



**CHALMERS**  
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# Development of an Innovative Spray Device for Slimline Dishwashers

Addressing Spray Limitations in Space-Constrained Designs

Master's thesis in Product Development

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2025

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MASTER'S THESIS 2025

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Cover: The complete assembled concept Fridge Organizer developed in this thesis, rendered in CATIA.

Typeset in L<sup>A</sup>T<sub>E</sub>X  
Printed by Chalmers Reproservice  
Gothenburg, Sweden 2025

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## **Abstract**

This thesis investigates how water coverage can be improved in new slimline dishwasher models by developing an innovative spray device concept. Slimline dishwashers are valued for their compact size but often face limitations in cleaning performance due to restricted water distribution. The project followed a structured design methodology, including generating product specifications, concept creation, concept selection, prototyping, and testing. Several promising design concepts were explored, with one in particular demonstrating superior spray coverage while remaining viable across multiple evaluation criteria. The findings suggest that more effective dish-cleaning solutions are possible through targeted design improvements that address the unique challenges of compact appliances. However, further research is needed to refine the concept, as well as assessment of its long-term performance and potential for integration into commercial dishwasher models.

Keywords: Product Development, Innovative Solution, Dishwasher, Water-Area-coverage, Bottom Spray Arm, Reciprocating Movement.



## Acknowledgements

We would like to express our sincere gratitude to Erik Hulthén, our academic supervisor, for his guidance on project structure and overall direction, ensuring the quality of the project. We would also like to thank Mikael Johansson at ASKO for supporting our development process and facilitating our work within the company, ensuring we had all the necessary resources at hand. A special thanks goes to Linn Jonsson at ASKO, whose continuous assistance, responsiveness, and support were invaluable throughout the project. We truly could not have completed this work without her help. We would also like to thank Adrian Pauli at ASKO for his expertise, thoughtful feedback, and for being an excellent support during our development process. Lastly, we thank Chalmers Fuse Makerspace for providing access to printers and all the necessary resources.

Filip Larsson and Robin Örtentfelt, Gothenburg, May 2025



# List of Acronyms

Below is the list of acronyms that have been used throughout this thesis, listed in alphabetical order:

CAD	Computer Aided Design
FMT	Function-Means Tree
PETG	Polyethylene Terephthalate Glycol
PLA	Polylactid Acid
POC	Proof of Concept



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# 1

## Introduction

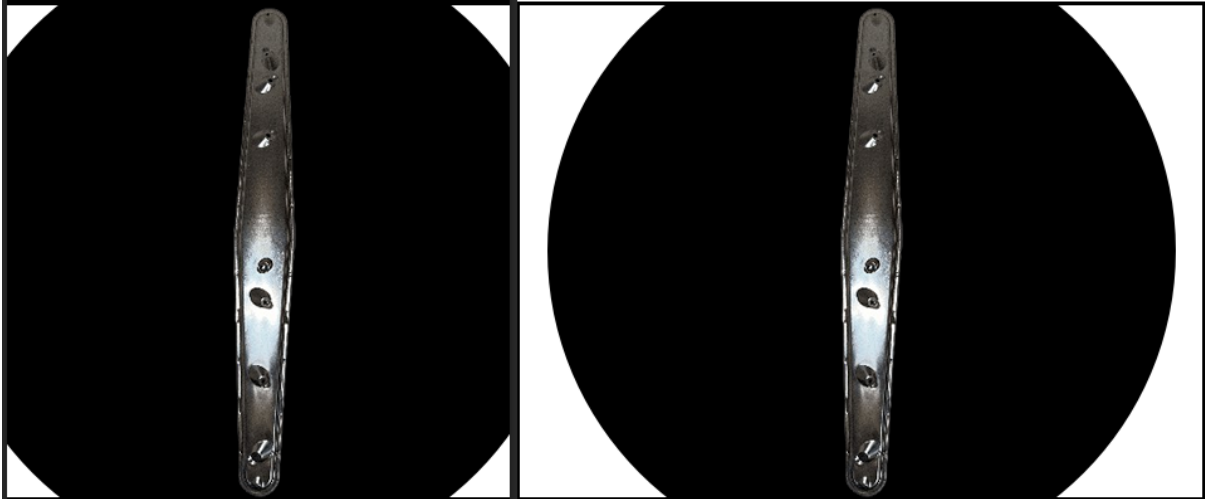
This chapter provides the contextual foundation for the thesis by examining the evolution, challenges, and current landscape of dishwasher technology, specifically focusing on narrower dishwashers, commonly named slimline models. The chapter outlines the historical development of dishwashing mechanisms, evaluates the limitations of current spray arm designs, and identifies the performance gap in existing solutions. It concludes by defining the problem, purpose, research questions, and the scope and limitations guiding this thesis.

### 1.1 Context

The modern kitchen has seen dishwashers become a central appliance, offering convenience, hygiene, and water savings. Moreover, demand for slimline dishwashers has grown due to changing living arrangements. As more individuals and couples reside in smaller households, the need for large dishwashers has decreased [1]. Urbanization has also reduced the average living space per person, causing a growing preference for space-efficient kitchen appliances [2].

A slimline dishwasher is a compact alternative to the standard model, typically measuring 45 cm in width compared to the standard 60 cm, while maintaining the same depth of 60 cm. These units are designed to fit smaller kitchens without compromising on cleaning performance [3], [4].

However, slimline dishwashers pose certain challenges. One significant issue, identified by ASKO, involves the standard water dispersion method, which uses a rotating spray arm that distributes water at varying angles. This approach, although effective in square models, does not effectively reach all interior surfaces, particularly in the corners and edges, in the slimline models (as illustrated in Figure 1.1). Due to their elongated design, slimline models can struggle with even water distribution when using this standard and most common method. This may result in suboptimal cleaning and force users to rewash dishes, leading to increased water and energy consumption.



**Figure 1.1:** Visualization of the great spray arm coverage in a square model, compared to the poor coverage in an oblong rectangular model, with the most commonly used spray-device.

Companies have attempted to address this issue through various design modifications, see Section 4.1.3, with mixed results. While most solutions improve water coverage to some extent, they also introduce several drawbacks. These include increased cost, added complexity, and greater material and water usage. Despite efforts to adapt to the changing market, none of the existing solutions consistently delivers truly satisfactory cleaning performance. Addressing these limitations of current designs remains critical to ensure that these appliances meet the expectations of modern, space-conscious consumers.

This demand forms the basis for this thesis, which aims to identify the core limitations of existing slimline dishwashers and propose an alternative spray device. The objective of the thesis is to design and develop a concept that improves water coverage while remaining suitable for compact machines.

## 1.2 ASKO Appliances

ASKO Appliances AB is a Swedish premium appliance manufacturer founded in 1950 by Karl-Erik Andersson in Vara, a village in western Sweden [5]. It began when Andersson built a washing machine to help his mother, which led to the founding of Junga Verkstäder. The company later expanded into dishwashers and other household appliances, emphasizing quality, durability, and Scandinavian design. ASKO focuses on the premium market segment and is now owned by the Gorenje Group, which in turn is part of the Hisense Group.

## 1.3 History

The history of the modern dishwasher dates back over a century to the 1880s, when Josephine Garis Cochran designed, patented, and commercialized the first automated dishwashing device, which used water pressure to clean dishes [6], [7]. This innovation laid the foundation for future advancements in dishwashing technology.

Subsequent improvements were made to enhance the original design. One of the first major technological breakthroughs came with the introduction of electric motors, which powered the pumps responsible for circulating water. From this development, two primary cleaning mechanisms emerged: the impeller system and the rotating spray arm, the latter of which became the industry standard. In the 1950s, the first fully automated dishwasher was introduced, marking a significant milestone in the evolution of kitchen appliances [8]. Modern dishwashers operate through a systematic cleaning process. A typical cycle begins with loading and pre-rinsing the dishes, followed by the intake and heating of water. Once the desired temperature is reached, detergent is dispensed into the water, initiating the washing and rinsing phases. The cycle concludes with drainage and drying, ensuring that dishes are cleaned and sanitized efficiently [9].

Compared to handwashing, which is time-consuming and increases the risk of damaging delicate items, dishwashers offer greater convenience, improved cleanliness, and reduced physical effort. Additionally, they help minimize kitchen clutter and streamline the cleaning process [10]. Given this, it is no surprise that they have become essential in modern households.

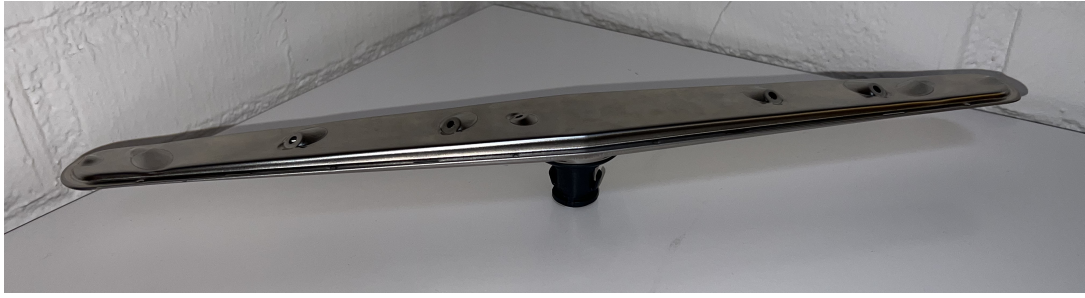
## 1.4 Recent developments

In recent years, the dishwasher industry has seen significant advancements. Major leaps have been made in features such as Wi-Fi connectivity, voice control, and smartphone integration, allowing users to monitor and control their dishwashers remotely [11]. These technologies are often combined with advanced diagnostics and maintenance alerts, which help prevent breakdowns and extend appliance lifespan [12]. Yet, despite these innovations, the bottom spray arm in most dishwashers remains largely unchanged and still resembles designs from nearly a century ago.

However, in recent decades, a large number of patents have suggested improvements to spray arm technology. Examples include a design with additional corner nozzles published in 2011 [13], the addition of four spray arms placed in the corners to enhance reach, published in 2012 [14], and a more recent concept featuring a rotating spray arm with extendable ends for improved corner coverage [15]. Despite these innovations, none of these designs have been widely adopted in standard dishwashing machines currently on the market.

## 1.5 Current solution

The most commonly used solution in slimline dishwashers is a scaled-down version of the rotating spray arm found in full-size models, see Figure 1.2. Typically made from plastic or metal, the arm is mounted at the centre of the dishwasher's base. It operates by using the momentum of pressurized water, which is expelled through small, angled openings. This force causes the arm to rotate, with varying speeds depending on the pressure. On bottom spray arms, orifices are arranged in a semi-even distribution and oriented at different angles to maximize coverage within the cleaning chamber. Additionally, one of the spray arm orifices is often angled downward and outward to help direct debris toward the central filter.



**Figure 1.2:** A spray arm made for standard machines, with close to identical appearance to those in slimline models.

## 1.6 Problem Description

The core issue addressed in this thesis is that current spray devices do not adequately cover all interior surfaces of the dishwasher. As a result, there remains a need for a more effective spray solution that delivers improved coverage and cleaning performance while still adhering to the spatial and functional limitations of the slimline format.

## 1.7 Purpose

The purpose of this project is to design and develop a spray device that ensures optimal water coverage over an oblong rectangular surface within a 45 cm wide dishwasher. The project involves researching existing technologies, generating and refining design concepts, building prototypes, and conducting performance tests. The final objective is to deliver a functional prototype that demonstrates improved coverage compared to current solutions.

## 1.8 Research Questions

The research questions to be addressed throughout this thesis are as follows:

1. What are the main limitations of current spray devices in slimline models, and how can coverage be improved?
2. What solutions are currently implemented to address insufficient spray coverage in dishwashers?
3. How can an innovative spray device concept be designed to achieve optimal coverage in a slimline dishwasher?

## 1.9 Scope and Limitations

Addressing the research questions requires a clear focus and efficient use of resources, thus, the scope and limitations of this study must be defined.

### Scope

The scope of the project includes:

1. Development of a spray mechanism designed to effectively cover an oblong rectangular surface.
2. Research and analysis of current spray systems to identify potential solutions and limitations.
3. Development and evaluation of multiple design concepts.
4. Building and testing of a functional prototype to validate the design and ensure its efficacy.

### Limitations

The following limitations will be applied to the project and the development process:

1. Only slimline dishwashers will be considered.
2. The design will focus solely on dishwashers intended for personal, residential use.
3. No modifications will be made to machine components outside the internal washing chamber.
4. A fixed flow rate of 30 litres per minute will be utilized for the design.
5. Material selection will not account for temperatures exceeding those typically generated within a dishwasher.
6. Only stainless steel and plastic will be used as materials, with the exception of sealants where needed.
7. The construction of prototypes will be limited to 3D printing only.

## 1.10 Ethical and sustainability considerations

The development of a spray device for dishwashers, while primarily a technical project, could have some implications that extend beyond performance. Improving energy efficiency is a key sustainability consideration. If the new spray device enhances cleaning performance, it may allow dishwashers to operate at lower temperatures or with shorter wash cycles, thereby reducing electricity consumption. Similarly, optimizing water distribution could lead to lower overall water usage. Although these factors could be affected, this will not be of focus in this project since its focus lies on optimizing the spray device's cleaning effectiveness and durability, rather than prioritizing energy and water efficiency. These aspects, while important, will be secondary in the current scope.

From an ethical standpoint, it is essential to consider responsible manufacturing practices. Ensuring fair labour conditions and environmentally friendly production methods contributes to the overall sustainability of the product. However this is not of importance for this project due to being outside of the scope, but will be of importance in the future work of the project.

However, ethical considerations must be taken into account when evaluating the perfor-

mance of the dishwasher spray arm. It is crucial to ensure an objective and transparent analysis, as any bias or misrepresentation of test results could lead to misleading conclusions. This could result in incorrect design choices or even intentional deception. Hence, integrity and honesty must guide the testing process to maintain the credibility of the project.

# 2

## Theory

This chapter outlines the theoretical foundations relevant to the development of dishwashers and dishwasher component design. It covers the key components of a dishwasher, the sequence of a typical wash cycle, as well as the role of water pressure in spray arm function, and the use of 3D printing for prototyping. These concepts provide essential context for the design and evaluation work presented in this thesis.

### 2.1 Components of a dishwasher

A dishwasher comprises several key components that work in coordination to perform efficient and effective cleaning. The main components include:

- **Housing:** The outer structure that encloses all internal components and holds the dishes during washing.
- **Control Panel:** Positioned on the front or top of the door, it allows users to select wash cycles, water temperatures, and additional settings.
- **Detergent Dispenser:** A compartment that holds detergent and, in some models, rinse aid. It releases these at specific times during the wash cycle.
- **Spray Arms:** Usually located at the bottom and sometimes the middle and top of the machine, they rotate and spray high-pressure jets of water mixed with detergent to clean the dishes.
- **Racks and Baskets:** Adjustable structures designed to securely hold plates, bowls, glasses, and utensils during washing.
- **Heating Element:** Heats the water during the wash phase and assists in drying dishes at the end of the cycle.
- **Pump and Motor:** Circulate water through the spray arms and expel it during the drain phase.
- **Filter System:** Captures food particles and debris to prevent redepositing on dishes.
- **Water Inlet Valve:** Regulates the flow of water from the household supply into the dishwasher.
- **Drain Hose:** Channels used water from the dishwasher into the home's drainage system.

## 2.2 Wash Cycle

A dishwasher wash cycle is a programmed sequence of operations designed to clean and sanitize dishes efficiently. A typical cycle consists of the following stages [16]:

- **Pre-wash:** Water is sprayed over the dishes to loosen and remove loose food particles. No detergent is used during this phase.
- **Main Wash:** Hot water mixed with detergent is sprayed through rotating spray arms to thoroughly clean the dishes. This is typically the longest phase of the cycle.
- **Rinse:** After draining the soapy water, clean water is sprayed to rinse away any remaining detergent residues.
- **Drying:** Heated air or residual heat is used to dry the dishes. The specific drying method may vary depending on the make and model of the dishwasher.

## 2.3 Spray Arm Performance and Water Pressure

Dishwashers require a regulated incoming water pressure, typically between 20 and 120 psi (1.4 to 8.3 bar), depending on the manufacturer, to function effectively [17]. This pressure ensures proper filling and enables the internal circulation pump to drive water through the spray arms at high velocity. For this project, minor pressure losses in transit are considered negligible.

Water exits the spray arms through small, strategically positioned orifices that generate jets to clean dishes. The size, number, and orientation of these orifices determine both the distribution and intensity of the spray. Notably, the reactive force from the water exiting the orifices also drives the rotation of the spray arms, ensuring even coverage of the dish load. If the force is too low, rotation may stall, leading to poor cleaning; if too high, the arms may spin excessively, reducing efficiency and increasing mechanical wear.

An earlier study conducted at ASKO Appliances AB, in collaboration with Chalmers University of Technology, found that water pressure has a greater impact on cleaning performance than the rotation speed of the spray arm [18]. Their experiments showed that higher pressure combined with slower rotation consistently produced better results. This highlights the importance of optimizing water pressure and orifice design to achieve effective and efficient dishwasher operation, while also balancing energy and water usage [18].

## 2.4 Prototype Materials

When making prototypes, 3D printing is a commonly used method. Material selection plays an important role in 3D printing, as it directly impacts printability, durability, and functional performance. Two of the most common materials used in 3D printing are Polylactic Acid (PLA) and Polyethylene Terephthalate Glycol (PETG). PLA is a biodegradable, plant-based polyester widely used for early-stage prototypes. It is easy to print, inexpensive, and has high surface quality with minimal warping, making it ideal for visual or conceptual models [19]. However, it is brittle, has poor impact resistance, and softens above 60 °C, which limits its use for functional parts or applications involving

heat or moisture. For more demanding use cases, PETG offers greater strength, flexibility, and resistance to water and moderate heat (up to  $\approx 80$  °C) [20]. While it requires more precise print settings, PETG is better suited for durable, stress-bearing, and water-exposed prototypes.

When selecting materials for moving parts, choosing different materials for contact surfaces is a common way to reduce friction and enhance performance [21]. This technique takes advantage of the distinct physical and chemical properties of each material to optimize the interaction between surfaces.



# 3

## Methodology

The following chapter will present the process followed during the thesis work. The thesis methodology follows a structured design process inspired by Ulrich and Eppinger's product development framework [22]. This approach ensures a systematic, repeatable, and effective development process that increases the probability of achieving a successful outcome.

### 3.1 Product Specifications

To establish clear design goals, product specifications are developed, primarily based on customer needs, with the addition of some market research and a shorter literature study of existing solutions. A more in-depth market research and literature study are conducted after the first rounds of concept generation. This approach is chosen to avoid heavy bias towards already implemented solutions, thus ensuring that the solution space is kept broad and more solutions are tested.

### 3.2 Concept Generation

In this phase, various methods are employed to, in a structured and iterative way, generate innovative solutions. The methods consist of the following:

- **Function-Means Tree:** A hierarchical breakdown of functions and possible solutions to address them.
- **Brainstorming:** A collaborative approach to explore multiple design possibilities.
- **Morphological matrix:** A structured method to combine different functional solutions into complete concepts.
- **Sketching:** Initial visualization of concepts to aid in evaluation.

By applying these techniques, multiple potential solutions are developed, ensuring a diverse range of design possibilities.

#### 3.2.1 Function-Means Tree and Brainstorming

A Function-Means Tree is created to systematically map the different functions of the spray device to various solutions [23]. Ideas are generated through brainstorming to explore a broad spectrum of the solution space and to refine ideas effectively [24]. This allows for a systematic approach to generate multiple design solutions.

### 3.2.2 Morphological Matrix

A Morphological Matrix is used to combine different design elements into various possible solutions [22]. This method is used to systematically generate a wide range of design concepts, helping to identify solutions that might not have been immediately obvious. By selecting different combinations of means across multiple functions, a variety of potential design concepts are created.

### 3.2.3 Sketching

Following the concept generation step in the Morphological Matrix, sketches are created to provide a clearer understanding of each concept [22]. The sketches translate abstract ideas into visual representations, making them easier to analyse and refine. These sketches also serve as visual aids to better illustrate the structure, components, and functionality of the proposed designs.

## 3.3 Concept Selection

Once initial concepts are generated, a systematic evaluation process is used to identify the most promising solution through the following steps:

- **Elimination Matrix:** Filters out infeasible concepts based on fundamental requirements.
- **Pugh Matrix:** Compares concepts against a baseline design on selected criteria.
- **Kesselring Matrix:** Evaluates design alternatives by systematically weighing multiple criteria to optimize selection and balance trade-offs.
- **Concept Synthesis:** Iterative improvements based on the results of the evaluation.

### 3.3.1 Elimination Matrix

A filtering process is conducted with an Elimination Matrix to discard concepts that do not meet essential requirements [25]. Each concept is evaluated against non-negotiable criteria such as functionality, manufacturability, and safety. Any design that does not satisfy these criteria is eliminated from further consideration, ensuring that only viable concepts proceed to the next step. Further development of the concepts is made before moving to the next step.

### 3.3.2 Pugh Matrix

To further refine the selection process, the remaining concepts are evaluated using a Pugh Matrix [26]. A baseline design is chosen as a reference point, and then each concept is compared against it based on generated criteria. The concepts are rated relative to the baseline, and grades are assigned to each to facilitate objective decision making. This comparative method helps to narrow down the most promising solutions.

### 3.3.3 Kesselring Matrix

For a more detailed evaluation, a Kesselring matrix, also known as a Weighted Pugh matrix, is used. It is a tool that is used to systematically evaluate and compare multiple design alternatives across a set of weighted criteria [26]. The results are summarized in a matrix where each alternative is scored against various parameters which are weighted relative to their importance. The scores are then added up to show which option performs best overall. This method allows for more informed and detailed decision-making.

### 3.3.4 Concept Synthesis

Concept synthesis is performed to refine the selected concepts throughout [22]. Insights gained from the Elimination, Pugh, and Kesselring matrices are used to improve the most promising concepts. This development process is conducted iteratively between all selection steps to continuously improve the viable concepts. The iterative concept synthesis ensures that the final concepts are well-balanced, practical, and closely aligned with the objectives of the thesis.

## 3.4 Prototyping and Testing

Selected concepts proceed to the prototyping and testing phase [22]. This stage is highly iterative, with each concept undergoing continuous refinement and increasing in complexity throughout development. Prototypes are initially created digitally and then physically constructed, primarily using 3D printing. Testing runs in parallel with development, beginning with targeted evaluations of core functions. As prototypes evolve, both their design and the tests performed become more comprehensive, progressing from isolated component assessments to full-system performance evaluations. In the final stage, the cleaning capabilities of the prototypes are tested to directly address the core research questions.

## 3.5 Final Prototype

The final stage of the development process involves constructing the refined prototype, which is delivered to ASKO for further testing and internal evaluation. This version emphasizes both functional performance and visual refinement to serve as a practical and presentable foundation for continued development.



# 4

## Work process

This chapter presents the application of all methods alongside the results from each part of the process. It explains and justifies the work carried out, highlighting the reasoning behind key decisions and the progression that led to the final outcome.

### 4.1 Product Specifications

The first section of this report addresses the initial step in the development process: determining the product specifications. Establishing well-defined specifications is critical to ensure that the project aligns with stakeholder expectations, meets technical feasibility requirements, and maintains competitive advantages. This phase involves a structured approach that includes identifying customer needs, establishing target specifications, conducting a literature review, analysing patents, and benchmarking existing solutions.

#### 4.1.1 Customer Needs

To ensure a successful project, an accurate assessment of customer needs was essential. A customer needs analysis was conducted, with the majority of needs obtained directly from ASKO. Additionally, assumptions made by the authors were documented and structured for clarity.

To systematically organize these needs for later stages, they were compiled into a Customer Needs Table, which categorized each need, assigned an importance rating, and categorized them into either wants or requirements, W and R, respectively. The table also provided a structured reference for further development [22], which can be seen in Table 4.1.1.

To derive accurate importance ratings, a multi-step approach was employed. Initially, each team member independently assessed and assigned perceived importance levels to each need. The individual assessments were then compared, discussed, and synthesized into preliminary ratings. Subsequently, these ratings were presented to ASKO, whose feedback was incorporated to finalize the importance ratings, ensuring alignment with stakeholder priorities.

Table 4.1: Customer Needs Table

Customer Needs List			
No	Category	Need	Importance (1-5)
1	<b>Performance &amp; Cleaning</b>	Improves the cleaning of the dishes	2
2		Provides superior water coverage.	5
3		Meets industry cleaning standards. (12% better than Miele)	2
4	<b>Durability &amp; Longevity</b>	Withstand temperatures of dishwasher	5
5		Modular design to fit ASKO:s "layout"	1
6		Designed for a 20-year lifespan.	2
7		Endures water pump pressure.	5
8		Resistant to wear and tear.	1
9	<b>Reliability</b>	Does not clog	4
10		Resistant to water damage.	5
11	<b>Safety</b>	The spraydevice wont harm the user	4
12	<b>Aesthetics</b>	Visually appealing design	1
13	<b>Instalation</b>	Easy to install.	1
14	<b>Sound</b>	Operates without excessive noise.	3
15	<b>Maintenance</b>	It will be easy to maintain	2
16	<b>Material</b>	Constructed from food-grade plastic or stainless steel.	1
17		Uses cost-effective materials.	2
18	<b>Cost Efficiency</b>	Designed for water conservation.	1
19		Affordable manufacturing costs	2
20		Energy efficient	1
21		Development cost	1

### 4.1.2 Establish Target Specifications

To further refine the customer needs into usable and applicable criteria for the concept generation stage, a Target Specifications Table was developed, see Table 4.2. The customer needs were systematically analysed, and from each need, one or more measurable metrics were derived.

Table 4.2: Target Specifications Table.

Metric No.	Need Nos.	Metric	Imp.	Units	Marginal Value	Ideal Value	Stakeholder
1	1, 2, 3, (14)	Generated water pressure		4 kPa	3-5	6-8	ASKO
2	1, 3	Generated Water flow rate		4 l/m	30	30	ASKO
3	(1, 3) 4	Withstandable temperature		5 °C	70	74	ASKO
4	1, 2, 3	Area coverage		5 %	75%	100%	ASKO
5	(1) 3	Quality of cleaning		2 % better than Miele	>=0	>12	European Commission
6	5	Machines fitted to		1 # of machines	1	>=2	ASKO
7	6, 8, 10	Uses before failure		2 # of uses	1000	>5600 cycles	ASKO
8	7	Withstandable water pressure		5 Bar	175	350	ASKO
9	9	Uses before clogging		1 # of uses	200	1120	ASKO
10	11	Sharpness of external parts		2 Microns	>1	>10	ASKO
11	11	Heat of external parts		3 °C	<77	<70	ASKO
12	12	Is aesthetic		1 Subj. 1-5	>2	>4	ASKO
13	13	Time to install		1 s	<120	<60	ASKO
14	14	Noise level		3 dB	<50	<44	ASKO
15	15	Time to disassemble/assemble for maintenance		1 s	<120	<60	ASKO
16	16	Uses non-toxic materials		1 Binary	Pass	Pass	ASKO
17	17	Total cost of materials		2 sek	<100	<60	ASKO
18	18	Required water volume		4 l/cycle	6<	3	ASKO
19	19	Cost to manufacture		1 sek	<100	<60	ASKO
20	20	Used energy		1 kWh	0	0	ASKO
21	21	Cost to develop		1 sek	<100	<60	ASKO

The Target Specifications Table contains several key columns: the corresponding customer need, a newly assigned importance rating derived using a method similar to that outlined in Section 4.1.1, the unit of measurement for each metric, marginal and optimal values, and the associated stakeholder.

Since these were target specifications, only a limited amount of resources was allocated to researching and determining precise values. However, many specification values were provided by ASKO, primarily based on benchmarks from their existing dishwasher models to ensure feasibility and alignment with current product standards.

### 4.1.3 Literature Study

The literature study was divided into two phases. The first phase, conducted before the concept generation stage, focused on finding inspiration. Broad research was carried out to explore various applications where the main objective was to find inspiration on how to disperse water over a surface. This wide scope was intentional, as avoiding a narrow focus on existing dishwasher solutions helped keep the creative process open. For example, sprinkler systems used on golf courses served as a source of inspiration for some of the early concepts.

After the initial concept generation and application of the Elimination Matrix, the first step in the concept selection process, the second phase of the literature study began. This phase consisted of a more thorough benchmarking against current solutions, as well as a more in-depth patent analysis.

#### Patent Analysis

Patents were examined in this study to provide insight into how similar problems have been addressed in existing industrial and research applications. This analysis allowed the authors to gain a deeper understanding of current solutions, draw inspiration for alternative approaches, and identify gaps in existing research that could be leveraged for innovation.

To ensure a broad coverage of potential solutions, an extensive independent patent search was conducted. Google Patents was the primary database used, with Espacenet serving as a secondary resource to enhance the comprehensiveness of the search, with the specific methodology presented below;

The keywords utilized during the patent search included:

- Dishwasher Arm
- Dishwasher
- Spray Arm
- Rectangular
- Compact

The classifications used to refine the search were the following:

- A47L 15/14 - Washing or rinsing machines for crockery or tableware with stationary crockery baskets and spraying devices within the cleaning chamber (for drinking glasses A47L 15/0065)
- A47L15/16 ●● with rigidly-mounted spraying devices
- A47L15/18 ●● with movably-mounted spraying devices
- A47L15/20 ●●● Swingable spraying devices

- A47L15/22 ●●● Rotary spraying devices
- A47L15/23 ●●●● moved by means of the sprays
- A47L15/508 - Hydraulic connections for racks
- A47L2501/20 - Spray nozzles or spray arms

Many of the identified patents exhibited strong similarities to concepts previously generated through independent research. However, certain patents contributed directly or indirectly to the refinement of new concepts. The complete table that summarizes the key patents identified is found in Appendix A.

Based on the patent analysis, several new concepts were developed, drawing inspiration from existing patents. While these concepts shared certain functional elements with the referenced patents, each was significantly modified to avoid any infringement. The resulting concepts were:

- Basket
- Mr. ExTend
- Printer
- Trickshot
- Tubular
- Waddle

These concepts emerged after the initial round of ideation, during this second and more thorough phase of literature and patent review. Descriptions of the concepts are found in Appendix D, and sketches of said concepts can be found in Appendix E.

### 4.1.4 Benchmarking

The majority of the benchmarking against competitor products was conducted in a semi-informal manner. Given the specificity of the project and the unique nature of the product being developed, a quantitative comparison of competitor spray devices was deemed unnecessary. Instead, a broader research approach was adopted, focusing on identifying how others have addressed similar challenges. Their solutions served as both inspiration and lessons for the development process. Examples of how other companies have tried to solve this problem are:

- Samsung, with their "Water wall" - This system replaces traditional rotating spray arms with a moving bar that shoots a high-pressure wall of water from side to side [27].
- AEG with dual spray arms - Two spray arms mounted side by side on the same level in the lower part of the dishwasher [28].
- Bosch with their "PowerControl" - This system consists of a smaller, three armed spray arm mounted at the end of the main lower spray arm [29].

These varied approaches demonstrate innovative attempts to improve cleaning performance through alternative spray mechanisms. However, they remain relatively niche and are not yet widely adopted across the industry.

## 4.2 Concept Generation

Once the target specifications were established and the initial benchmarking phase completed, the next step was to develop new and original concepts to address the problem at hand. The concept generation phase followed a structured methodology, largely based on the work of Ulrich and Eppinger [22], with some modifications made to better suit the specific challenges of this project.

### 4.2.1 Function-Means Tree

The first step was to create a Function-Means Tree (FMT) to be able to systematically map the different functions of the spray device to various solutions. The key function was defined as "Clean Dishes", whereafter different subfunctions and means were identified through brainstorming sessions.

The brainstorming sessions started off with each person writing down both subfunctions and various means to each. This was then followed by a collective session where the already created functions and means were summarized and merged into one big tree that was adjusted accordingly, this tree can be seen in Appendix B. Having the structure of the tree laid out, brainstorming for more means was conducted by going through the tree function by function. If new means under a function needed subfunctions, these were added.

### 4.2.2 Morphological Matrix

Following the FMT, the next step was to develop the Morphological Matrix. The matrix incorporated the FMT-generated 'Functions' as subfunctions for each respective row, while the derived 'Means' served as possible solutions for each subfunction in the columns. Once the appropriate subfunctions and solution alternatives were identified, the concept generation process was initiated. Multiple complete concepts were developed by combining relevant sub-solutions using various methodologies.

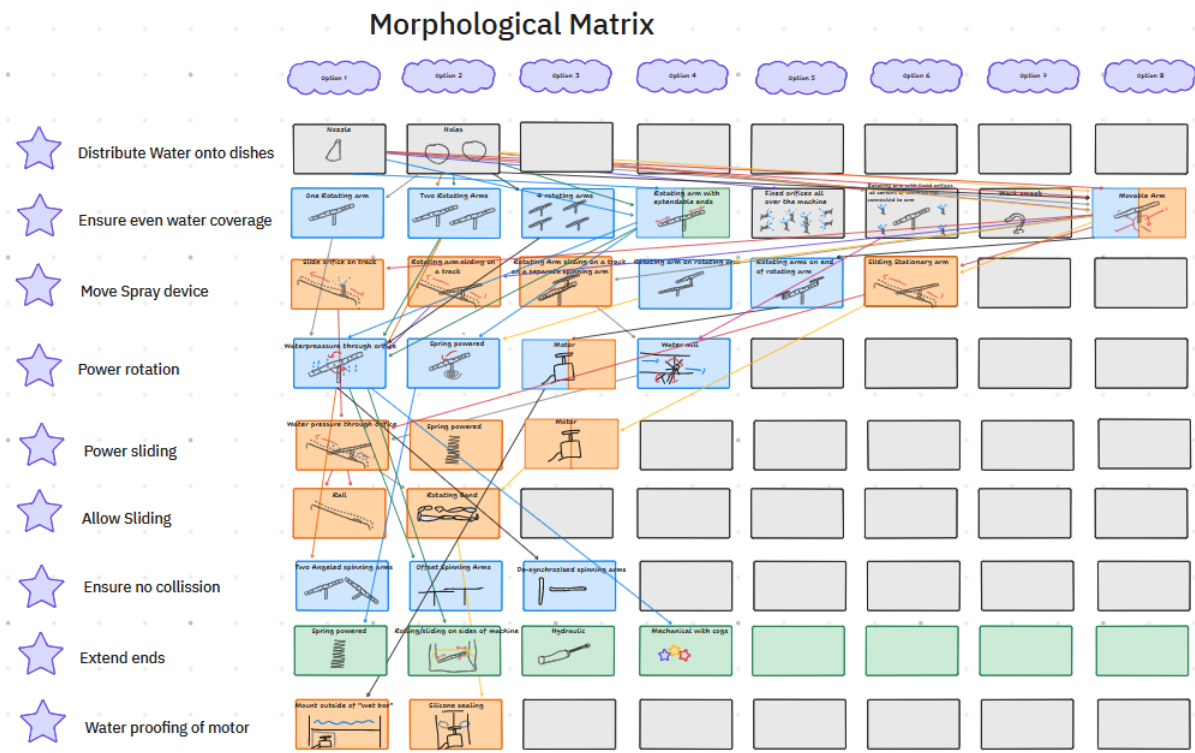
After generating only three concepts, it was determined that several subfunctions were superfluous to the core concept design and would not significantly impact its quality, while still increasing the complexity of the concepts. These subfunctions could be defined at a later stage. Consequently, a revised Morphological Matrix was developed, including only the most relevant subfunctions.

Using this refined matrix, more concepts were generated through multiple methodologies:

- Randomization: Randomly drawing connections between functions or rolling a die for selection.
- Theme-Based: Developing concepts around predefined themes, such as simplicity or cost-effectiveness.
- Completion: Ensuring all major functionalities were included at least once and combining them appropriately.

The Morphological Matrix with all subfunctions and means included is seen in Figure 4.3. This revised morphological matrix, with the inclusion of the generated concepts, can be found in Appendix C. Brief descriptions of all concepts, including their main features and design focus, are provided in Appendix D for reference. To enhance clarity and effectively visualize the concepts, sketches were produced. Each sketch provided a visual representation of all subsolutions, along with the corresponding concept name. The sketches aimed to present the structural and functional aspects in a clear and comprehensible manner, aiding in further refinement and discussion. The sketches are found in Appendix E.

**Table 4.3:** Morphological Matrix subfunctions and means



### 4.3 Concept Selection

At this stage of the thesis, the initial concept generation phase has been completed. Moving forward, it is necessary to refine, merge, or discard underperforming concepts. This process is carried out in the concept selection phase. To ensure that all concepts are fairly evaluated and no viable ideas are prematurely dismissed, while also avoiding excessive time spent on unfeasible solutions, a structured approach is employed, consisting of:

- Elimination Matrix
- Pugh Matrix
- Kesselring Matrix

These methods systematically assess and compare concepts, ensuring an efficient and objective selection process [26]. The details of each method are outlined in the following sections.

### 4.3.1 Elimination Matrix

The Elimination Matrix served as an initial screening tool to ensure that only feasible concepts progressed to further development. Each concept was evaluated against predetermined criteria and classified as either, viable for continued development or discarded. Some concepts required additional research for a more accurate assessment. After conducting the necessary investigations, all concepts were deemed viable for further refinement except for one concept which required excessive modifications to meet all criteria. As a result, the Elimination Matrix ultimately had minimal impact on concept selection, rendering it ineffective in this instance. The Elimination Matrix is found in Table 4.4. The different criteria were defined as follows:

- **Criterion A:** Be compatible with the overall task and with one another.
- **Criterion B:** Fulfil the demands of the requirements list.
- **Criterion C:** Be realizable in respect of performance, layout, etc.
- **Criterion D:** Be expected to be within permissible costs.

#### Legend

- + = Yes
- - = No
- ? = Lack of information

**Table 4.4:** Elimination Matrix

#	Concept	A	B	C	D	Decision
1	Deemed Doable	+	+	+	+	+
2	Rotorception	+	+	+	+	+
3	Sliding Stationary	+	+	?		?
4	Tank	+	+	?		?
5	Orifinity	+	+	+	+	+
6	Nexcog	+	+	+	+	+
7	Easiest	+	-			-
8	Complicado	+	+	+	+	+
9	Nobody Puts Orif...	+	+	?		?
10	The Orifice that C...	+	+	+	+	+
11	Quadwash	+	+	+	+	+
12	Spinny Spin	+	+	?		?
13	Mechanix	+	+	+	+	+
14	Race n' Wash	+	+	+	+	+
15	Spring Time	+	+	?		?
16	Angled Magician	+	+	+	+	+
17	Power-house	+	+	?		?
18	Basket	+	+	+	+	+
19	Mr. ExTendo	+	+	+	+	+
20	Printer	+	+	+	+	+
21	Trickshot	+	+	+	+	+
22	Tubular	+	+	+	+	+
23	Waddle	+	+	+	+	+
24	Oliver	+	+	+	+	+

### 4.3.2 Further Development

The further development of concepts was an iterative and continuous process that persisted throughout the entire project. After each matrix evaluation, most concepts had aspects that could be improved. Consequently, components were removed, the level of detail in the concepts was refined, and alternative solutions were implemented to address emerging issues.

### 4.3.3 Pugh Matrix

The Pugh Matrix was used as a secondary screening step to further refine and select the most promising concepts. The selection criteria were derived and adapted from the target specifications, chosen based on a combination of their importance rating, measurability without prototyping, and their ability to differentiate the concepts effectively. A standard 45 cm dishwasher, with a single rotating spray arm, was selected as the reference point.

Each concept was systematically compared against the reference machine for each criterion, receiving a score of -1, 0, or +1, indicating whether it was deemed inferior, equal, or superior, respectively. Finally, the scores were summed for each concept, allowing for a ranked comparison based on overall performance.

Multiple Pugh matrices were conducted, in which the selection criteria were refined and improved. The final criteria, and their meaning, were as follows:

- **Spray Coverage Area:** The estimated percentage of the total area of dishes covered by the waterjets
- **Design Complexity:** The intuitiveness of the design, estimated number of unique pieces and components, and if it requires any electrical engineering or programming.
- **Durability:** The concepts ability to handle defects or deviations.
- **Engineering Elegance:** Ability to generate maximum functionality and performance with minimal complexity.
- **Water Use:** The estimated amount of extra water needed to run the concept.

The concepts were also developed between the various evaluation matrices. One example of this is after the first Pugh, where the concepts Rotorception and Spinny Spin were merged into the better concept RotoSpin. This is also where the concept Fridge Organizer originated, between Pugh 2 and Pugh 3.

Further Pugh evaluations were conducted until it was confirmed that the superior concept from the evaluation consistently remained at the top in subsequent Pugh analyses. According to Pugh [26], this was the indication to proceed with the process. In total, four Pugh evaluations were performed until the concept named Trickshot proved to be superior based on the specified criteria.

It is important to note that concepts were not eliminated or retained solely based on their ranking. Instead, the rankings served as a guide, with discussions on their real-world viability following each evaluation. This approach resulted in a more refined outcome compared to relying purely on numerical rankings. However, it should be noted that after the final Pugh evaluation, the rankings closely aligned with the authors' preferred concepts. Consequently, the four lowest-ranked concepts were ultimately eliminated. This

outcome highlights how the improved selection criteria more accurately reflect the true evaluation parameters. The outcome after all the Pugh matrices resulted in a selection of nine concepts, as seen in Table 4.5. The complete set of Pugh matrices are found in Appendix F.

**Table 4.5:** Pugh Matrix #4

Selection Criteria	Reference									
	Trickshot	Deemed Doable	Mechanix V2	NexCog	NPOITC	One Direction	Orifinity	Race n' wash	Tubular V2	FridgeOrganizer
Spray Coverage Area	0	-1	0	0	0	0	1	1	0	0
Design Complexity	0	0	-1	-1	0	-1	0	-1	-1	-1
Durability	0	0	-1	-1	0	-1	0	0	0	-1
Engineering elegance	0	-1	0	1	-1	1	-1	0	0	1
Water use (preliminary)	0	0	0	0	0	0	-1	0	0	0
Total:	0	-2	-2	-1	-1	-1	-1	0	-1	-1
Rank:	1	8	8	3	3	3	3	1	3	3
Comment:	Move on	Move on	Discard	Move on	Move on	Move on	Move on	Move on	Move on	Move on

### 4.3.4 Kesselring Matrix

To aid in the selection of concepts, a more detailed comparison was necessary. One approach could have been to further develop each concept, refining its design and detailing its individual components. However, this method was considered too inefficient at this stage of the project, as the number of viable concepts was still too high, making a thorough evaluation overly time-consuming. Therefore, the authors opted to conduct a Kesselring evaluation.

While both the Kesselring and Pugh matrices utilize the same evaluation criteria, they differ in their approach to concept assessment. The Pugh matrix compares concepts against each other, highlighting relative performance. In contrast, the Kesselring matrix evaluates each concept based on its perceived performance against an ideal value. Furthermore, the Kesselring matrix incorporates weighted criteria to emphasize the relative importance of each factor [30]. This approach was considered more practical, as determining the relative weight of each parameter was more straightforward and significantly improved the concept selection process.

The weights for the selection criteria were determined based on a combination of their respective importance in the customer needs, engineering intuition, and feedback from Mikael.

The complete Kesselring Matrix is seen in Table 4.6, and it was scored according to the following:

- **Spray Coverage Area:** Percentage of dish area reached by water.  
Ratings: 1 =  $\leq 90\%$ , 2 =  $> 92\%$ , 3 =  $> 94\%$ , 4 =  $> 96\%$ , 5 =  $\geq 98\%$ .
- **Design Complexity:** Based on intuitiveness, unique components, and innovation.  
Ratings: 1 = Very High, 2 = High, 3 = Medium, 4 = Low, 5 = Very Low.
- **Durability:** Relates to construction and number of moving parts.  
Ratings: 1 = Very Low, 2 = Low, 3 = Medium, 4 = High, 5 = Very High.
- **Water Use:** Amount of water present in the system during operation.  
Ratings: 1 = Very High, 2 = High, 3 = Medium, 4 = Low, 5 = Very Low.
- **Engineering Elegance:** Reflects design quality and minimalism.  
Ratings: 1 = Basic, 2 = Acceptable, 3 = Decent, 4 = Impressive, 5 = Exceptional

**Table 4.6:** Kesselring matrix

CRITERIA		SOLUTION ALTERNATIVE																			
		IDEAL		A		B		C		D		E		F		G		H		I	
Name:	W (1-5)	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t
Spray Coverage Area	5	5	25	4	20	4	20	5	25	5	25	5	25	5	25	5	25	1	5	5	25
Design Complexity	2	5	10	4	8	5	10	2	4	4	8	2	4	5	10	3	6	3	6	2	4
Durability	1	5	5	5	5	5	5	3	3	5	5	3	3	5	5	4	4	5	5	2	2
Engineering elegance	4	5	20	4	16	1	4	5	20	2	8	5	20	1	4	3	12	2	8	4	16
Water use (preliminary)	1	5	5	3	3	2	2	4	4	2	2	4	4	1	1	4	4	2	2	5	5
Total:		25	65	20	52	17	41	19	56	18	48	19	56	17	45	19	51	13	26	18	52
Rank			1		4		9		2		7		2		8		6		10		4

The solution alternatives in the Kesselring corresponds to the following concepts:

- A: Trickshot
- B: Deemed Doable
- C: NexCog
- D: Nobody Puts Orifice In The Corner V2
- E: One Direction
- F: Orifinity
- G: Race n' wash
- H: Tubular V2
- I: Fridge Organizer

Based on the scores generated through the Kesselring matrix, the number of concepts advancing to further development was reduced from nine to five, these being:

- Race n' wash
- Trickshot
- Fridge Organizer
- One Direction
- NexCog

These concepts proceeded to the next stage of development, involving a higher level of detail and initial testing to assess their feasibility.

The score assigned to each criterion was determined using different methods depending on the specific criterion. However, all evaluations were broadly based on qualified estimates. A notable selection criterion was area coverage, where values were derived by estimating the coverage of current standard spray arms in square dishwashers. This baseline measurement was then used to approximate the coverage of each concept, allowing a calculated percentage comparison.

The following image, see Figure 4.1, provides a visual representation of the hypothesized spray patterns for the area coverage of the concepts.



**Figure 4.1:** Hypothesized spray coverage pattern of the following concepts in order: Race n' Wash, Trickshot, Fridge Organizer, One Direction, NexCog

## 4.4 Prototyping

With these five concepts selected, the next step was to transform the ideas into prototypes. The prototyping phase was divided into two main parts: digital prototypes and physical prototypes.

### 4.4.1 Digital prototypes

The first step of bringing the concepts to life was to create digital prototypes using CAD. The software used for this was CATIA, since both members had previous experience and expertise with the program, and the license was readily available.

The development of the concepts into digital CAD models served several purposes: to assess the feasibility of each concept, evaluate the practicality of their construction, gain a deeper understanding of their complexity, and most importantly, prepare them for testing.

### 4.4.2 Physical Prototypes

After the digital prototypes were completed, they underwent an iterative 3D printing process involving repeated cycles of printing and redesigning until satisfactory results were achieved. The printers used for this project were the Prusa MK4 Input Shaper, Prusa MK4S, and Prusa XL, due to their availability at Chalmers FUSE Makerspace and ASKO, respectively. To balance quality and print speed, a layer height of 0.2 mm was commonly employed. For parts with relative motion between connected components, a clearance of 0.15 mm was applied to ensure smooth movement. In contrast, pressure-fit connections were designed with a tighter clearance of 0.05 mm. All components were printed with a grid-infill, and depending on the design, either a snug or organic support structure was used. The infill pattern was decided to be rectangular with a 15% infill rate due to its simplicity, and the fact that no extreme forces would be exerted on the parts.

## 4.5 Testing

All concepts underwent testing. This section outlines each concept individually and details the relevant tests conducted. Testing was divided into smaller, purpose-specific evaluations to keep both the designs and the testing process focused and manageable.

### 4.5.1 Tests

**Table 4.7:** A table summarizing the results of each concept at the corresponding test, using a check mark to indicate success and a cross to indicate failure.

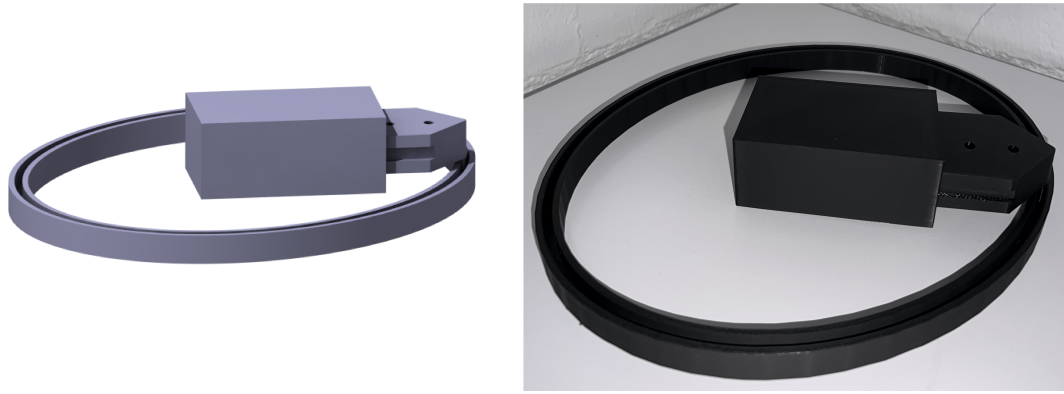
Tests/Concept	Race N' wash	Nexcog	One Direction	Trickshot	Fridge Organizer
Proof of concept	✓	✓	✓	✓	✓
Core functionality	✗	✗	✓	✓	✓
Connect to Water			✓	✓	✓
Run with water			✗	(✓)	✓
Area coverage					✓

#### Description of tests:

- **Proof of Concept:** Evaluates the feasibility of the idea by creating a 3D CAD model, followed by 3D printing to demonstrate the constructability of the concept.
- **Core Functionality:** The core functionality test evaluated the mechanical viability of each concept in a dry, hand-powered environment. Concepts were divided into functional subsystems, tested individually, and then integrated. The focus was on the most critical and unique aspects of the design, as there is no value in optimizing minor details if the core functionality proves unworkable or unmanufacturable. Failures were documented and addressed through iterative development.
- **Connect to Water:** Assesses the concept's ability to securely connect to a water outlet and allow proper water flow through its internal channels. This includes ensuring watertight seals and unimpeded movement. Connections are designed with the dishwasher interface in mind and refined through iterative testing.
- **Run with Water:** Verifies full functionality under actual conditions—mounted in a dishwasher, connected to water, and operating with machine-controlled pressure. Movement and performance are observed under wet, pressurized conditions.
- **Area Coverage:** Measures the effective cleaning range of the solution by placing a surface with tracing material to visualize the coverage pattern.

### 4.5.2 Race N' Wash

**Concept and Functionality** The Race N' Wash concept needed to be tested for its core functionality in a proof of concept test. The first test is in the form of creating a 3D model of the entire concept, all components, and their relationships. This stage of the test was successful and generated a full 3D model of the concept. The design consisted of a sliding arm mechanism housed in a box, intended to distribute water across a surface by moving along an oval-shaped track. The concept included a water connection to the sliding box via a hose that would allow the movement of the sliding box, without causing major water leaks, and aimed to cover a large area efficiently using mechanical motion. A proof of concept was developed in CAD and 3D printed to test water delivery and sliding performance, see Figure 4.2. However, multiple issues were encountered.



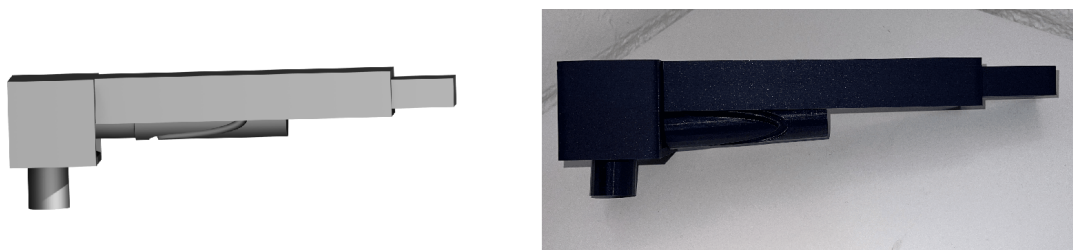
**Figure 4.2:** Render of Race n' Wash and the 3D printed prototype

**Conclusion and Discontinuation** While the prototype confirmed basic feasibility, it faced critical issues: poor sliding due to friction, a flawed fit between components, and high clogging sensitivity. The design's complexity and likely incompatibility with dishwasher interiors led to the concept being discontinued.

### 4.5.3 NexCog

**Concept and Functionality** The NexCog concept aimed to convert rotational motion into a linear movement pattern, allowing for the coverage of an oblong rectangular area. It also featured a system to distribute water to the ends of a spray arm through a central rotating component. To test the core functionality, a digital 3D model of the full concept was created, including all critical components and their interactions.

The initial design used a grooved cylinder with a peg attached to the outer spray arm to produce the desired motion. Several versions of the groove pattern were explored to refine performance. A CAD model was developed and 3D-printed to test both the motion mechanism and water delivery through the central component. Still, the tests revealed several complications and unexpected setbacks. A render of Nexcog as well as a 3D printed prototype, is seen in Figure 4.3.

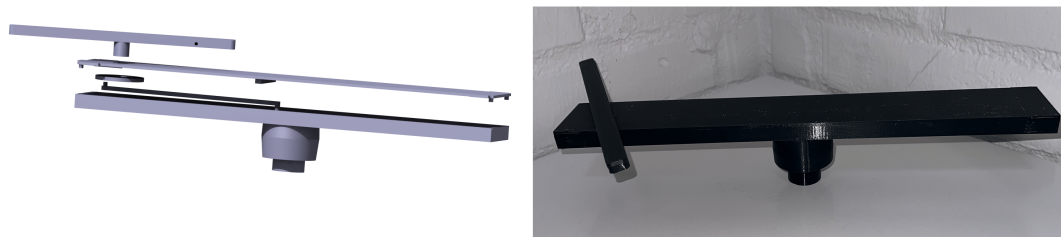


**Figure 4.3:** Render of Nexcog and the 3D printed prototype

**Conclusion and Discontinuation** Although the concept showed theoretical promise, the prototype faced multiple challenges: poor compatibility between the peg and groove, excessive friction from steep groove angles, and an overly complex mechanism prone to clogging. Alternative designs, such as motorized systems or patterned discs, were considered, but added unnecessary complexity. Due to these issues, along with the large scale required for the mechanism to function effectively, the NexCog concept was discontinued.

### 4.5.4 One Direction

**Concept and Functionality** The concept behind One Direction involves attaching a secondary arm to the outer end of the main spray arm. This secondary arm maintains its orientation while the main arm rotates, allowing it to cover a larger surface area. A digital 3D model was first developed to validate the idea, followed by a successful 3D-printed prototype, see Figure 4.4. The prototype functioned as intended, confirming the mechanical feasibility of the concept. When installed in the machine, it worked when rotated manually by hand.



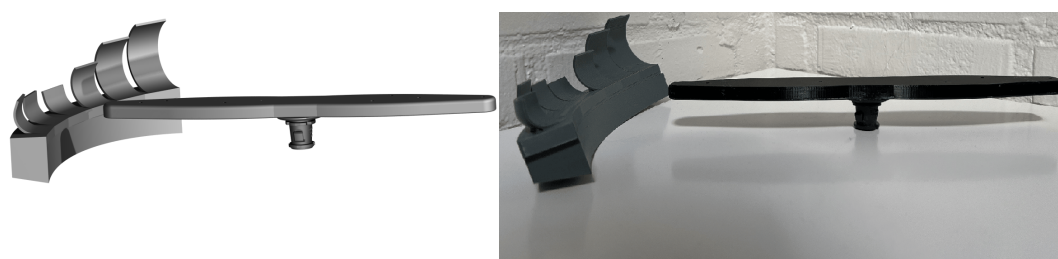
**Figure 4.4:** Render of One Direction and the 3D printed prototype

**Power by water** The water connection was designed to fit the dishwasher's mounting hole. Minor leakage was detected but stayed within acceptable limits. However, the mechanism failed to operate when driven solely by water pressure. Despite several iterations, no meaningful improvements were achieved.

**Conclusion and Discontinuation** While the concept performed well in both the digital model and the 3D printed prototype, it ultimately failed under real operating conditions. The water pressure inside the dishwasher proved insufficient to power the mechanism effectively. Multiple design refinements were explored, but none yielded a functional solution. Consequently, the concept was discontinued.

### 4.5.5 Trickshot

**Concept and Functionality** Trickshot uses angled surfaces on the walls combined with an orifice on the spray arm aimed horizontally to hit said surfaces. On hit, the water splashes on the surface, producing a stream of water angled upwards to reach otherwise hard-to-reach spots. To test the core functionality of this concept, it was 3D printed and mounted in a dishwasher. Having it mounted and stationary, the concept was functional. A render of Trickshot as well as a 3D printed prototype is seen in Figure 4.5.



**Figure 4.5:** Render of Trickshot and the 3D printed prototype

**Power by water** The simplicity of Trickshot’s design allowed it to utilize ASKO’s existing mounting point in the dishwasher, enabling a smooth and problem-free water connection. In stationary tests, the concept performed well, producing water streams that reached nearly the top of the dishwasher, as previously noted. However, once the arm was set in motion, performance dropped significantly, falling far short of the results achieved in the stationary setup.

**Conclusion and Discontinuation** This concept performed well in water tests, thanks to its simple construction. It also showed promising results in stationary conditions, reinforcing its potential viability. However, when tested with the spray arm in motion, the upward water streams were significantly reduced. While further development could likely resolve these issues, time and resource constraints led to the decision to discontinue the concept. It is important to note that this decision was based on practical limitations, not a lack of potential.

#### 4.5.6 Fridge Organizer

**Concept and Functionality:** The concept Fridge Organizer is utilizing the power of rotation to also move the spray arm back and forth, using a reciprocating rack and pinion mechanism. The movement is driven completely by the water pressure coming out of the orifices on the spray arm. To test the core functionality with this concept, a 3D model in CAD was first designed to ensure that all parts had an overall good fit. Then it was 3D printed to see if the mechanism was working. After several iterations, the mechanism worked as desired, thus, the decision to continue testing this concept was validated. A render of Fridge Organizer as well as a 3D printed prototype is seen in Figure 4.6.



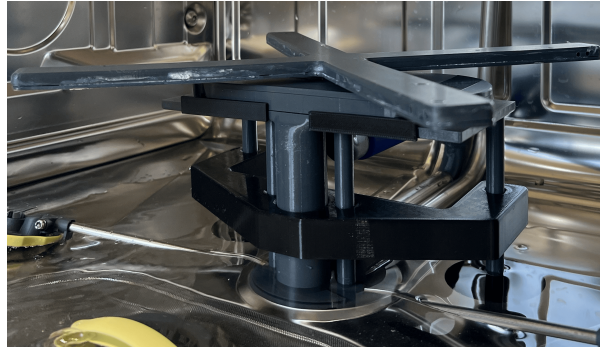
**Figure 4.6:** Render of Fridge Organizer and the 3D printed prototype

**Power by water:** To verify whether the concept could be powered by water pressure, establishing a secure connection was essential. After several iterations, it was discovered that a good solution for this was to utilize the pipe that delivered water to the top basket. This ensured minimal leakage of water. Initial tests confirmed that the concept could indeed be driven by water, However, it quickly became apparent that the rotation speed decreased linearly over time. To have it run for a longer period, the pump speed had to be gradually increased.

**Area Coverage Test:** With the concept successfully demonstrated to be water-powered, area coverage testing was initiated. A piece of cardboard was placed above the spray device, followed by a short water cycle to capture the resulting spray pattern. The outcome of this test is presented in Section 5.2. Additionally, a cleaning test was conducted using

burned raspberry jam on a metal sheet to evaluate the concept's cleaning effectiveness. The results of both tests are included in the same section.

**Conclusion and Continuation:** This concept was shown to be viable throughout all the tests, although it needed some modifications in the process. With the concept delivering promising results in all the tests, most importantly the area coverage test, it is deemed a viable solution to look into. It should be noted that the factors that lead to the linear deceleration are unknown, and need to be further looked into. The concept installed in a dishwasher is seen in Figure 4.7.



**Figure 4.7:** Fridge Organizer installed in a dishwasher

# 5

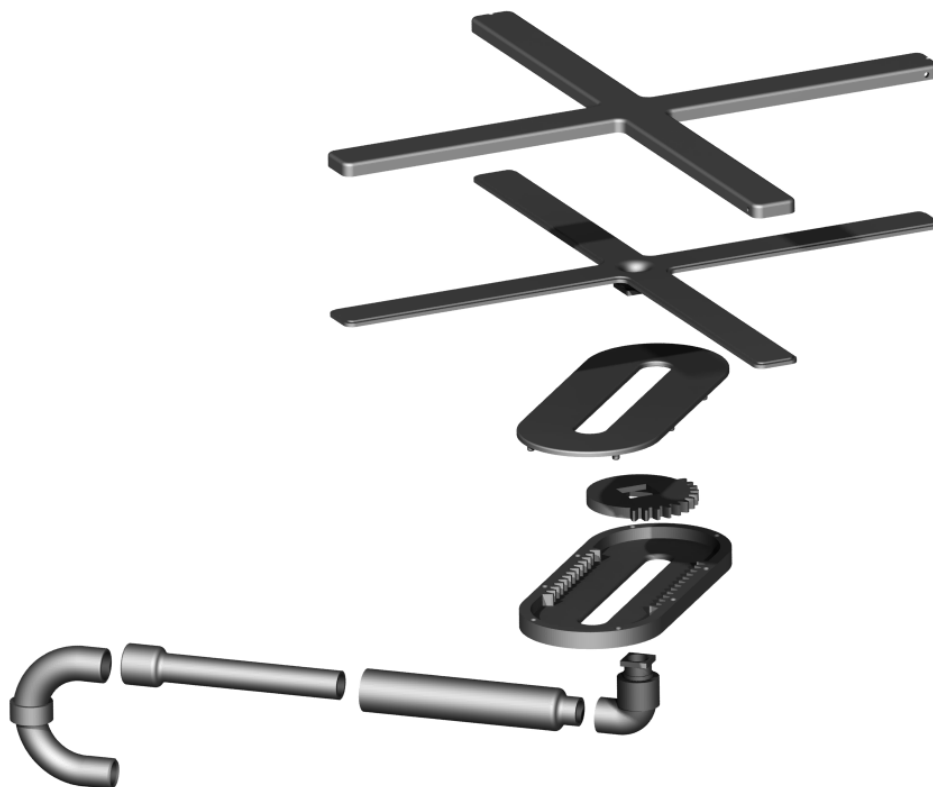
## Results

This chapter provides an overview of the findings from the research conducted. It aims to provide the answers to the research questions and briefly describe them. It includes a description of the final prototype, description of the main limitations of current solutions as well as the results regarding spray coverage and cleaning capabilities.

### 5.1 Final Prototype - Fridge Organizer

The final prototype resulted in a cross-shaped spray arm with orifices in various directions, used for cleaning and momentum. The arm is mounted on a pinion with a part of the pinion's sector populated with cogs. The pinion and arm move linearly along the base while simultaneously rotating around their axes. This linear motion results from the cogged pinion rotating along the rack situated on both sides of the mount.

The core components are mounted on a stand in the middle of the machine. The water is supplied through a cut-off tube that otherwise would supply the top spray arm. On said tube, an engineered swivel is mounted, which is then connected to a pair of telescopic arms. These arms connect to another swivel on the bottom side of the main spray arm device. The swivel is, in turn, mounted to the pinion used in the reciprocating rack and pinion mechanism that allows the spray arm to move with the power of its rotation. The concept is found in Figure 5.1, and the complete assembled concept is found in Figure 5.2.



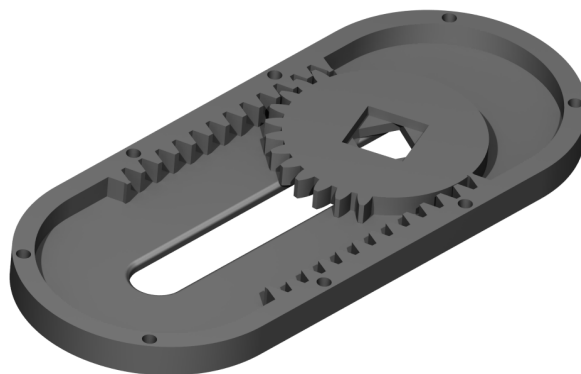
**Figure 5.1:** Exploded view of Fridge Organizer without stand



**Figure 5.2:** Fridge Organizer assembled on stand

### 5.1.1 Reciprocating Rack and Pinion Mechanism

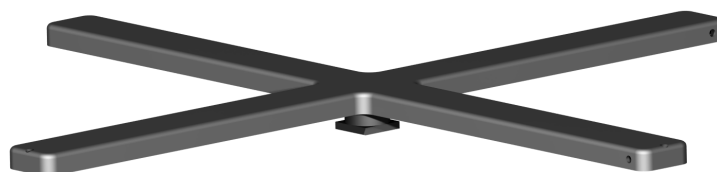
The main principle behind the concept is a variant of a rack and pinion mechanism, see Figure 5.3. When the pinion is rotating and moving along the racks on one side, it moves the spray arm in one direction, and when it reaches the end of the rack, the outermost cog on the pinion makes contact with the opposite side, thus moving the pinion in the opposite direction, while still rotating the same way. The reason behind the cogs on both the pinion and the racks being of various lengths was to enable a continuous, smooth movement of the mechanism.



**Figure 5.3:** Image of the rack and pinion mechanism used.

### 5.1.2 Spray arm

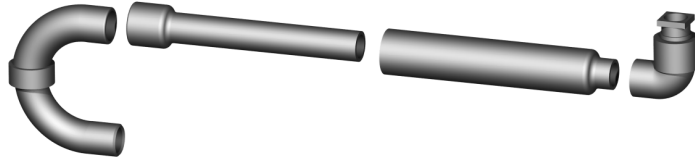
Instead of using the standard spray arm, the spray arm designed and used in this concept is in the shape of a cross. The rationale for this is that when the spray arm moves back and forth, it will always end up in the same position when it reaches one end. Therefore, having the spray arm in the shape of a cross enables a more uniform area coverage pattern. The spray arm is seen in Figure 5.4.



**Figure 5.4:** Fridge Organizer's cross shaped spray arm

### 5.1.3 Swivels and Tubes

To achieve a continuous flow of water to the spray arm while maintaining the movement pattern, two swivels were designed and used. One swivel is attached to the bottom of the spray arm, while the other is attached to the cut-off tube that would otherwise provide water to the top spray arm in the dishwasher. These swivels are linked via a telescopic arm, which accommodates the extension and retraction of the spray arm during its motion. This setup allows for both flexible movement and uninterrupted water delivery throughout the wash cycle, See Figure 5.5.



**Figure 5.5:** The two swivels with telescopic tubes connecting them

### 5.1.4 Stand

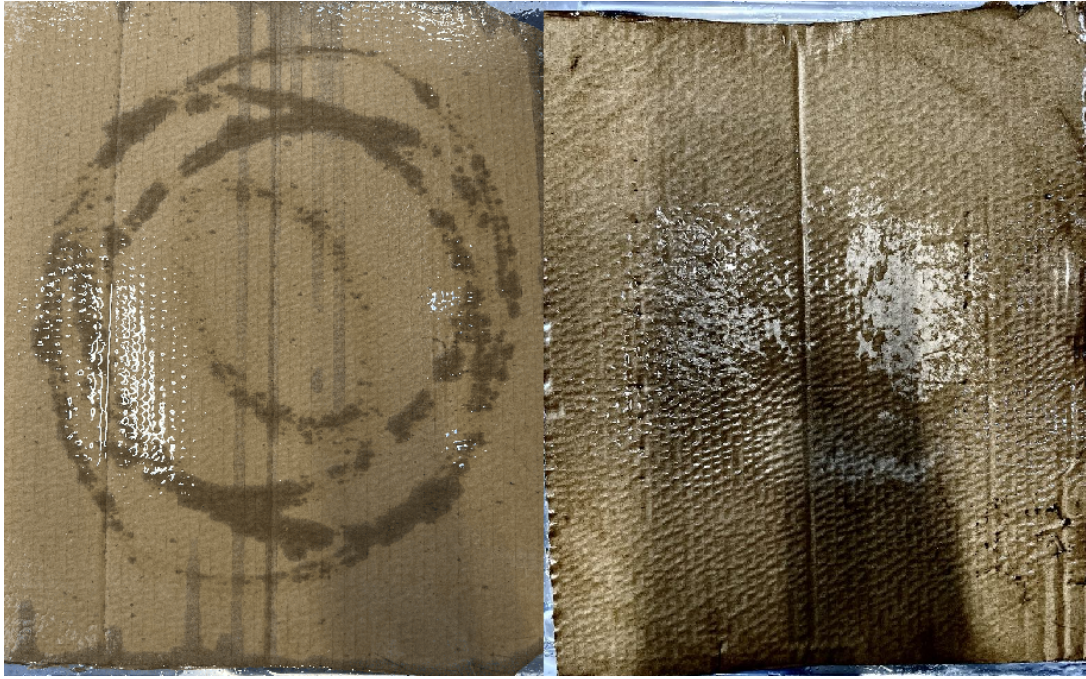
The stand, see Figure 5.6, is designed to be mounted on top of the existing spray tower (where the original bottom spray arm is normally mounted) in the middle of the dishwasher. To increase the robustness and stability of the spray arm assembly, two additional support legs were added to the stand.



**Figure 5.6:** The stand designed to hold Fridge Organizer

## 5.2 Spray coverage result

The spray coverage test with the cardboard sheet resulted in an oval-shaped pattern, as shown in Figure 5.7, which confirmed the expected spray distribution. The size of the oval is approximately 33 cm wide and 39 cm high. The test using holes angled to match the original arm design is shown on the right side of the image. Compared to the typical circular spray pattern produced by standard spray arms, this oval shape shows a wider reach in one direction. This means the spray can cover a larger area more effectively, especially along edges or corners, where circular patterns might miss spots. The results suggest that the design helps spread the water more evenly across the target surface, offering better overall coverage than a traditional setup.

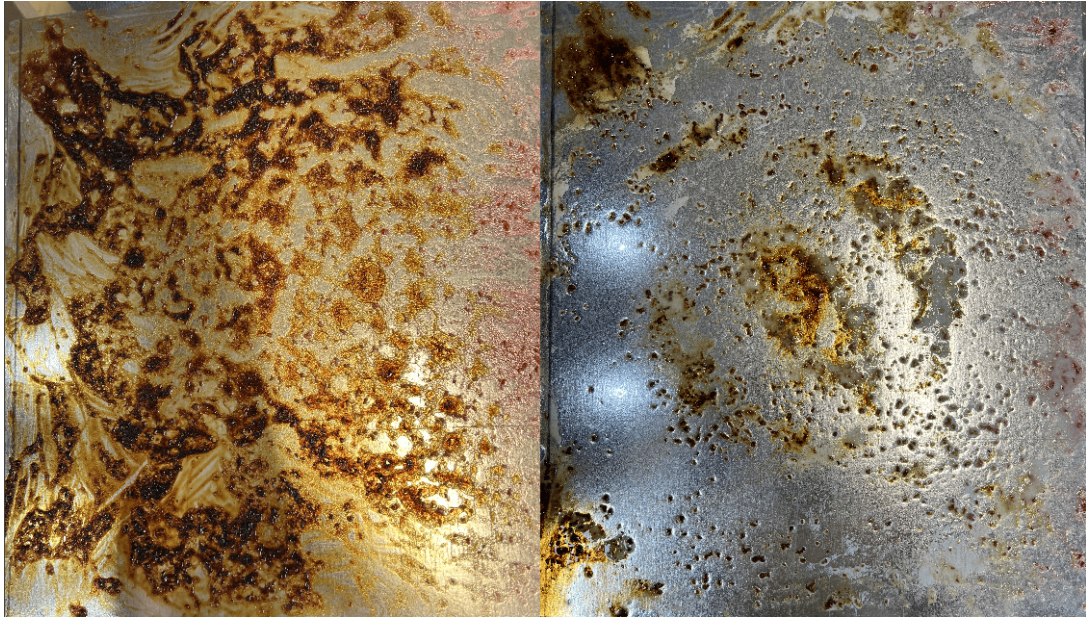


**Figure 5.7:** Spray coverage pattern of Fridge Organizer, pattern test and coverage test

### 5.3 Cleaning capabilities

As seen in Figure 5.8, the prototype was effective in removing food residue from the areas directly impacted by the water jets. The cleaned regions show that the jets delivered enough force to remove material where contact was made. The resulting spray pattern closely resembled what was observed in the earlier cardboard test (Figure 5.7), reinforcing the reliability of that method for visualizing spray distribution.

It is important to note that the primary objective of this test was not to completely remove all the burned jam, but rather to examine how the spray performed at the outer edges of its reach. These observations provide useful insight for future improvements, such as refining jet pressure or nozzle design, to enhance the spray arm's cleaning effectiveness across the entire surface.



**Figure 5.8:** Test sheet with burned jam, before and after test

# 6

## Discussion

This chapter presents a critical analysis of the project's outcomes, methods, and overall approach, highlighting areas of strength, limitations, and opportunities for further development. The purpose of this discussion is to provide deeper insight into the decisions made throughout the project and to evaluate how effectively the objectives were met.

The following structure begins with how well the project answered the research questions, drawing conclusions based on the prototype testing and comparative analyses. The chapter then explores further development opportunities. Lastly, the chapter assesses an evaluation of the methodology and work process.

### 6.1 Results

This section discusses how well the project succeeded in answering the research questions, the quality of the answers, and what might have been lacking.

#### 6.1.1 Current limitations of spray devices

This section discusses Research Question 1 regarding the current limitations of spray devices. From the competitor analysis, combined with the results presented in 5.2 it is clearly shown that the ordinary solutions of today have a coverage problem. This coverage of the standard arms are primarily limited by their central placement within the machine. Since spray arms are typically located in the middle, they struggle to provide adequate water coverage throughout the entire interior in slimline dishwashers. This centralized position creates challenges in reaching the far corners and edges of the dishwasher, and as a result, dishes placed in these areas may not receive sufficient cleaning, leading to inconsistent washing performance. Additionally, the limited range of motion and spray radius of the arms restricts their ability to cover all surfaces effectively, further reducing overall cleaning efficiency.

#### 6.1.2 Current solutions

This section discusses Research Question 2, focusing on the current solutions and other solutions that have tried to solve the problem of insufficient spray coverage. From the competitor analysis, it is clear that there is one design that reign the market, and that is a scaled-down version of the standard arm for 60x60 machines. Many companies simply choose to more or less ignore the constraints this method has. The most common method outside of the standard is a rotating arm with an added freely rotating satellite arm. This does improve the cleaning quality towards the edge of what the standard arm can reach.

However, it does not significantly increase the reach, since the distance from the water-ejecting orifice to the centre of rotation remains the same.

### 6.1.3 Evaluation of Concept Performance

This section addresses Research Question 3, which concerns how a spray device could be designed to maximize spray coverage in a slimline dishwasher while complying with all requirements. The design described in Subsection 5.1, along with the results, show demonstrates the superiority of spray coverage. The following is a discussion regarding the concepts' performance compared to the customer needs requirements.

- **Provides superior water coverage:** The prototype evidently succeeded in generating an improved area coverage pattern. The visualization of this could be clearer with the use of an improved method, but the result still stand.
- **Withstand temperatures of dishwasher:** The materials used for the prototype certainly could withstand all temperatures generated during the testing phase, however, it is clear that the 3D-filaments would, from longer exposure of the heat, deform and not be able to withstand it. For the concept to be a viable alternative, a more heat and water-resistant material needs to be used.
- **Endures water pump pressure:** From the testing conducted, all parts could withstand the pressure; all the individual components held successfully; however, the connection between some parts were not sufficient. Mainly the lid to the base, and the integration of the spray device to the machine. The current method is held together with additional parts, which would need to be improved to meet the stated customer need.
- **Resistant to water damage:** The prototype is resistant to water damage in the short term. In the longer term, the material and manufacturing method are susceptible to swelling and other tears from the water.

It is not relevant to discuss the concept against the target specifications, due to them being very specific and detailed, whereas the concept is in a much simpler state, and would need to be greatly refined and developed to be able to be measured against those aspects with any relevance.

Overall, the evaluation shows that the prototype presents a promising response to Research Question 3, particularly in terms of achieving superior spray coverage. Nonetheless, improvements in material selection and assembly design are necessary to fully meet all customer requirements.

## 6.2 Further Developments

Although the concept performed to expectations and outperformed today's method in the area coverage test, there are still several areas that require further development. These range from major overhauls in currently unaddressed aspects to refinements in small details that could enhance the product to a production-ready state.

### 6.2.1 Overall functionality

The prototype, in its final version, could not perform consistently for more than 3 minutes. Some factor caused the prototype to slow down linearly until it could no longer move.

The source of this problem was never discovered, and is a key element to fix for the concept to be truly viable.

### 6.2.2 Mounting of the Spray Device

The current mounting of the spray device is positioned too high above the machine's base, requiring the bottom rack to be suspended significantly. Lowering the spray device is a critical step towards transforming the prototype into a practical and functional solution.

Three primary steps are required to achieve this:

- **Redesigning the Water Outlet:** The water outlet should be redirected outside the wet box, entering from the side of the machine. This is the most important change and would have a great effect on the overall height of the spray device.
- **Component Height Reduction:** Lowering the overall height of the prototype components could not only reduce the total system height but also enhance performance by minimizing the loss of water pressure. This can be achieved in several different areas: lowering the arm cross-section, switching to stronger material, which can lead to reduced wall thickness, and decreasing the height of all components where feasible.
- **Swivel Design:** To support the new water routing and height difference, the swivel mechanism must be redesigned, since it is currently adapted to the height of the current solution.

Additionally, the bottom area of the machine will require reconfiguration. This includes either redesigning or removing the spray tower, which, with the redesign, would be completely unnecessary for the main spray arm.

The current mounting setup also needs to be improved, the current version is material-intensive, overly tall, and unstable. Therefore lowering it to the new height would improve it, however, further developments could include integrating the mounting stand into the base of the machine, or using a lower-profile metal stand with pre-installed mounting holes for increased stability and ease of assembly.

### 6.2.3 Reduction of Friction

System-wide friction can be reduced through several strategies. The current prototype used readily available materials, with little focus on friction characteristics. Future development should involve adding the friction properties of the materials as a key aspect of material selection. Additionally, using dissimilar materials at points of contact could further reduce friction due to improved material interactions. Further efforts should be put into more methods of reducing the friction, since that is a core negative attribute to the viability of the concept.

### 6.2.4 Alternative Concepts

While the main concept was prioritized, two other compelling ideas, Trickshot and One Direction, showed significant potential. With further development, these concepts may still prove viable.

**Trickshot** The deflector walls in the Trickshot design were promising when the spray arm was stationary, but failed to perform adequately during movement. Further design iterations on the deflectors, particularly with slower rotation speeds, could improve effectiveness. The concept also struggled with tolerance sensitivity; even small deviations led to failure. Redesigning both the arm and deflectors to be more robust against variation would enhance performance.

**One Direction** The One Direction concept faced several challenges, most notably in its connection to the water outlet. Improving the water connection to be more watertight, easier to install, and less friction would make rotation easier and more reliable. Additionally, the current prototype suffers from a need for very small margins of error. Using metal parts and more precise manufacturing methods could allow the top arm to rotate more reliably, addressing one of the key weaknesses of the design.

### 6.3 Workprocess

A potential essential flaw in the development of the concept lies in the generation of customer needs. This thesis relied heavily on ASKOs' input, and in a sense, their word was taken as truth. More resources could have been delegated to more research and critique of the customer needs. This would ensure that the needs generated truly were the ones existing, and it would also give a greater insight to the authors on what exactly was needed and have them conclude their own opinion, instead of relying so heavily on ASKO.

The literature study section during the project had an interesting structure. Generating ideas before any great deal of study, and then doing a more detailed literature study after generating new concepts. The authors do believe this was overall beneficial to the result since it allowed them to think freely and not be constrained in their allowed possibilities. However, the literature study could still have been more thorough. A great deal was put towards patent analysis, but little time was put towards competitor research. Although this could seem to be detrimental to the work process, the authors do not believe it to be so, since early on in the competitor research, it was apparent that a vast majority of bottom spray devices functioned in the same way, rendering this step of the process irrelevant for the development of new ideas.

In the concept selection phase, specifically in the Pugh matrices, there is a large amount of refinement of the selection criteria. It could be argued that these should have been more adequately developed for the first Pugh, to optimize time usage and reduce the number of Pughs. However, these early versions were necessary since the selection criteria were not yet known, but were developed alongside the concepts, which were iteratively updated after each Pugh.

The testing phase could have been improved in some different areas. It could have been more efficient to develop and test smaller segments of each concept early in the process, evaluating the fit and function of individual components or pairs of parts, rather than requiring a full reprint due to minor changes in specific sub-parts. During the tests at ASKO where the connection and drive to water were tested, a faster elimination of the lower-performing concepts could have been beneficial. More improvements and refinements could have been done to Fridge Organizer if more time was available, but many

resources were put into testing and redesigning the later discarded concepts.



# 7

## Conclusion

Current spray devices, constrained by their circular motion, have limited reach into corners, an issue particularly pronounced in slimline dishwashers. To address this limitation and improve spray coverage, the Fridge Organizer concept was developed. This design features a spray arm mounted on a reciprocating rack-and-pinion mechanism, enabling linear motion and significantly expanding the coverage area compared to traditional rotary arms. Additionally, a telescopic water connection system ensures a continuous water supply throughout both the translational and rotational movements of the spray arm, see Figure 7.1.

Initial testing of the early-stage prototype demonstrates promising results and suggests that this approach offers a substantial improvement in coverage for slimline dishwashers, while in theory maintaining or improving the cleaning quality. However, before the concept can be considered for commercial implementation, further development is required. This includes refining the mechanical design, conducting comprehensive performance evaluations, and ensuring compliance with industry standards for safety, efficiency, and durability. Gathering feedback from engineers and end users will also be crucial to guiding further enhancements and ensuring seamless integration with existing dishwasher architectures.



**Figure 7.1:** Full assembly of the final proposed concept Fridge Organizer



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# A

## Appendix A

**Table A.1:** Relevant Patents, sorted in the order they were found

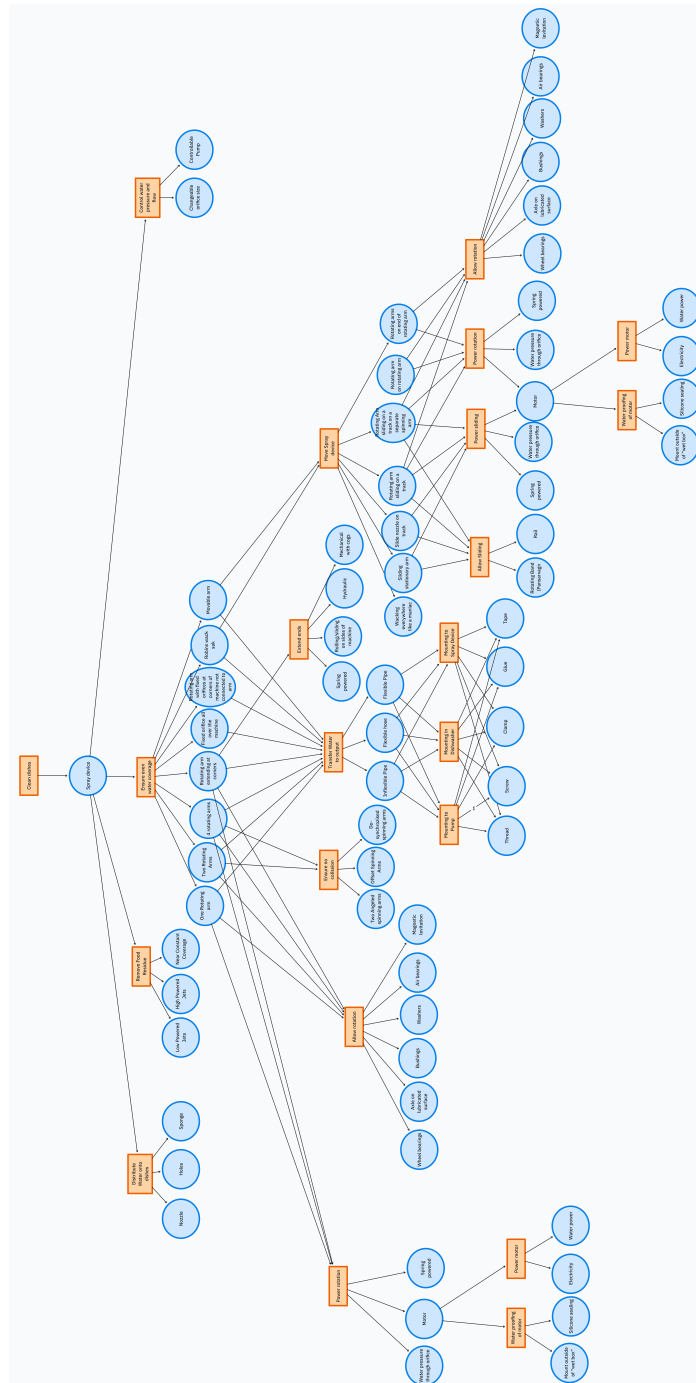
Patent number	Name of Applicant	Publ. Date	Technology Summary
US7896977B2	Whirlpool Corp	2011-03-01	Rotary spraying devices
US10349805B2	Whirlpool Corp	2019-07-16	Cornered spray devices
US8282741B2	Whirlpool Corp	2012-10-09	Four rotating arms
CN106510587A	Wuhu Guangying Industry Co Ltd	2017-03-15	Four rotating arms avoiding intersection
FI126362B	Shefqet Krenzi	2018-01-01	Four rotating disks for car part cleaning
US11019981B2	Whirlpool Corp	2021-06-01	Spray arm with extendable secondary arm
TR201910146A2	Vestel Beyaz Esva Sanayi Ve Ticaret Anonim Sirketi	2019-10-10	Extendable arms at corners
US9936850B2	Whirlpool Corp	2018-04-10	Rotating spray arm with secondary arm
US10499787B2	Whirlpool Corp	2019-12-03	Wall-mounted rotating disks
CN107874726B	Qingdao Haier Dishwasher Co Ltd	2021-03-12	Rotating disks
US11800963B2	Midea Group Co Ltd	2023-07-18	Multiple rotating spray tubes
US11375872B2	Whirlpool Corp	2022-05-17	Rotating tubes
CN104523208B	Midea Group Co., Ltd.	2019-06-11	Motor-controlled spin targeting dirty areas
US10517458B2	Midea Group Co Ltd	2019-12-31	Cutlery box with integrated sprayers
US7935194B2	Whirlpool Corp	2011-05-03	Movable sensor to detect dirty dishes
US7988791B2	Whirlpool Corp	2011-08-02	Water spray bouncing on angled surfaces
KR20130119448A	Electrolux Home Products Corporation N.V.	2013-10-18	Adjustable nozzles
RU2647139C2	Electrolux Appliances Aktiebolag	2018-03-27	Movable intense washing zone
CN116530907A	Guangdong Human Touch Intelligent Tech CO LTD	2023-08-04	Rotating extendable arm
CN106821252A	Midea Group Co., Ltd.	2017-06-13	One arm with two rotating sub-arms
US2014261584A1	Sears Brands LLC	2014-09-18	Fixed full coverage wash system
US2014332042A1	Whirlpool Corp	2014-11-13	Rack corner spray system
EP2292134A1	Whirlpool Corp	2011-03-09	Moving water nozzles
CN116982896A	Ningbo Fotile Kitchen Ware Co	2023-11-03	Multiple rotating arms
US2010154845A1	Whirlpool Corp	2010-06-24	Belt-driven spray assembly
KR20240148041A	SK Magic Co	2024-10-11	Belt driven extendable spray device
US2021345853A1	Midea Group Co Ltd	2021-11-11	Two rotating spray tubes



# B

## Appendix B

Here is the Function-Means-Tree.





# C

## Appendix C

Here is the Morphological matrix with subfunctions, means, and all generated concepts.





# D

## Appendix D

Here are the descriptions of all the concepts. If there is an associated sketch, it is referenced after the name of the concept.

### D.1 First Concepts

**Complicado** (see Figure E.3): Two spinning, angled rotating arms to prevent collision, powered by water. The usage of two smaller arms makes it easier to reach the corners since the arms can move closer to them.

**Deemed Doable** (see Figure E.4): Two spinning, angled rotating arms to prevent collision, powered by the water pressure through the holes. Using two smaller arms makes it easier to reach the corners, since the arms can reach closer to them.

**Easiest V.2** (see Figure E.5): A spinning arm sliding on a track, powered by water pressure. The difference from a normal dishwasher is that it slides on the rail, otherwise the same. This concept tries to keep it simple, but to reach corners better, the arm will move back and forth.

**Nexcog** (see Figure E.7): A rotating arm with extendable ends, that extends with the usage of cogs. Rotates with the water pressure through the orifices. The thought behind this concept is the utilization of cogs to make the arms extend at the corners and then retract when moving towards the walls, getting to the hard-to-reach spots at the corners.

**Nobody Puts Orifice in the Corner (NPOITC)** (see Figure E.8): A rotating arm with additional fixed orifices at the corners. The rotation of the arm is done using a water mill. This concept covers the corners with orifices, thus covering a larger surface than one spinning arm.

**Orifinity** (see Figure E.10): Stationary moving nozzles all over the dishwasher mounted on pipes running through the machine. Placing orifices all over the machine covers a large area and ensures clean dishes.

**Quadwash** (see Figure E.13): Four spinning arms placed at the corners. They are desynchronized to ensure that they do not collide. They spin by the water pressure created through the orifices. The usage of four spray arms covers a larger surface than one.

**Race n' Wash** (see Figure E.14): A rotating arm of which the ends are sliding on the sides of the machine. The rotation is powered by the water pressure through the orifices. With extendable ends, the spray device reaches a larger area than before.

**Spring Time** (see Figure E.18): A rotating arm of which the ends are extended towards the corners with springs, that then retracts when the rotation moves away from the walls. With extendable ends, the spray device reaches a larger area than before.

**Tank** (see Figure E.19): A stationary arm that moves with a rotating band that is powered by a motor. The motor is waterproofed by silicone sealing. By having a stationary arm that moves back and forth through the machine, the whole area is covered.

**The Orifice that Could** (see Figure E.20): An orifice that slides on a track with the help of water pressure. Covers a large area by moving back and forth.

**Angled Magician** (see Figure E.1): Four rotating arms that rotate with the power generated by the water pressure. They will not be able to collide due to the angle of the spray arms. The usage of four spray arms covers a larger surface than one.

**Basket** (see Figure E.2): Water is connected to the basket with extendable tubes, where the orifices are at the plate holders. This concept ensures good coverage all over the dishwasher.

**Mr. ExTendo** (see Figure E.6): A rotating spray platform is mounted on an arm that swings back and forth on one side. When reaching the corners, the spray platform is moved out towards the corner because of the swinging motion. There are in total two arms in the dishwasher, one towards each short side. The rocking motion back and forth ensures that the corners are properly washed.

**Oliver** (see Figure E.9): An arm that slides on an oval track, moving around due to the water pressure through the orifices. Using an oval track removes the necessity to switch direction on a track, and covers a large surface. No need for rotations of arm since it covers anyways.

**One Direction** (see Figure E.29): A rotating arm that has another arm mounted on the end. The mounted arm stays in the same direction all the time, while the rotating arm moves it around in the dishwasher. Powered by water pressure This concept makes for better reach towards the corners, and covers a more oblong rectangular surface than the traditional arm.

**Power-House** (see Figure E.11): Four rotating arms that rotate with a motor that is connected from the outside of the “wet-box”. They will not collide due to the angle of the spray arms. The usage of four spray arms covers a larger surface than one.

**Printer** (see Figure E.12): A rotating spray arm that moves around in the machine, similar to a 3D-printer head. This concept covers a large area of the machine and can focus on spots that are dirtier than others.

**Rotorception** (see Figure E.15): A rotating arm with two separate rotating arms on the ends of the main arm. The rotations are powered by a motor that is mounted outside of the cleaning chamber. This concept provides more water coverage towards the ends of the main arm.

**Sliding Stationary** (see Figure E.16): An arm that moves back and forth in the machine on a rail with the help of water pressure. This concept focuses on simplicity, and targets the whole area of the machine easily.

**Spinny Spin** (see Figure E.17): A rotating arm that is powered by a spring. Mounted on said arm is a smaller arm at one end that rotates on its own axis. Having the arms synchronized means that the smaller arm reaches better towards corners.

**Trickshot** (see Figure E.21): A spinning arm that utilizes angled surfaces on the walls that re-directs the water to reach spots that are otherwise difficult to reach. Using extra surfaces to redirect the water makes for an interesting way of reaching the corners.

**Tubular** (see Figure E.22): Two arms that rotate back and forth, spraying water all over the machine. They are powered by a motor that is mounted outside of the “wet-box”. This concept makes reaching the corners easier, with the arms that extend through the whole machine.

**Waddle** (see Figure E.23): Multiple arms mounted to a middle arm in the machine. The main arm waddles back and forth with a motor that is placed outside of the “wet-box”. This concept targets a large area, that can reach the corners due to the waddling arms

being mounted closer to these points.

**Fridge Organizer** (see Figure E.24): One Spinning arm connected to cogs where the rotation of the arm is powering the movement of the device. It is moving on a rail similar to that of Oliver

## D.2 Merged Concepts

**Rotospin** (see Figure E.30): A rotating arm that is motor-powered. Mounted on said arm is a smaller arm at one end that rotates on its own axis, powered by the same motor through gears, which also synchronizes the arm to ensure it doesn't crash on the long side. Having the arms synchronized means that the smaller arm reaches better towards corners.

## D.3 Revised Concepts

**Easiest V3** (see Figure E.29): A spinning arm sliding on a track, powered by a motor with a hydraulic arm moving the spray arm back and forth on the rail. This version of the traditional spray arm improves corner reach.

**Nobody Puts Orifice in a Corner V2** (see Figure E.28): A rotating arm with additional fixed orifices at the corners. The rotation of the arm is done with water pressure. This concept covers the corners with orifices, thus covering a larger surface than one spinning arm.

**Mechanix V2** (see Figure E.26): This concept consists of a rotating arm on which there is another arm that moves back and forth on a rotating band. Both arms rotate, and the combination of the arms and the band provides great coverage in the machine. The rotations and the sliding motion are powered by a motor.

**Mr. ExTendo V2** (see Figure E.27): A spray platform is mounted on an arm that swings back and forth on one side. An additional spray arm is rotating in the middle. When reaching the corners, the spray platform is moved out towards the corner because of the swinging motion. There are in total three arms in the dishwasher, one towards each short side, and one rotational in the middle. The rocking motion back and forth ensures that the corners are properly washed.

**Tubular V2** (see Figure E.32): Two arms that rotate back and forth, spraying water all over the machine. They are powered by water pressure. This concept makes reaching the corners easier, with the arms that extend through the whole machine.

**Tank V2** (see Figure E.31): A stationary arm that moves with a rotating band that is powered by a motor. The motor is mounted outside the wet-box. The motor reverses the direction of the spray arm when it reaches the edge. By having a stationary arm that moves back and forth through the machine, the whole area is covered.



# E

## Appendix E

Here are all the sketches of all the concepts.

### E.1 First Concept Sketches

Sketches of first concepts

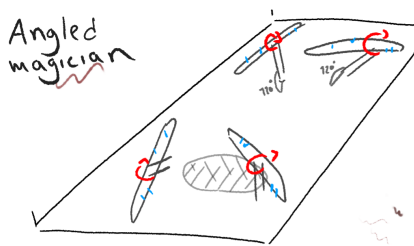


Figure E.1: Angled Magician

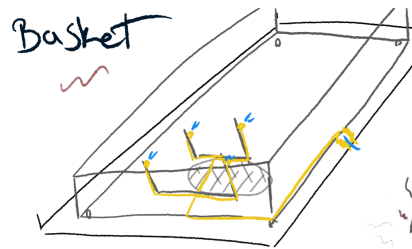


Figure E.2: Basket

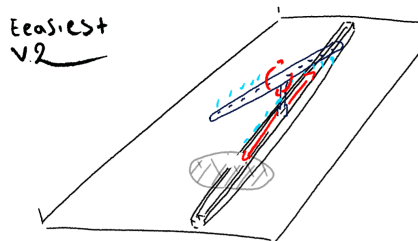


Figure E.5: Easiest V2

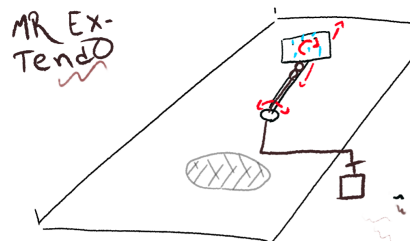


Figure E.6: Mr.ExTendo

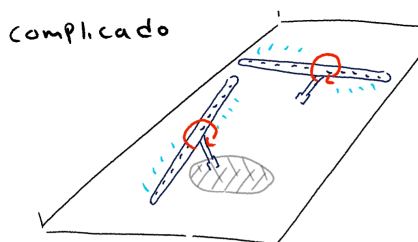


Figure E.3: Complicado

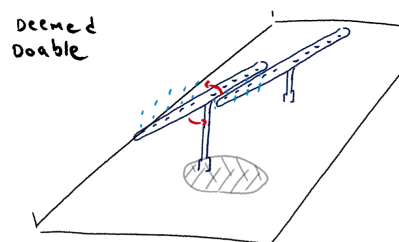


Figure E.4: Deemed Doable

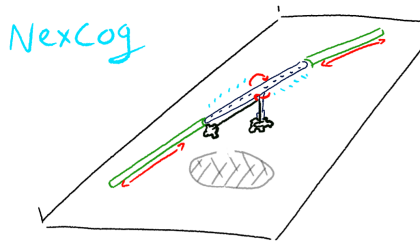


Figure E.7: Nexcog

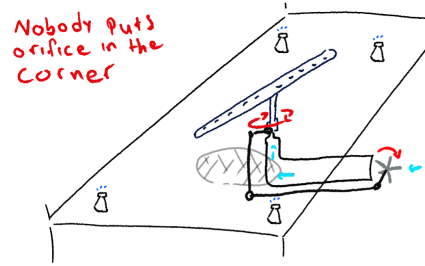


Figure E.8: Nobody Puts Orifice in The Corner

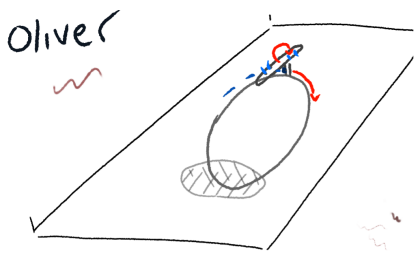


Figure E.9: Oliver

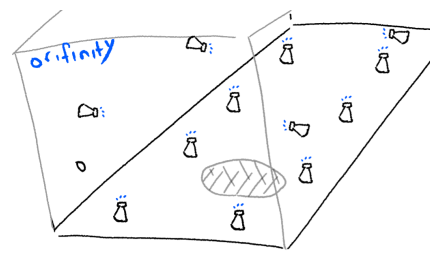


Figure E.10: Orifinity

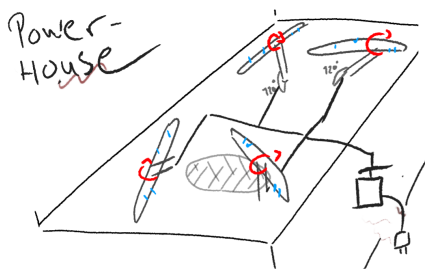


Figure E.11: Power-house

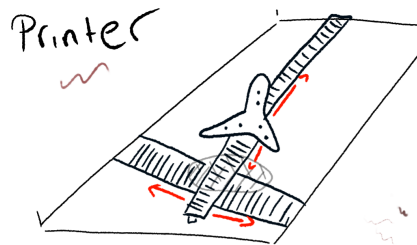


Figure E.12: Printer

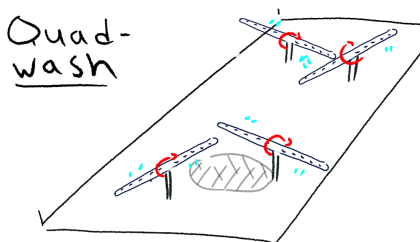


Figure E.13: Quadwash

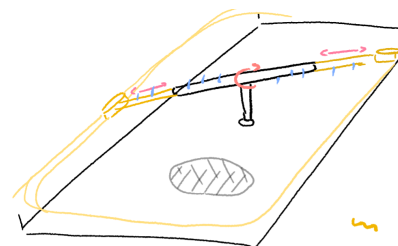


Figure E.14: Race n' wash

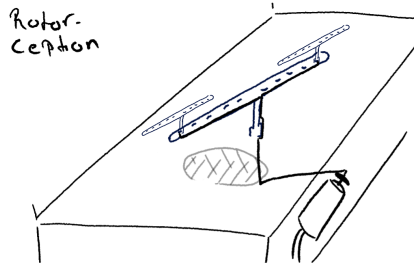


Figure E.15: Rotorception

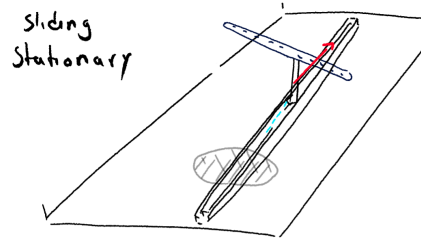


Figure E.16: Sliding Stationary

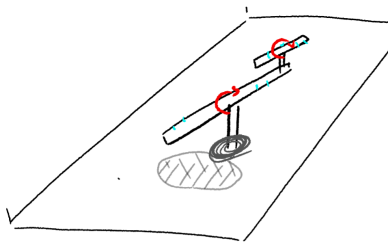


Figure E.17: Spinnny Spin

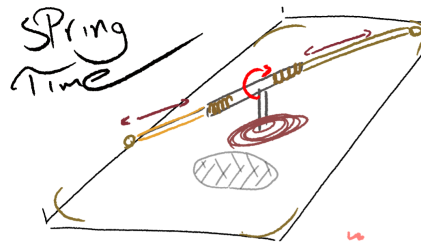


Figure E.18: Spring Time

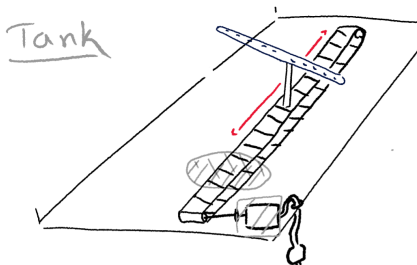


Figure E.19: Tank

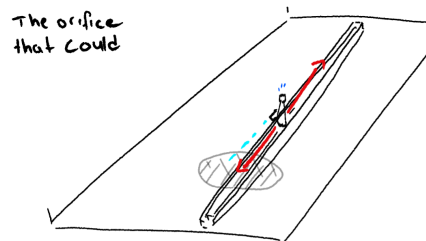


Figure E.20: The Orifice That Could

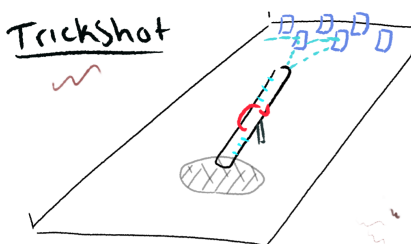


Figure E.21: Trickshot

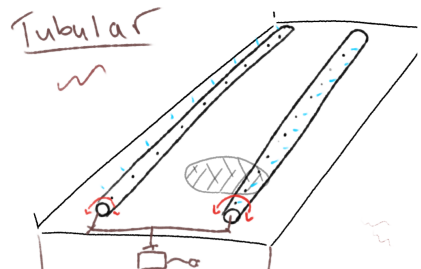


Figure E.22: Tubular

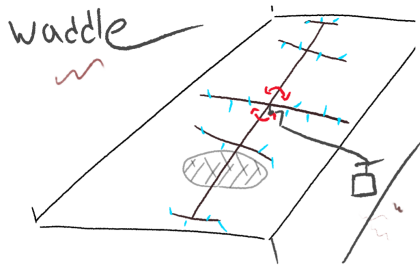


Figure E.23: Waddle

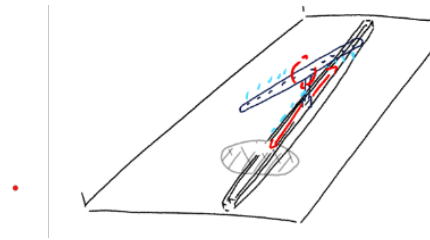


Figure E.24: Fridge Organizer

## E.2 New Concept Sketches

Sketches of new version of concepts

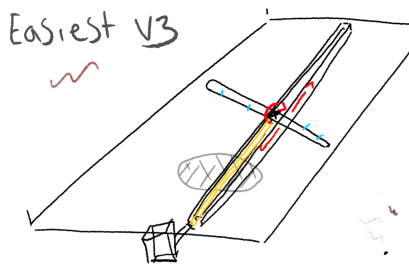


Figure E.25: Easiest V3

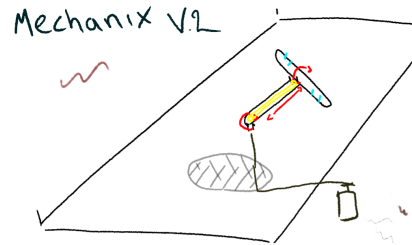


Figure E.26: Mechanix V2

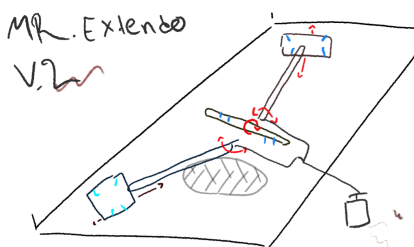


Figure E.27: Mr.ExTendo V2

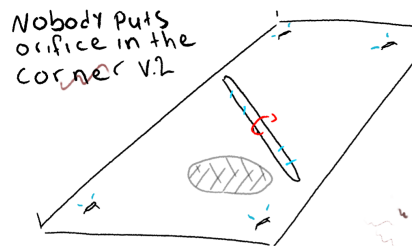


Figure E.28: Nobody Puts Orifice in The Corner V2

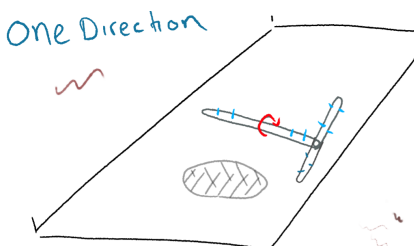


Figure E.29: One Direction

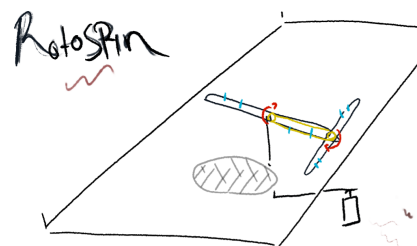


Figure E.30: Rotospin

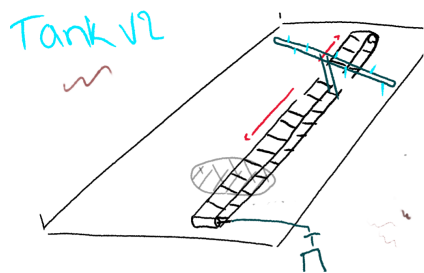


Figure E.31: Tank V2

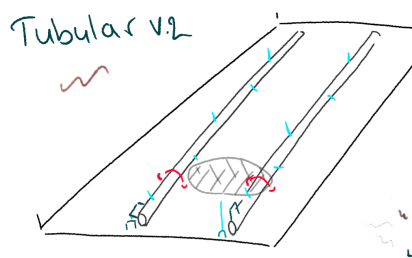


Figure E.32: Tubular V2



# F

## Appendix F

Here are all the Pugh Matrices conducted. Explanation for the definitions are as follows:

- **A:** Miele
- **B:** Deemed Doable
- **C:** Rotorception
- **D:** Sliding Stationary
- **E:** Tank
- **F:** Orifinity
- **G:** Nexcog
- **H:** Easiest V2
- **I:** Complicado
- **J:** Nobody puts orifice in a corner
- **K:** The Orifice that could
- **L:** Quadwash
- **M:** Spinny spin
- **N:** Mechanix
- **O:** Race n' wash
- **P:** Spring time
- **Q:** Angled Magician
- **R:** Power-house
- **S:** Basket
- **T:** Mr. ExTendo
- **U:** Printer
- **V:** Trickshot
- **W:** Tubular
- **X:** Waddle
- **Y:** Oliver

Evaluation criteria:

- **Area Coverage:** How large a percentage of the dish area gets covered by water.
- **Spray Uniformity:** How evenly the water is dispersed—does every dish get equal coverage?
- **Quality of Cleaning:** How well are the dishes cleaned? Considers pressure, angles, and overall effectiveness.
- **Design Complexity:** How difficult the design is—number of components, need for electrical engineering, programming, etc.
- **Manufacturing Complexity:** How challenging and expensive the solution is to manufacture.
- **Mechanical Reliability:** How likely the system is to fail or require maintenance during use.

## F. Appendix F

- **Noise Level:** How much noise the solution generates during operation.
- **Compatibility with Asko Machines:** How easily the solution integrates with existing Asko dishwasher models.

For the comments:

- M = Move on
- E = Eliminate

**Table F.1:** Pugh 1

Selection Criteria	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Area Coverage	0	1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1
Sprayuniformity	0	-1	0	1	1	1	0	-1	-1	-1	0	-1	0	-1	0	0	-1	-1	-1	0	0	-1	-1	-1	-1
Quality of cleaning	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	1	0	0	0
Design Complexity	0	0	-1	-1	-1	0	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	0	-1	-1	-1
Mechanical reliability	0	0	-1	0	-1	1	-1	0	0	-1	0	-1	-1	-1	-1	-1	0	-1	0	-1	-1	0	-1	-1	-1
Noise Level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	-1	0	0	0
Compatibility with Asko machines	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0
Total:	0	0	-1	1	0	4	-1	-1	0	-3	-2	-2	-1	-2	-2	-2	0	-2	-1	-3	-2	0	-2	-2	-2
Comments																									
Rank		3	8	2	3	1	8	8	3	23	13	13	8	13	13	13	3	13	8	23	13	3	13	13	13
		M	M	E	M	M	M	M	E	M	E	M	M	M	M	E	E	E	E	M	E	M	M	M	M

Evaluation criteria for Pugh 2:

- **Spray Coverage Area:** How large a percentage of the area of dishes gets covered by water.
- **Design Complexity:** Unintuitive design, number of unique pieces and components, requires innovative design, electrical engineering, or programming.
- **Design Robustness:** How it performs under varied conditions, error resistance (e.g., can handle broccoli or a fork), and system redundancy.
- **Durability:** Likelihood of breaking and the number of moving parts.
- **Cost to Manufacture:** Based on number of parts, material usage, presence of motors, and unique components.
- **Ease of Prototyping:** Possibility to 3D print, use readily available parts, and conduct testing (not necessarily quickly).
- **Ease of Installation:** How simple and efficient it is to install in the machine, with minimal tools and time required.

**Table F.2:** Pugh 2

Selection Criteria	Deemed Doable	Easiest V3	NexCog	NPOITC	Orifinity	Quadwash	Race n' wash	Tank V2	Mr. Extendo V2	Trickshot	Tubular V2	Waddle	Oliver	RotoSpin	Mechanix V2	One Direction
Spray Coverage Area	0	1	1	-1	1	1	1	1	1	1	-1	1	1	1	1	1
Design Complexity	0	-1	-1	-1	1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1
Design Robustness	0	1	-1	1	1	-1	-1	1	0	-1	1	1	-1	-1	0	-1
Durability	0	-1	-1	1	1	-1	-1	-1	-1	1	0	0	0	-1	-1	0
Cost to manufacture	0	-1	-1	0	-1	-1	-1	-1	-1	0	0	-1	0	-1	-1	0
Ease of prototyping	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ease of installation	0	-1	1	0	-1	-1	0	-1	-1	0	0	0	0	0	0	1
Total:	0	-3	-2	0	2	-4	-3	-2	-3	0	0	0	-1	-3	-2	0
Comments																
Rank	2	12	9	2	1	16	12	9	12	2	2	2	8	12	9	2
		E	M	M	M	M	M	M	E	M	M	M	M	E	M	M

Evaluation criteria for Pugh 3:

- **Spray Coverage Area:** How large of a percentage of the area of dishes that gets covered by water at all ( $\pm 10\%$  units are deemed equal).
- **Design Complexity:** Unintuitive design, number of unique pieces and components, requires innovative design, electrical engineering, or programming.
- **Design Robustness:** Its error resistance (can handle defects or deviations like broccoli or a fork).

- **Durability:** Likelihood to break and the amount of moving parts.
- **Cost to Manufacture:** Number of parts, amount of material, use of motors, and unique components.
- **Water Use:** How much water remains in the pipes at all times when running.
- **Engineering Elegance:** A design that is optimal, with minimal waste or a clever mechanism that simplifies function (clean design).

Table F.3: Pugh 3

Selection Criteria	Orifinity	Deemed Doable	Mechanix V2	NexCog	NPOITC	Oliver	One Direction	Quadwash	Race n' wash	Tank V2	Trickshot	Tubular V2	Waddle	FridgeOrganizer
Spray Coverage Area	0	-1	0	0	-1	0	-1	0	0	1	0	-1	0	-1
Design Complexity	0	0	-1	-1	0	-1	-1	0	-1	-1	0	-1	-1	-1
Durability	0	-1	-1	-1	0	-1	-1	-1	-1	-1	0	-1	0	-1
Engineering elegance	0	0	1	1	0	-1	1	-1	0	-1	1	1	-1	1
Water use (preliminary)	0	1	1	1	0	0	1	0	1	1	1	1	0	1
Total:	0	-1	0	0	-1	-3	-1	-2	-1	-1	2	-1	-2	-1
Comments														
Rank	2	5	2	2	5	13	5	11	5	5	1	5	11	5
	M	M	M	M	M	E	M	E	M	E	M	M	E	M

Evaluation criteria for Pugh 4:

- **Spray Coverage Area:** How large a percentage of the area of dishes gets covered by water at all ( $\pm 10\%$  units are deemed equal).
- **Design Complexity:** Unintuitive design, number of unique pieces and components, requires innovative design, electrical engineering, or programming.
- **Design Robustness:** Its error resistance (can handle defects or deviations like broccoli or a fork).
- **Durability:** Likelihood to break and the amount of moving parts.
- **Water Use:** How much water remains in the pipes at all times when running.
- **Engineering Elegance:** An optimal design with minimal waste or a clever mechanism that simplifies function (clean design).

Table F.4: Pugh 4

	Reference										
Selection Criteria	Trickshot	Deemed Doable	Mechanix V2	NexCog	NPOITC	One Direction	Orifinity	Race n' wash	Tubular V2	FridgeOrganizer	
Spray Coverage Area	0	-1	0	0	0	0	1	1	0	0	
Design Complexity	0	0	-1	-1	0	-1	0	-1	-1	-1	
Durability	0	0	-1	-1	0	-1	0	0	0	-1	
Engineering elegance	0	-1	0	1	-1	1	-1	0	0	1	
Water use (preliminary)	0	0	0	0	0	0	-1	0	0	0	
Total:	0	-2	-2	-1	-1	-1	-1	0	-1	-1	
Rank:	1	8	8	3	3	3	3	1	3	3	
Comment:	Move on	Move on	Discard	Move on	Move on	Move on	Move on	Move on	Move on	Move on	

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