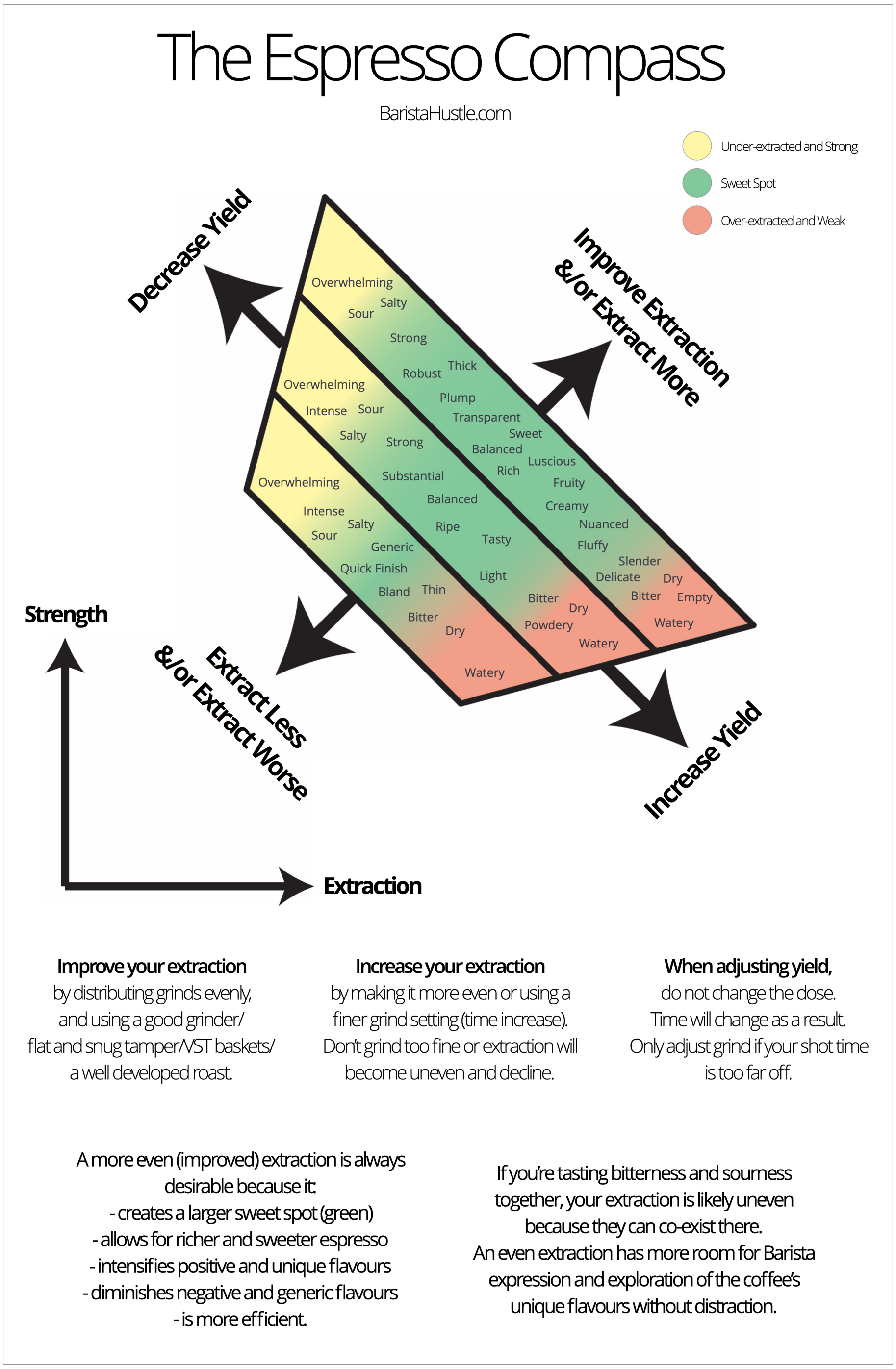


Figure B.3: Espresso Compass [17]

Where Q is the permeability dependent on porosity ϵ and particle diameter d_p. μ is the fluid dynamic viscosity. This relation does not hold exactly in the percolation process as it holds only for $Re < 1$. It does however indicate that the parameters are related.

Governing parameter relations

In conclusion the pressure p and permeability Q must match in order to get the correct flow velocity v. However for EC the p is also generally required to be in a small range to ensure proper crema and extraction. Moreover in commercial machines control over the pressure is generally absent and are therefore flow-controlled rather then pressure controlled. Therefore the permeability is the only unset variable which must be set such that it satisfies the boundary conditions.

This gives rise to the need for controlling the coffee cake parameters to result in the required cake permeability Q for a desired pressure p. Of these parameters the cake width dimension is set by the brew chamber. The cake porosity is set by the grinder and compacting force. The particle distribution is influenced by the grinding process and subsequent handling on the ground coffee as larger and smaller particles mix and unmix when actuated.

Crema Valve

Because cake permeability is hard to control many modern machines use a special crema valve. This valve is used to set the desired pressure and produces crema by creating a cyclone where the fluid mixes with drawn in air to emulsify with the coffee drink. Subsequently the coffee cake no longer has to provide a certain permeability in order to get correct water flow and pressure. More traditional machines omit this crema valve.

This crema valve however does not solve the other problems of an undefined coffee bed:

- Varying global cake porosity due to varying bed height and corresponding varying cake porosity.
- Varying global cake porosity due to varying compacting force means a varying global cake bed resistance causing a varying pressure drop over the cake bed which influences the global extraction of the cake bed.
- Varying local cake porosity and particle distribution causes local changes in cake permeability which induces varying local water flows such as channelling causing local over- and underextraction.

The global variances are mostly governed by the cake dimensions before compression as well as the compression force. The local variances however are caused by differences in particle distribution which in mixing terms is known as segregation.

Mixing

To understand the variance of local particle distribution an overview of the basic concepts of mixing and segregation is presented. In many systems, particles tend to exhibit segregation (demixing). Three mechanisms of segregation due to difference in particle size may be identified [9]:

1. Trajectory segregation: When a small particle with its drag governed by Stokes law with diameter x and density ρ is projected horizontally with a velocity U into a fluid with viscosity μ_f the limiting distance that it travels horizontally is $\frac{U\rho_p x^2}{36\mu}$. This means that a particle with twice the diameter would travel four times further in the same system. This mechanism causes particles to segregate when caused to move through air for example when they fall down from the grinder.
2. Percolation of fine particles and rise of course particles: If a mass of particles is disturbed such that individual particles move, gaps are created such that smaller particles fall down and push larger particles up. This way a rearrangement in the packing of the particles occurs. This occurs with most shaking and vibration like movements of ground coffee.

3. Elutriation segregationNn: When a powder with very fine particles ($< 50\mu m$) is discharged into a confined space, air is displaced upwards through the powder. The upward velocity of air caused the finer particles to remain in suspension after the larger particles have settled creating a pocket of fine particles atop the larger particles. Although coffee ground consists of considerable amounts of fines ($< 50\mu m$) this mechanism rarely occurs in EC machines the upward stream of air does rarely occur as spaces are generally spacious when compared to the amount of amount of ground coffee falling through.

In free-flowing powders such as ground coffee, shear and diffusive mixing give rise to the mechanisms of size segregation and are therefore unsuitable. For such powders convective mixing is the major mixing method.

Local volume measurement

Other (pseudo) scientific tests have been conducted by others to quantify coffee bed homogeneity. One uses a circular tool to measure volume output per section of the portafilter. Each section has equal surface area and therefore a good distribution should have a relatively equal amount of coffee in each segment [14]. A similar measurement tool is developed to be used with the same espresso coffee machine as used in Appendix C. Ultimately, the developed local volume measurement tool is not used to quantify coffee bed homogeneity. It could be useful for future use however.

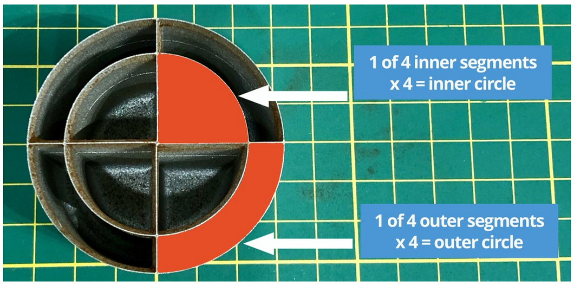


Figure B.4: Section tool [14]

C Project Carlo: Initial height distribution influence test

A test is performed to determine the significance of a different height distribution in a coffee bed.

Materials

Materials used are:

- Coffee machine with integrated grinder and pressure valve and gauge, Quick Mill 3135 with grind setting at 10 to 12 o-clock and pressure set at $9,5$ bar.
- Bottomless portafilter, dimensions $58 * 26mm$
- Beans, Pelikaan Koffie Brasil Santos
- Tamper, diameter $57,5mm$
- Scale 0-12 kg, KERN GAB 12K0.1N
- Scale 5-3100 g, Mettler PM3000
- TDS measurement, VST Lab Coffee Refractometer
- Plastic cups, syringes and

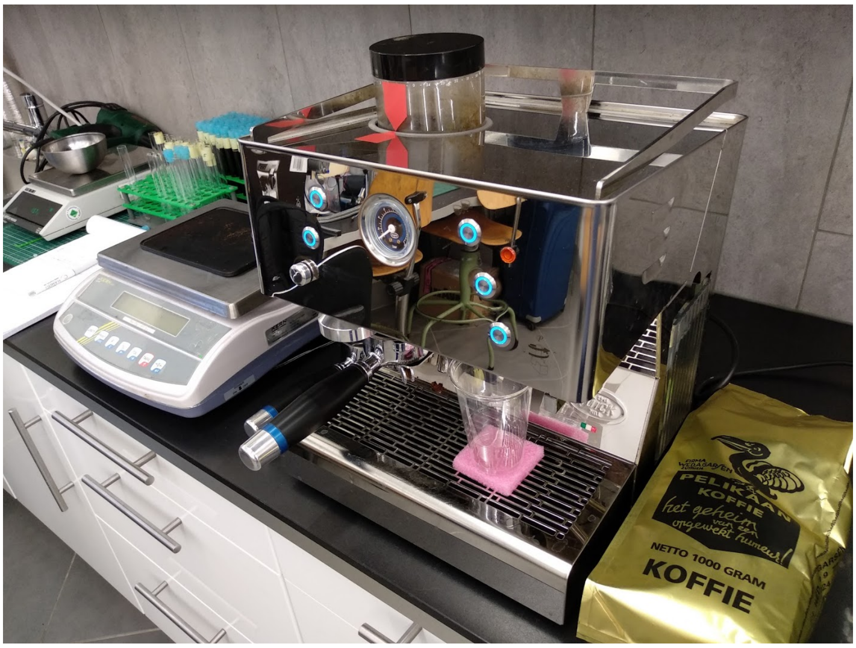


Figure C.1: Test setup

Method

Three distinct height distributions shown in figure C.2 are considered.

1. Even height distribution.
2. Tilted height distribution.
3. Cone shaped height distribution.

Height distribution 1 and 2 are realised by hand. Distribution 3 is realised by not changing the output generated by the grinder. First, the amount of ground coffee produced by the grinder is tested by making and weighing 3 ground coffee samples. Subsequently for

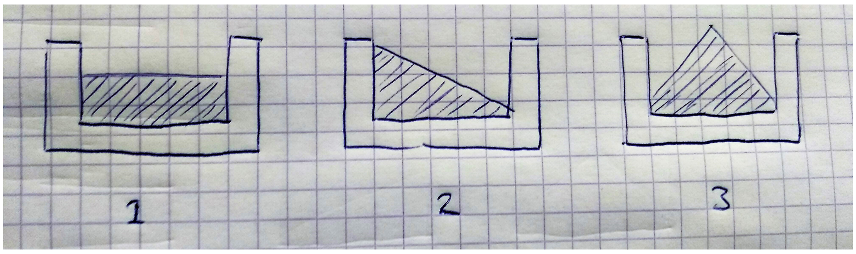


Figure C.2: Schematic height distributions

each distribution 3 samples are tested. For each sample the grinder provides ground coffee after which the desired height distribution is realised. The tamper is used to tamp each distribution with $10kg$ of force. Then, the bottomless portafilter is used to brew a double espresso. In the brewing process the bottom of the portafilter is filmed and the water pressure gauge is monitored. The resulting brew volume is measured immediately. Subsequently the brew is stirred before a sample is extracted from the middle (height and diameter wise) and put in a test tube with cap while still hot to limit evaporation. The test tubes are then allowed to cool down to room temperature. TDS measurement is done by extracting and injecting the test tubes into a syringe twice to ensure proper mixing before performing TDS measurement.

Results

The amount of ground coffee produced by the grinder is $16g$ on average with a standard deviation of $0,75g$. Due to the large deviation a batch of coffee ground is produced and samples of $15g$ taken for each test sample.
From weighing the puck weights the average amount of water held by the coffee bed after extraction is $15,3g$ which is used to update figure B.2.
Only height distributions 1 and 2 were tested ultimately. The results are shown in table C. The goal was to determine the influence of the geometry of the coffee bed and to see whether this influences the measured parameters. The averages for the test are given in table C. The yield % and TDS % do not show a significant difference.
Additionally, the visual parameters such as the amount of observed jets and centrality of the outflow of the brew show no correlation with the tamp method. Jets are an indication of channelling while an off center outflow indicates global differences in flow velocity over the extraction bed.

Tamp	Yield %	TDS %	Jets nr	Center stream 1-5
1 Straight	0,239	4,60	3,00	3,33
2 Tilted	0,235	4,75	2,50	3,33

Table C.1: Sample averages

Taste

As a side note the samples were tested for taste. The test subjects were not trained for espresso tasting but noticed a significant difference between the tilted and straight coffee

		Physical parameters								Visual parameters	
Tamp	**Sample nr**	**Ground g**	**Tamp kg**	**Time s**	**Pressure bar**	**Brew g**	**Puck g**	**Yield %**	**TDS %**	**Jets nr**	**Centered 1-5**
1 Straight	**1**	15,0	10,0	x	9,5	76,4	31,2	0,241707	4,40	2	5
	2	15,0	10,5	33	9,5	71,4	30,4	0,240456	4,66	3	3
	3	15,0	10,8	27	9,5	68,4	30,5	0,234608	4,73	4	2
2 Tilted	**1**	15,0	10,0	27	9,5	66,8	x	0,2184	4,50	2	4
	2	15,0	10,0	30	9,5	63,7	x	0,244879	5,27	4	2
	3	15,0	9,8	30	9,5	66,8	x	0,246064	5,07	3	4
	4	15,0	10,2	22	9,5	73,9	32	0,234906	4,41	2	2
	5	15,0	10,1	42	9,5	66,9	27,8	0,226476	4,66	1	3
	6	15,0	12,0	37	9,5	72,8	30	0,240603	4,58	3	5

Table C.2: Results of test samples with tamp 1 and 2

beds. The tilted coffee had significantly more sour and bitter flavour which indicated both under and overextraction.

Conclusion

The tested parameters, Yield %, TDS %, number of jets and location of the center stream did not differ significantly between tamp type 1 and 2. Based on this the conclusion should be that the significance of the height distribution of the coffee bed cannot easily be described by the tested parameters although taste testing did indicate a difference between the two tamp methods.
The jets that occurred indicated that both coffee beds were imperfect. This could be due to grind size and amount of coffee used.
Additionally the measured yield and TDS values indicate a weak and overdeveloped EC according to figure B.2. The ratio between amount of coffee ground and amount of brew should be adjusted.

D Project Carlo: Concept solutions for a uniform density distribution

There are various methods and tools that are used by baristas or industry to create an equal bed height of granular matter such as coffee ground. Baristahustle came up with a distribution tool [1] named the 'Hog', shown in figure D.2 which resembles a hairbrush but with equally spaced metal pins. A highly regarded tool is the OCD distribution tool in figure D.3 which is sold for over 150 USD.

Figure D.1: Generic coffee distribution tool

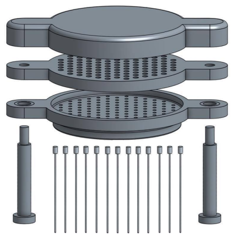


Figure D.2: The 'Hog' [1]

Figure D.3: OCD distribution tool [12]

In industry various other methods are used to mix granular matter such as a ribbon blender, nauta blender or an impeller blender shown in figures D.4, D.5 and D.6.

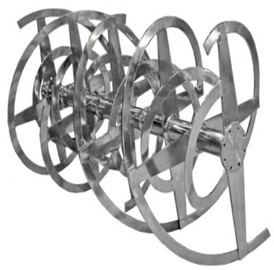


Figure D.4:Ribbon [16]

Figure D.5: Nauta [11]

Figure D.6: Various impeller blenders [3]

E Project Carlo: Concept Generation

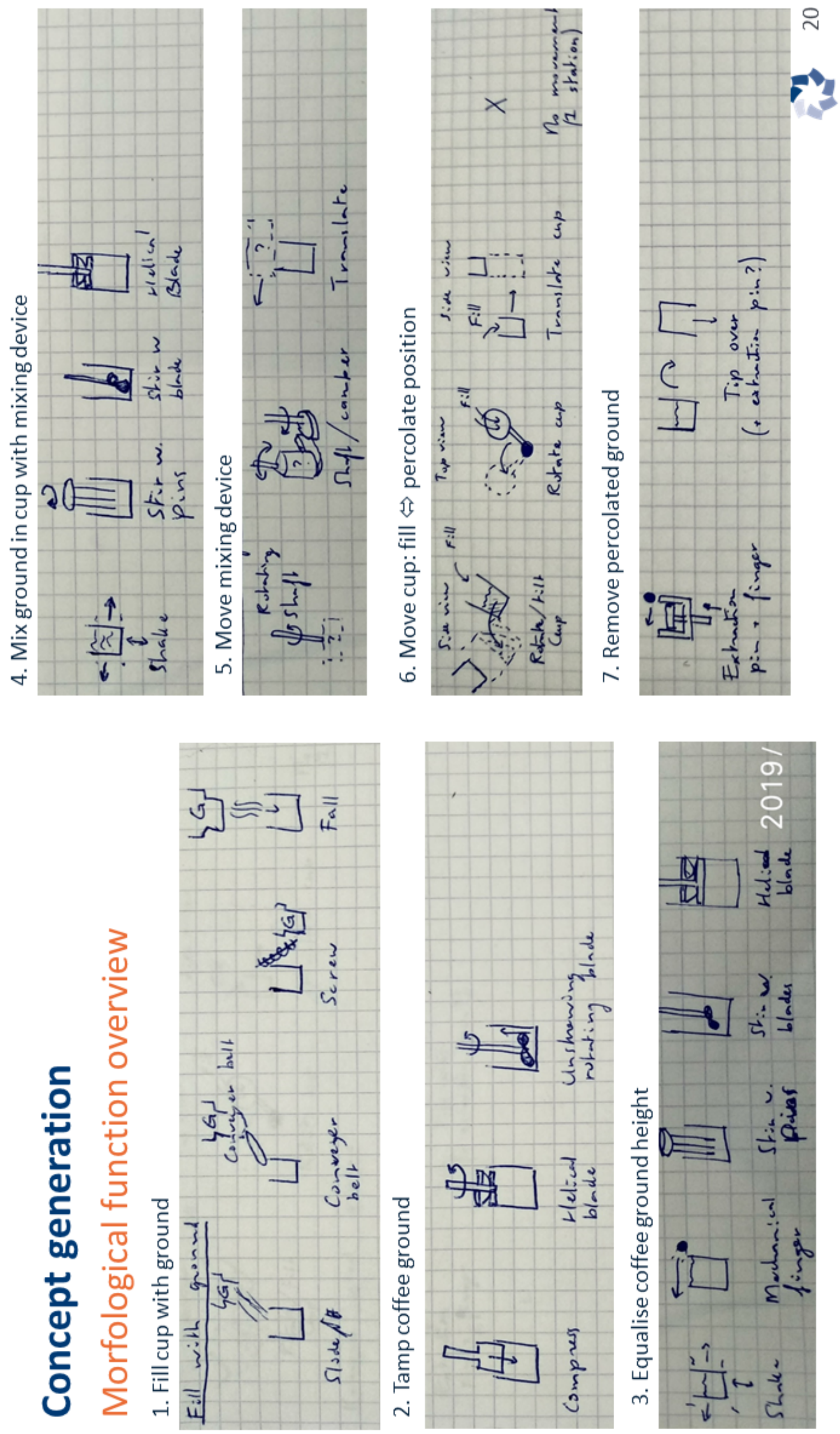


Figure E.1: Morphological overview

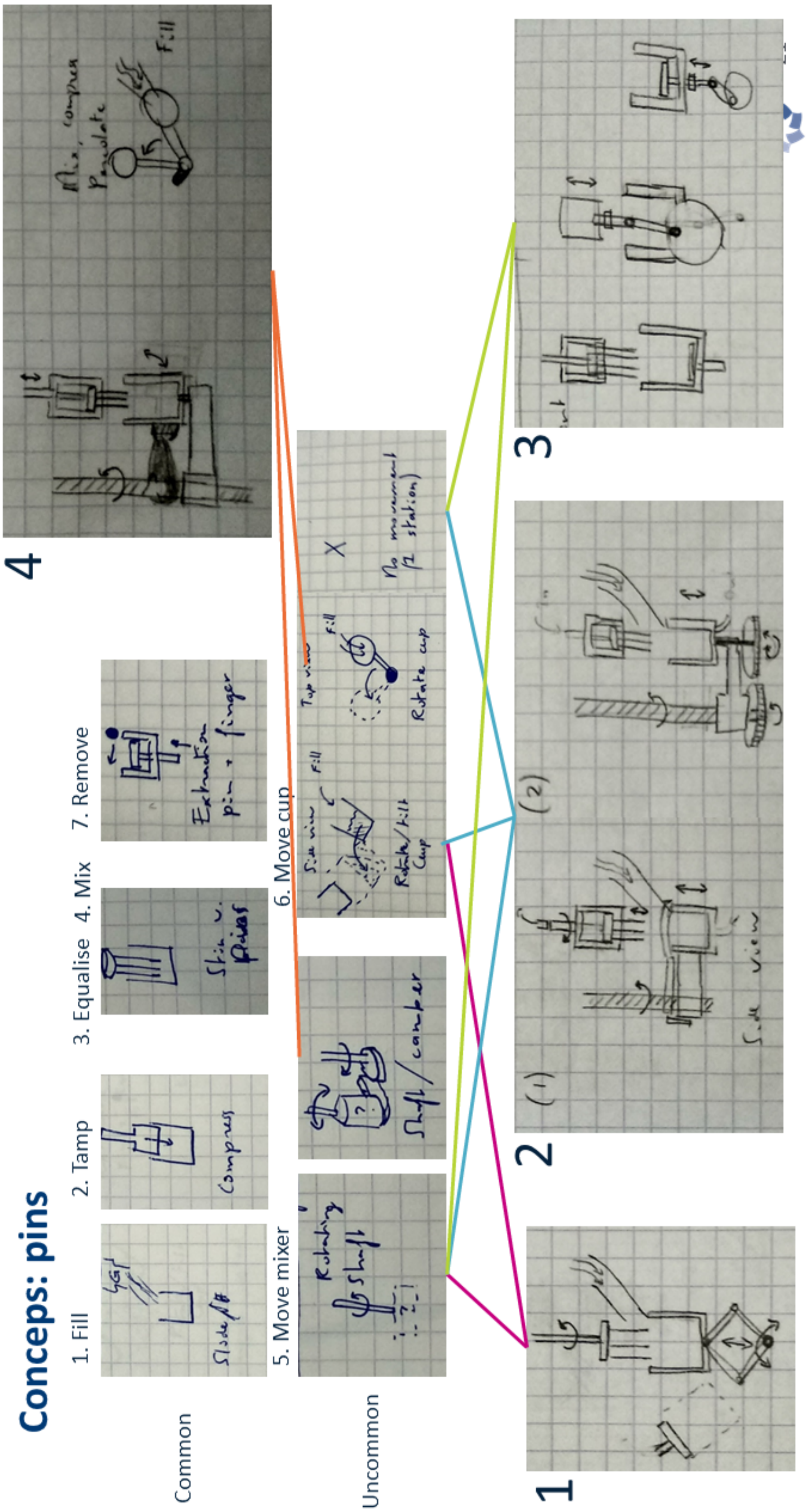


Figure E.2: Concept 1-4 based on pins end-effector

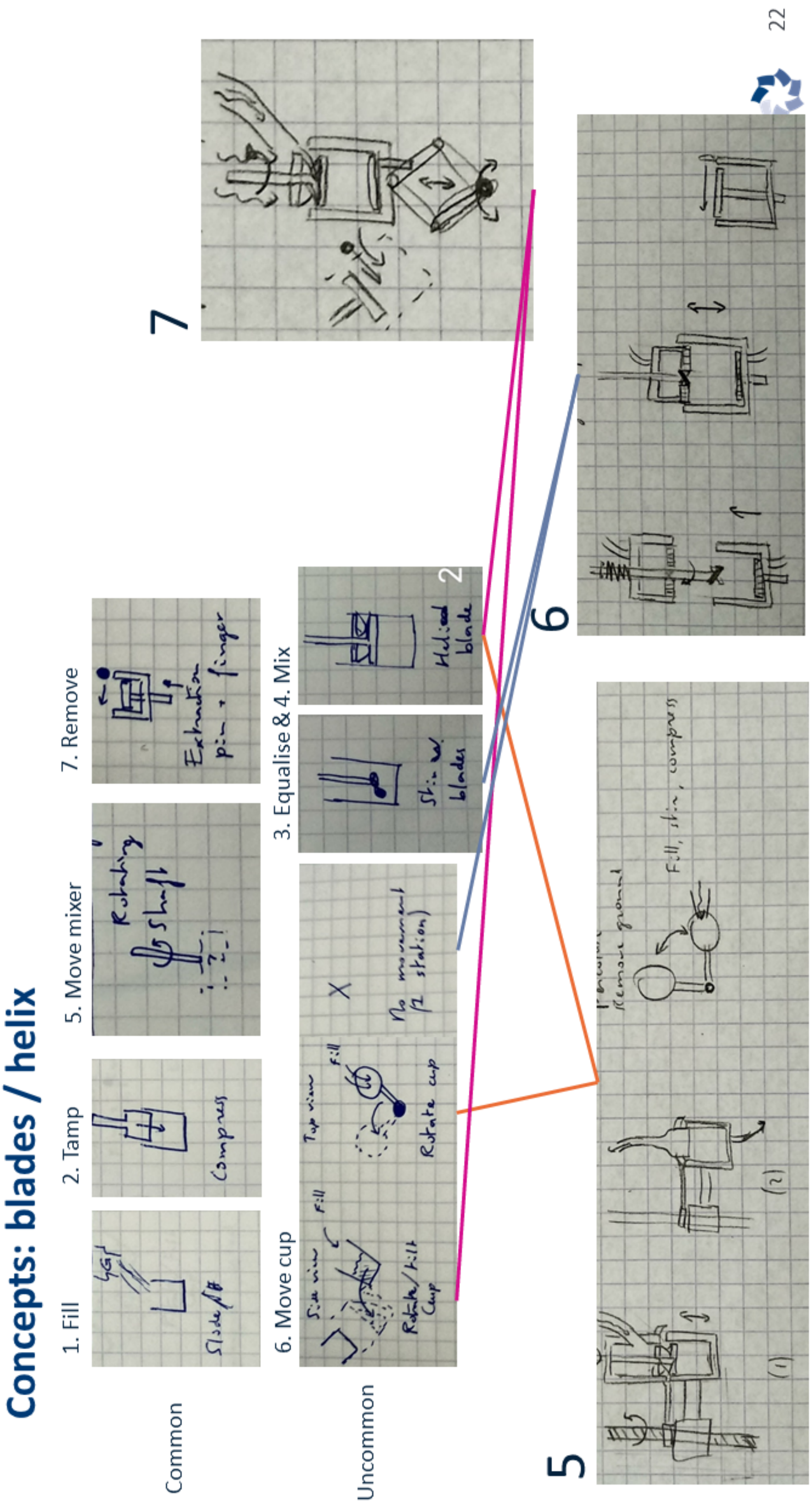
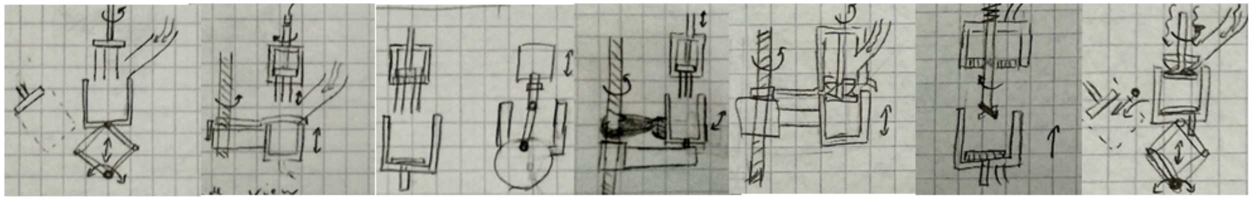


Figure E.3: Concept 5-7 based on blades end-effector

Concept selection, score chart



Concept selection	1	2	3	4	5	6	7	Weight
	Pins 2 station	Pins 1 or 2 station	Pins 1 station	Pins 1 or 2 station	Helix 2 station	Blades 1 station	Helix 2 station	
Motors	3	3	3	3	3	3	3	15
Seals	3	3	2	3	2	2	3	15
Parts	3	2	3	3	2	3	3	20
Complexity	3	2,6	2,7	3	2,3	2,7	3	50
Dimensions	3	2	4	2	2	4	3	20
Prototype Flexibility	4	2	2	3	3	1	4	30
	3,3	**2,3**	**2,75**	**2,8**	**2,45**	**2,45**	**3,3**	

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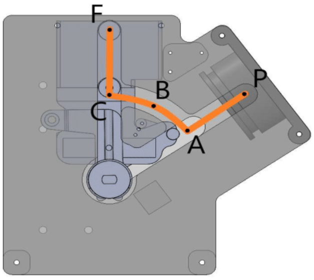
Figure E.4: Concept selection score chart

F Project Carlo: Function status overview

Statusses	Score
does not work / untested	1
sometimes works how/why partially unknown	2
works although how/why partially unknown	3
fully works how/why partially known	4
fully works and is fully understood	5

Fuction	VI	VII	VIII
I. Basic function	**1**	**5**	**5**
a. Move coffee ground into chamber	1	5	5
b. Hold coffee ground in brew chamber	1	5	5
II. Movement	**3**	**4,25**	**5**
a. Perform full brew chamber motion	5	3,5	5
1. Move brew chamber from Percolation position (P) to A and vice versa	5	5	5
2. Move brew chamber from A to B and vice versa	5	2	5
3. Move brew chamber from B to C and vice versa	5	2	5
4. Move brew chamber from Fill position (F) to T and vice versa	5	5	5
b. Rotate end effector at desired RPM	1	5	5
III. Equalising and tamping	**1**	**3,611111**	**4,277778**
a. Equalise coffee ground to <1mm height difference	1	4,833333	4,833333
1. Equalise coffee bed heigth for minimum dose of 7g of coffee ground	1	5	5
2. Equalise coffee bed heigth for mean dose of 10.5g of coffee ground	1	5	5
3. Equalise coffee bed heigth for max dose of 14g of coffee ground	1	4,5	4,5
b. Tamp coffee bed with force F > 6kg	1	2	3
c. Mix the ground coffee with a mixing device	1	4	5
IV. Percolation	**1**	**1**	**3**
a. Seal brew chamber and used bed extractor axle at 9 bar	1	1	3
b. Seal brew chamber and percolation head at 9 bar	1	1	3
c. Percolate water of 100 deg through coffee bed at 9 bar	1	1	3
V. Used coffee removal	**1**	**1,75**	**1,75**
a. Remove coffee ground from the brew chamber	1	2,5	2,5
1. Coffee ground removal axle can move through seal	1	3	3
2. Coffee ground removal lever can translate force from blocker to axle	1	2	2
3. Blockers moves ground removal lever to correct position	1	1	1
4. Ground removal axle is moved to compressed state during filling	1	4	4
b. Flush residual coffee from brew chamber	1	1	1

Movement diagram



G Project Carlo: Prototype setup

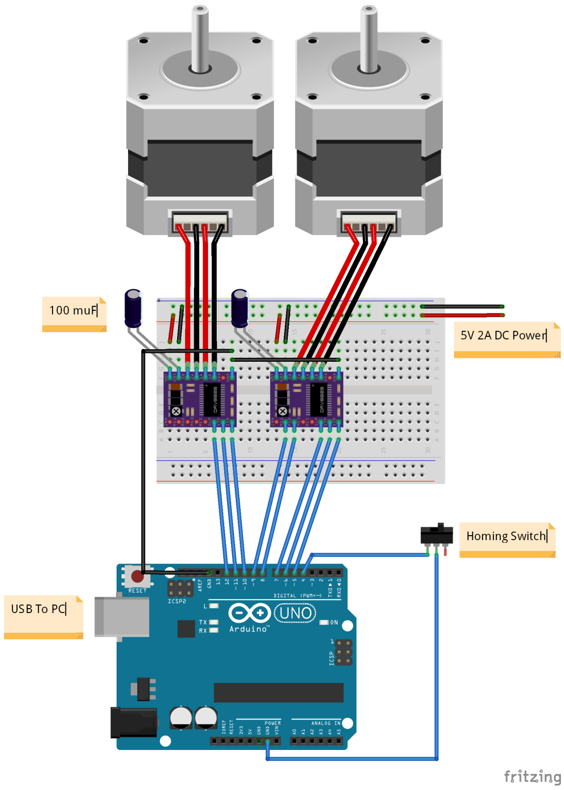


Figure G.1: Wiring schematic

Materials

- Prototype V3 assembly
  - 2x ST4118L1804-A stepper motors 3.15V 1.8A
- Electronics
  - Arduino Uno
  - 2x DRV8834 stepper driver
  - Homing switch
  - 2x 100 microfahrad capacitors
  - Dupont cables
- Power supply 5V 2A DC Power
- Pressurised hot water source
- Ground coffee

Use

Setup the prototype according to the wiring schematic. Disable the power supply and connect the Arduino USB to a PC and establish a Serial connection to the Arduino that communicates at 9600 baud. Now, reset the Arduino and check in Serial monitor if homing starts, then enable the power supply output to start homing. Follow Serial instructions.

H Reflection Report

The learning goals were an integral part of the internship. As such, they can be found in the main report in chapter 4. Below, for each learning goal one situation is described below which typically occurred in one project. Please note that in practice learning goals were achieved in more that one project in most cases and that these additional cases are not described.

H.1 Reflection on learning goals

Soft skills

- **Stakeholders:** With regard to stakeholders from the viewpoint of consultancy I learned a lot from the project with the paint sprayer. With the lead engineer we were tasked with verifying the problem that the client had with the spray performance. The client set out a design project to design a new system which they thought would improve spray performance. As the understanding of the system improved we figured that the client had a solution in mind that was not inline with what the actual problem was. I was tasked with understanding and explaining the physical fluid mechanics that caused the problem to the project team such that the client could be properly informed and project goals redefined. I showed the technical team the technical issue by working out calculations and explaining them, then, together with the technical team the project lead was assisted in conveying the problem to the client. The project was then shaped more towards a root-cause-analysis with recommended areas of improvement instead of a design project. The biggest learning here was aligning all stakeholders with the found issue and defining a new goal. This alignment is of great importance and should be kept in mind in future project.
- **Phases of product development and development tools:** In project Carlo the starting phases of product development were worked through and corresponding tools were used. Examples of tools are the Critical to Quality assessment to help with project scope and requirements and the TRIZ function analysis to come up with concepts. The phases include the prototype phase with Proof of Function (PoF) and Works-Like-Real (WLR) milestones. To be able to perform these tasks I've consulted employees in all layers of the organisation (from management and experts to workshop employees) for tips and help and participated in internal training sessions. This way I became aware of the available tools, and effectively knew whom to ask questions. The outcome was a very structured way of product development taking into account all stakeholders while working in an effective manner. The used development tools are excellent tools for future use to work effectively in projects and development.
- **Type of work:** During the internship I've done testing, analysis, team projects, solo projects in many phases of product development. Undergoing these different ways of working has shown me that the phase of development and the task at hand is not that important, but rather the way of tackling these tasks. I've realised that I really like a combination of facets of working and to combine these in an agile way to find an effective solution. This means performing tests when needed, organising a brainstorm with colleagues when required, working out an elemental problem in an academic way if necessary, and relying on experts when dealing with a concept not easily grasped. Working in a team enables this flexible approach more easily and as such is my personal preferred way of working for future work.

- **Time management:** In project Carlo time management was an issue as too many tasks had to be done in too little time. I've tried to prioritise tasks by consulting stakeholders and informing them on possible underdeveloped areas due to time limitations. The result was that stakeholders knew which tasks had my priority, what possible risks were and in that way could give effective feedback in those areas. Also, I've asked my personal supervisor for assistance in planning to make use of his engineering experience to formulate a realistic planning. This way I could asses which tasks took more, or less time than planned and again inform stakeholders on progress and readjust goals in time on time. Communication was key in time management and I would like to take this by heart in future work.

Hard skills

- **CAD:** As project Carlo involved developing a prototype, I knew that CAD design and production would eventually be required. To be able to do this I've asked my personal supervisor for a CAD course such that I could improve my CAD skill to the level required to effectively develop and produce a functional prototype. In hindsight this CAD course was an effective way of improving my skill before actually using it in a project. Considering the amount of hours spend in CAD this was definitely worthwhile. In the future I should consider doing a course on any skill that will likely pay itself off with interest with regard to time.
- **Testing:** I've done tests for the paint sprayer project (6.3) and the alternative to PUR foam project (6.4). I've performed these tests in such a way that the main process parameters were found and examined in an academic approach. However, most of the time there was no budget for extensive pre-analysis and thus testing was aimed towards finding these parameters by setting up a wide test program at first and then focusing on areas of interest. As a result, the project teams understood the problem better and could work towards a solution in conjunction with the client more effectively. However, sometimes important physical phenomenon were not understood or simply unknown during testing and only afterwards were seen as important. In future work, I would insist on doing a limited pre-analysis to be able to develop an initial test plan besed on more than previous experience and the knowledge of the client alone. This way, a better overview of relevant physics is established before focusing on certain areas.
- **Coding:** For project Carlo I've coded an Arduino to control the prototype, which runs on a programming language based on C with code structures similar to Matlab. For this, I've not done a course but translated my knowledge in Matlab to Arduino by looking up examples and using extensive function documentation to learn the relevant Syntax rather than code structure. This was effective in this case as code was not too complex, however C and other coding languages can be way more complex and for those instances dedicated courses are advisable.
- **Field of expertise:** For project Carlo I've used basic electronics to implement a micro controller with motor drivers to drive the prototype. Also, this prototype was to be visually appealing and as such user aspects came into view which are typical to Industrial design. For both cases, I've asked experts on the subject to formulate their opinion of the solution proposed and used their feedback to improve. By trying myself first, and then asking checking the proposed solution with experts I was more knowledgeable about the subject, which enabled them to give feedback on a slightly higher level. If time allows, this approach is an effective way of learning new skills quickly in the future and checking if the delivered level is good enough. If time

is short however or if the task at hand is too complex, it is more effective to let an expert perform the task at hand.

H.2 Analysis of supervisor's feedback

Regarding professional behaviour the feedback of the external supervisor is evaluated.
An appearing theme in the feedback by Daniel is the enthusiasm for technology. This enthusiasm is supported with a theoretical skillset and a pro-active approach to dealing with technological challenges. This was received very well and any missing skills were identified and dealt with. Another theme is communication. Daniel comments that the way of communicating is clear, structured and that feedback is taken seriously in addition with easily being able to deal with a flexible working environment. Third point is time management which was in general coped with very well. I am in agreement with these statements and they fit the reflection on the learning goals.
However, a pitfall here was that the technological drive could interfere with the way of communication, especially when time ran out. For future work I should remind myself that communicating should remain top-priority when dealing with challenging tasks under time pressure.

H.3 Future learning goals

For the future leaning goals I've tried to translate the results of the supervisor's feedback and personal reflection on the learning goals into new learning goals.

Soft Skills

- **Improve in teamwork.** The reflection on the type of work and feedback provided by the supervisor indicates that working in a team is a great strength and my personal preferred way of working. I would like to stay focused on improving in teamwork. This includes:
  - Communication skills, such as communicating clearly, in a professional and understanding way.
  - Managing stakeholders, by aligning everyone involved on status and goals, and keeping all noses in the right direction.
  - Showing leadership, in being able to steer a team towards a possible solution route in a self-confident manner while taking the expertise and opinion of others into account.

  The next step in my studies is graduation. As graduation is in essence an individual tasks it will be relatively hard to improve in teamwork. However, I hope to communicate with professor and experts in a teamwork oriented way and implement the soft skills mentioned above.
- **Time management.** I would like to improve in time management for larger projects in situations where I cannot rely on experts. In my internship I've had excellent supervision with regard to time management, however I realise that this will not always be the case and as such must be self-managing in time management. I will try to implement this in my graduation project by making weekly plannings and reflecting on those with supervisor or personally.