Hospital Waste article for the 11th Mechman symposium

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Abstract
Novel legislation from the EU has affected the requirements for sorting waste at Danish hospitals. To accommodate the new requirements, a catalog of solutions is presented, each solution serving different aspects of the new requirements. This paper seeks to analyze the economic and technical feasibility of said solutions. A main obstacle to the hospital waste handling problem is that any initiatives need to be taken at a municipality-wide, or country-wide scale in order to have a significant impact. However, as hospitals and health facilities differ, there is no one-size-fits-all solution that can be applied to all hospitals in the same way. This problem was tackled by presenting a customizable solution structure, using the theory of product architecture from Steven Eppinger containing elements inspired by mass customization. Such a solution structure would provide the scalability needed to employ initiatives nationwide while allowing different health organizations to tailor the solution to their specific needs. The paper concludes upon the findings of the feasibility analysis of two solution instances derived from the product architecture.

Keywords: Waste handling, hospitals, product architecture, robotics, machine learning, YOLOV8, plastic sorting

1. General Introduction

The management of medical facility waste plays a crucial role in upholding hygiene standards within hospitals and ensuring the well-being of healthcare providers and surrounding communities. This comprehensive procedure encompasses various stages, including categorization, gathering, storage, transportation, and proper disposal. In the context of Region Nordjylland, the implementation of waste sorting practices in local healthcare facilities has encountered certain challenges. These obstacles primarily stem from ambiguous guidelines regarding waste segregation, the demanding nature of medical professionals' work, and insufficient space and designated containers for sorting purposes. Given these circumstances, there is an opportunity to investigate and evaluate potential remedies to address these issues.

2. Types of waste

The legislation set by EU requires companies to sort into 10 waste fractions as seen in Figure 1. In this paper, the focus is on one of these fractions, plastic.

Fig. 1 Waste sorting categories in Denmark [1]

It was discovered that in order to extract value from the waste category of plastic, the category had to be broken down further, into 7 additional categories.

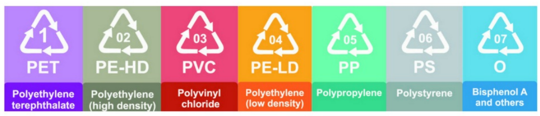


Fig. 2 The 7 fractions required for plastics to be sorted into.[2]

It is these 7 categories that will be the focus of waste sorting moving further into the report.

3. Identified problems within waste sorting at hospitals

Through the analysis, several waste management problems were discovered within the health sector. Only if these problems were considered, could the waste handling problem be solved effectively.

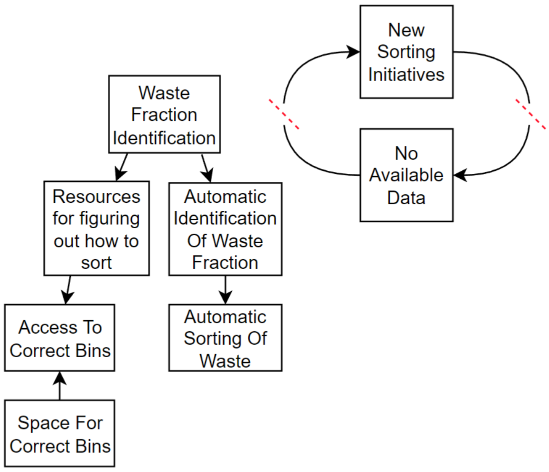


Fig. 3 The Problem Chart: The problem of not having automated identification and automatic sorting of plastic.

4. Accommodating problems within hospital waste sorting

A product architecture was created to accommodate each of the identified problems. An arbitrary health organization does not necessarily have all the described present in the organization simultaneously. Therefore a modular product architecture was chosen as a basis for the solution.

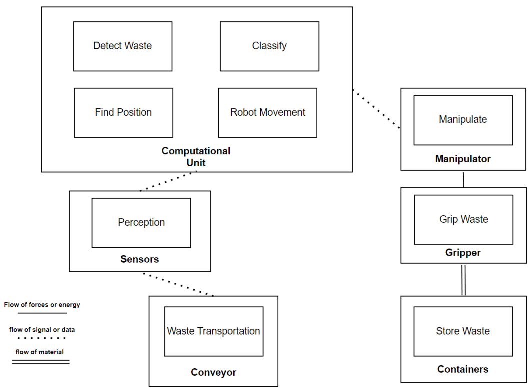
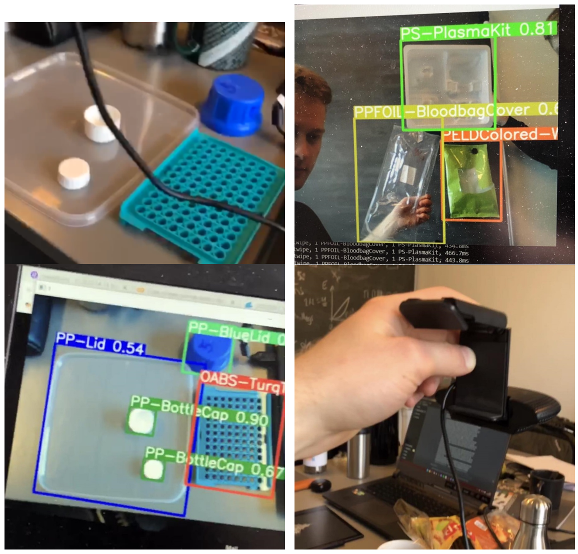


Fig. 4 Clustered elements of the schematic for the Centralized Sorter

In Figure 4, the product architecture has been applied to the most general solution to accommodate the problem of waste sorting, namely, the centralized sorter. The centralized sorter is in its ideal form a centralized sorting plant that can handle all the waste from plastics. It contains automatic identification of waste and mechanical manipulation of said waste in fractions, to move it into its assigned waste buckets.

5. Testing of prototype

With the architecture for the ideal solution established, a technical feasibility test was conducted, to confirm whether it is possible to automatically separate plastic into 7 fractions.



A Yolov8 architecture was chosen as the method of classification and testing of the solution was carried out. State of the art standard of classification is 99% accuracy, this was used as a benchmark for determining the results of the test. The test concluded a 96% classification accuracy. False positives and false negatives were both considered failures of classification. The testing was conducted in a non-controlled environment on top of a table in a group room. Better results might have been achieved in a controlled environment. An external company that deals in acquiring sorted plastic was contacted, and they verified that if a supplier could supply a 96% purity of plastic, they would want to do business with such a supplier.

6. Implementing the project in phases

The basis for the technical validity had been established. But there is a long way from going from a prototype to a full-scale setup that can handle the waste of an entire hospital. The implementation of the product was therefore broken down *into phases of implementation*:

Phase 0 seen in Figure 5 describes the simple setup that was used during the testing setup and contains a categorization system based on computer vision.

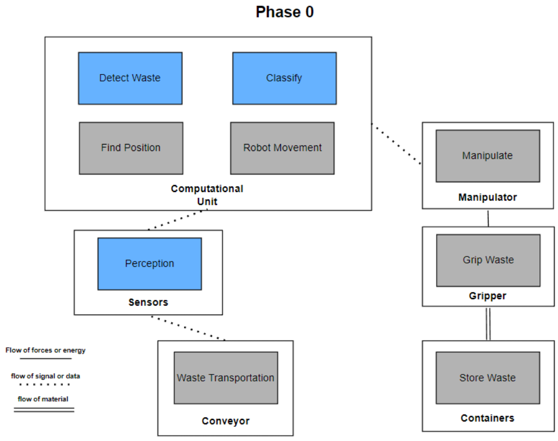


Fig. 5 Phase0 Explained on the Product Architecture

After implementing the vision system, it was possible to move into Phase 1:

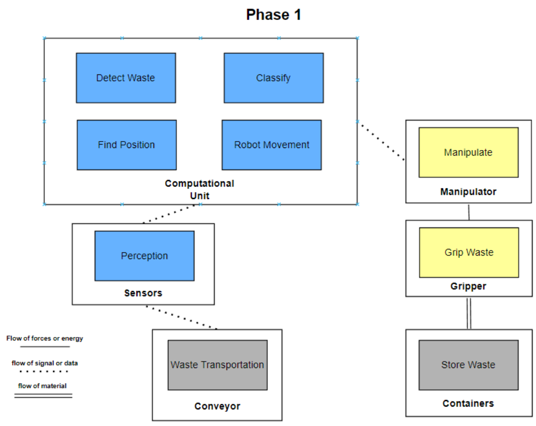


Fig. 6 Phase1 Explained on the Product Architecture

As seen in Figure 6 a robotic element has been introduced into the solution architecture. The code for robotic movement coupled with waste classification and localization was established in such a way that the robot could identify and sort waste into the aforementioned fractions. The yellow color of the manipulator and gripper indicates that the elements are present in the current implementation, but that they should at a later date be exchanged with more suitable hardware, namely a better-suited robotic manipulator and a better-suited gripper. A snapshot of the working robotic simulation can be seen in Figure 7. The environment was created to match the physical testing setup, and the code was created so that the simulation would match the physical workspace approaching a 1:1 relationship.

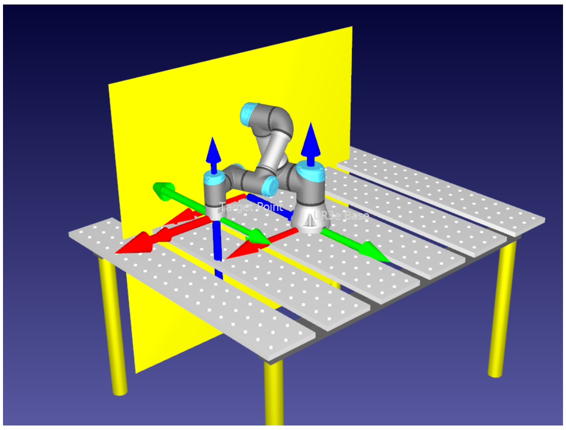


Fig. 7 Simulated setup of robot

After the robot had been implemented, the setup could be scaled to accommodate an entire hospital as seen in Figure 8. Here, all the elements of the architecture is denoted in blue, meaning that they have all been implemented to a satisfactory degree.

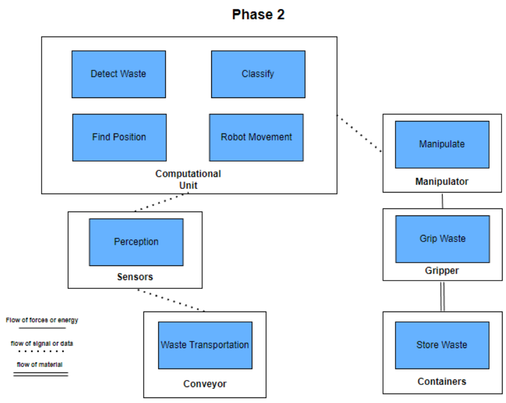


Fig. 8 Phase2 Explained on the Product Architecture

With the phases of implementation being established, the project could move into checking the economic feasibility of the product.

7. Economic Analysis

When looking at how much there is to be gained from selling sorted plastic first it is required to know how much plastic a hospital produces. However, there was no available data on this, so a spectrum of possiblities were created after consulting waste workers and waste managers.

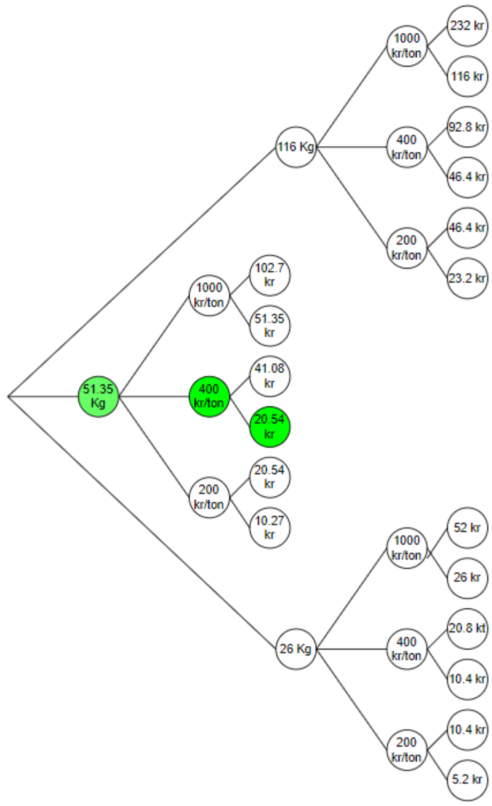


Fig. 9 Third layer of the tree. Most likely outcome marked with green.

Figure 10 describes the spectrum of these outcomes and their economic effects on the price of plastic sold per container. Now that a best-case, worst-case, and middle-case had been established, The most likely outcome was determined, marked by green. Economic analysis could be conducted. NPV analysis was chosen as the tool for the job. In **??** a NPV value of roughly 40.000 USD was determined, on the premise that an external company would pick up plastic waste sorted into fractions, which would save the hospital the pick-up fees from a waste company. The analysis was based on the assumption that the developed product had a lifetime of 5 years.

Time	NPV	Development	Investmen	Wages	Materials	Operation:	Savings	Total	
Year 1	-12318.85	-6404	-19096.1	0	0	0	17575	-7925.1	USD
Year 2	15977.27273	0	0	0	0	0	17575	9649.9	USD
Year 3	14524.79339	0	0	0	0	0	17575	27224.9	USD
Year 4	13204.35763	0	0	0	0	0	17575	44799.9	USD
Year 5	12003.96148	0	0	0	0	0	17575	62374.9	USD
	43391.53522								

Fig. 10 Cashflow and NPV.

If such a deal could not be established, a new analysis was conducted on the premise that the waste could be sold. The result was still a positive number, but a negligible amount, that could be described as a break-even value of 5 years.

The economic feasibility of the project had now been established.

8. Conclusion

Throughout this spring semester 2023, the group has acquired valuable insights into waste management practices employed by Danish hospitals and assessed the current state of their implementation. These practices were subsequently examined in relation to the potential integration of robotic sorting technology, aiming to evaluate its viability in the waste sorting industry. The theoretical knowledge obtained served as a foundation for the groups visits to real hospital departments, which provided firsthand experience and shed light on the disparities between theoretical concepts and practical implementations.

Surprisingly, despite belonging to the same industry, Danish hospitals exhibited notable differences across various aspects highlighted in the report for this article. This revelation led the group to draw inspiration from an article on mass customization theory. Hence, the group made the decision to view the hospital industry as a customer in need of customized solutions. Recognizing that a singular solution would not suffice for all hospitals in Denmark. Utilizing the mass customization theory, product architecture theory was used to cover some of the fundamental capabilities to ensure the requirements of mass customization theory.

Based on the proposed structure, a catalog of solutions was developed for the visited hospitals. These solutions were then evaluated with respect to cost and benefits, revealing the feasibility of plastic waste sorting both in centralized and decentralized scenarios. However, due to resource limitations, the group were compelled to narrow the focus of the project to the development of a physically feasible prototype. This prototype aimed to demonstrate the viability of selected proposed solutions.

A final problem formulation was formulated, which could be answered with a developed prototype:

"How can a robotic manipulator and a camera be utilized for automated waste sorting?"

The prototype developed for this project effectively answered this problem formulation, providing evidence of the feasibility of automating waste sorting through the use of a single RGB camera and a robotic manipulator.

Acknowledgement
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